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Improvement of Overall Equipment Efficiency with Root Cause Analysis and TPM Strategy: a Case Study

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Abstract

Nowadays, industrial businesses are more aware of the value of machine maintenance, and more especially, the adoption of an effective maintenance strategy. Total Productive Maintenance (TPM), which involves everyday chores involving the entire workforce, increases equipment efficiency, prevents breakdowns, and promotes autonomous operator maintenance. TPM is a fantastic technique for maintaining buildings and machines. This article provides research and a review of TPM implementation in an RMG Industry to help enhance Overall Equipment Effectiveness (OEE). Data from the past have been studied, and the findings obtained in terms of motivated employees, improved OEE, and a decrease in the number of rejects/accidents on the production line are fairly positive. The methodology calls for gradually applying lean principles, Autonomous Maintenance (AM), 5S, and planned maintenance. After TPM deployment on the critical machine, improvements in availability, performance, and quality are seen boosting the overall efficacy of the equipment. A comparison of OEE before and after implementation demonstrates the effectiveness of TPM deployment throughout the industry.

Keywords: Overall equipment effectiveness, RCA, Total productive maintenance, 5S.

1 | Introduction

For businesses in the manufacturing and industrial sectors to succeed, equipment productivity and efficiency must be maximized. Implementing Total Productive Maintenance (TPM) is one method for doing this. TPM involves all staff members in maintenance tasks to increase the equipment's overall effectiveness. TPM involves all employees in improving product quality while boosting equipment uptime and reducing maintenance expenses. TPM strives to prevent equipment breakdowns through proactive maintenance techniques such as regular inspections, cleaning, and lubrication. TPM also takes into account continuing efforts to increase productivity, simplify the production process, and reduce waste. By using this technique, the equipment's general efficacy is increased and less reactive maintenance is necessary, which can help save time and money. The company needs to undergo a culture change so that everyone, from operators to executives, participates in maintenance activities to implement TPM. Management must also completely commit to TPM and adopt a disciplined approach to continuous improvement.

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A key element of TPM is employee involvement in identifying and fixing equipment issues since it promotes their sense of ownership and involvement. TPM has several benefits, some of which include improved product quality, cheaper maintenance costs, more production, and increased equipment uptime. Implementing TPM can help businesses reach their sustainability objectives by reducing waste, improving energy efficiency, and reducing the environmental impact of operations. Businesses that have implemented TPM report higher production, cheaper maintenance costs, and more productive machinery. There have been instances when TPM has been utilized to achieve sustainability goals, such as waste reduction and improved energy efficiency. The following is what the letter TPM stands for Total denotes a complete analysis of all maintenance-related tasks and their impact on equipment availability. Unlike what is usually supposed, the term "productive" refers to the effort's ultimate objective, which is efficient production rather than just efficient maintenance. The program's emphasis on establishing dependable operations and maintaining production is known as maintenance. In today's highly dynamic and continuously changing environment, increased expectations of industrial organizations are a result of global business competition. Manufacturers must deliver a variety of products in the quickest possible period at prices and of acceptable quality. Overall Equipment Effectiveness (OEE) is used to calculate the performance gap between a manufacturing unit's current performance and its anticipated performance. Three metrics are included in OEE for tracking performance, availability, and quality. By categorizing the significant losses that affect the production process, these helps determine the plant's effectiveness. Downtime can be quickly decreased by using OEE to get visibility into machine status and do root-cause investigation of problems [1], [2].

Applying the methodology increased productivity and quality based on performance indicators, as well as improved organizational climate and a decrease in risks that were highlighted in the workshop. TPM aims to decrease the six significant equipment losses, to zero, which have been acknowledged as essential to the company's survival. TPM is a distinctive plant management method from Japan that was created from the concept of preventive maintenance. To achieve equipment improvement goals, this strategy places a strong emphasis on the importance of collaboration, small-group activities, and employee participation [3]. Breakdowns caused by machine failures are a common source of waste for manufacturing companies, and the implementation of strategies for strategic maintenance management is the best method to reduce them [4], [5].

In this study, a critical production line's availability is improved using the TPM technique and lean maintenance tools. After the problems are identified, a plan of action is made and put into effect to use 5S tools, visual management, and maintenance progress to find the root cause of the high frequency of errors and defects in one piece of equipment on the line. This study suggests a framework that combines the generic OEE model with problem-solving techniques to reduce three significant losses for knitting machines, boosting overall output, machine availability, and product quality. The foundation of process improvement in firms is the 5S methodology, which strives to get rid of all waste. Organizational practices like classification, cleanliness, standardization, and discipline help businesses make the most use of their resources. Higher productivity will be attained through increased production and improved resource management.

1.1 | Aim and Objective

The research was conducted to uphold specific tenets. The following list includes the research's primary goals:

- *To identify major losses by root cause analysis.*
- *To reduce major losses through the identification and elimination of root causes with TPM.*
- *To evaluate the effectiveness by analyzing OEE.*

2 | Literature Review

The TPM concept provides a quantifiable measure of OEE for evaluating the productivity of the equipment in a production line. Companies must restructure themselves and drastically increase their level of competition to meet this market need. Businesses must eliminate all production-related waste to achieve this. In the process industry, increasing production efficiency is a key component. Numerous studies have looked into the problems with an injection molding process in a company making vehicle parts. The participation of the entire organizational structure, from the CEO to the remaining employees, who must be always dedicated to the goals specified and with the responsibilities allocated to each, is a necessary step for the TPM's success.

The TPM maximizes productivity and equipment availability while fostering a stimulating atmosphere to encourage employee engagement and outperform competitors in terms of quality, reliability, cost-effectiveness, and inventiveness [6]. The personnel are in charge of maintaining the equipment with which they work daily. The operations have been well-planned and structured from the start. One of the key aspects of the TPM originated as the idea of "Autonomous Maintenance (AM)" [7]. Preventive maintenance and AM are used in this methodology. To prevent production downtime and manage the machine's service life, cleaning, inspection, component replacement, and planned repairs are all a part of AM [8].

On the other hand, the TPM can be defined as strategy-based care teams designed to maximize equipment effectiveness by developing production systems' comprehensive maintenance that covers the entire life of the equipment, which includes all equipment-related fields (planning, use, and maintenance) and involves everyone in the organization [9]. The OEE is a tried-and-true method and a particularly potent instrument that can be used to compare production units across industries and to carry out diagnostics. As long as the corrective actions are structural and simple to perform, the OEE might approve either long-term planned actions or short-term reactive actions [10], [11].

TPM is essentially a new maintenance approach created to gather the evolving maintenance requirements. TPM is an American method of meticulous maintenance that has been improved upon and tailored to work in the Japanese industrial setting. It is now acknowledged in the Japanese business and other Western nations as well [2], [12]. The TPM can be summed up using the definition below. Total productive manufacturing, also known as ordered equipment-centric nonstop enhancement, aims to maximize production effectiveness by identifying, and eliminating equipment and efficiency losses throughout the life cycle of the production system and by recruiting the active participation of team-based employees at all levels of the operating network of control [13]. Numerous studies in the literature show that TPM programs have a significant influence on organizations when they are properly implemented. Gupta and Vardhan [14] looked into the application of TPM in a well-established Indian tractor manufacturing company. According to their research, TPM reduced production costs and improved OEE, which resulted in a threefold gain in profit over three years and a doubling of sales revenue. The high defect rate prompted the organization to incur considerable costs due to product loss and poor product quality.

Using TPM, four primary reasons for failures were identified: human error, subpar raw materials, underperforming equipment, and work practices [12], [15]. Additionally, by focusing on the engine damage to the machines, they began to gather data and analyze it using Pareto charts and descriptive statistics. As a result, there were fewer machine breakdowns and mistakes, which in turn led to fewer flaws in the gloves. The majority of TPM implementation situations are found in the manufacturing industry. McKone et al. [16] looked at the connection between TPM and manufacturing performance in 2001. They showed that low-cost, high-quality standards and effective delivery performance are all significantly and positively connected with TPM. Gupta et al. [17] said that OEE is a powerful tool for identifying and eliminating losses, thereby developing an efficient production system for achieving world-class manufacturing. Rove its business performance to meet the ever-growing expectations of customers. TPM is one such methodology that has a strong potential to enhance productivity, and quality and reduce product cost [18],

[19]. The OEE value can be increased by minimizing the breakdowns and changeover losses which are associated with availability and by minimizing the defects and setup scraps losses which are associated with quality [20].

TPM generally accepts organizations in manufacturing as the most effective maintenance strategy to improve maintenance performance. Previous research showed that TPM had a direct impact on the performance improvement of production equipment [21].

3 | Methodology

Primary and secondary data for inquiry are shown in *Fig. 1*. To acquire primary data, observation of the production process, equipment monitoring, and interviews are used. During the interview process, targeted questions are directed at the pertinent company stakeholders. According to the observations of the manufacturing process on the production line, a certain machine or piece of equipment was disrupted during the production process. Secondary statistics, such as the amount of downtime, total production, the number of faults per day, and the amount of non-productive time, were obtained using historical data from both before and after the installation of TPM. Finding OEE values is the initial stage in the calculation process and it involves combining data for availability, performance, and quality. The key errors that impacted availability, performance, and quality are then identified from the six primary losses. Setup and adjustment losses, breakdown losses, and idle losses make up the availability factor. The yield or scrap losses, rework losses, minor stoppage, and reduced speed losses make up the performance component. The strategy for machine maintenance was put into place to solve the problem of low OEE values that didn't meet international standards. This strategy focused on the six major widely used factors that reduce machine efficacy.

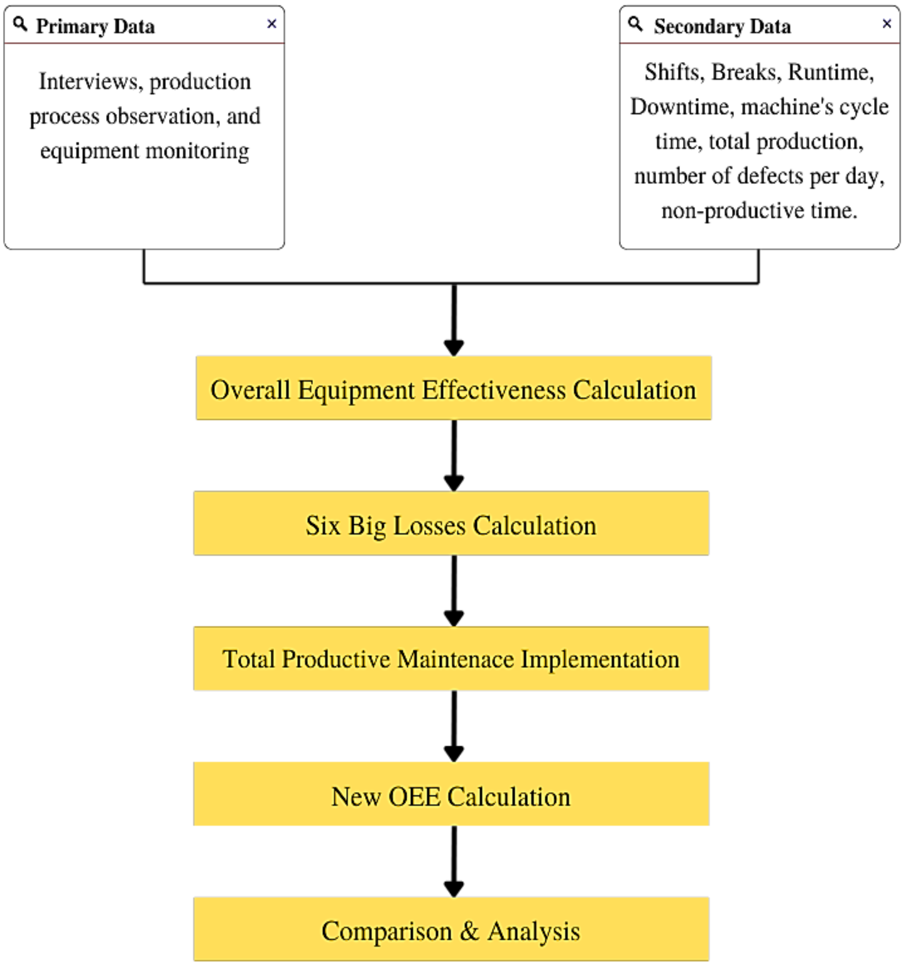

Fig. 1. Research framework.

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3.1 | Overall Equipment Effectiveness Calculation

OEE is a simple tool that will help in assessing how effective their machinery is. OEE is the result of the three main factors that contributed to the six large considerable losses shown in *Table 1*.

Table 1. Six big losses.

Sl. No.	Six Major Loss Category	OEE Factor	OEE Loss Category	Example of Loss Category
01	Machine Breakdowns	Availability	Downtime	Equipment breakdowns, tool damage, and unplanned maintenance.
02	Machine setups and adjustment	Availability	Downtime	Process acclimatization, machine swaps, and material storage
03	Minor Stops	Performance	Speed	Product fraud, component blockage, and product flow obstruction
04	Machine Reduced Speeds	Performance	Speed	Level of machine operator training, tool wear, and equipment age
05	Production Rejects	Quality	Quality	Adjusting tolerance, the warming-up process, and damage
06	Rejects on start-up	Quality	Quality	Improper assembly, rejects, and rework

$$\text{OEE} = \text{Availability}\left(\text{A}\right) \times \text{Performance Rate}\left(\text{P}\right) \times \text{Quality Rate}\left(\text{Q}\right). \tag{1}$$

The OEE's strength as a measurement instrument lies in the way it unifies various crucial manufacturing processes into a single tool. The maintenance effectiveness, production efficiency, and quality efficiency perspectives are included in the OEE tool. OEE is therefore dependent on three factors: availability (A), performance rate (P), and quality rate (Q) as *Fig. 2*.

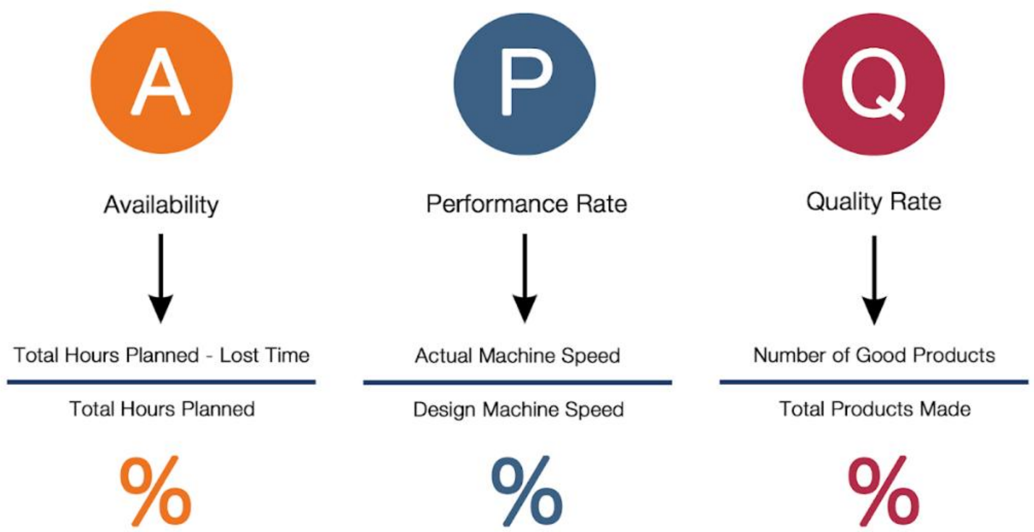

Fig. 2. OEE equations.

3.2 | OEE Calculation before TPM Implementation

Using *Eq. (1)*, the OEE of the selected production line is calculated. Here, the company's shift = 9 hours or 540 min. Lunch break = 1 hour or 60 min. So, the planned production time is 8 hours or 480 min, extra break = 20 min.

The downtime in this case encompasses startup, idling, small stoppages, speed loss, defects (scarp and rework), and equipment failure. The OEE condition of the chosen production line on the chosen level is represented in *Table 2* below:

Table 2. OEE calculation before TPM.

Machine Name	Availability (%)	Performance (%)	Quality (%)	OEE (%)
Flat lock (front neck top)	86.04	83.93	99.52	71.06
Flat lock (sleeve hem)	87.08	88.15	98.1	75.3
Flat lock (side seam)	85.20	82.46	97.78	68.69
Flat lock (body hem)	86.45	83.12	99.1	71.21
Lock stitch (neck rib tuck)	88.12	85.56	99.56	75.07
Over lock (shoulder join)	85.83	83.18	99.08	70.74
Band knife	92.08	94.46	99.56	86.60
Metal detector	91.25	87.31	100	79.67
Thread suction	90.83	93.38	100	84.82
Iron machine	90.62	93.82	99.46	84.56
Production line OEE %	82.35	83.53	85.21	67.77

So, the production Line OEE was found 76.77%. A comparison of this value with world-class standards is shown in *Fig. 3*.

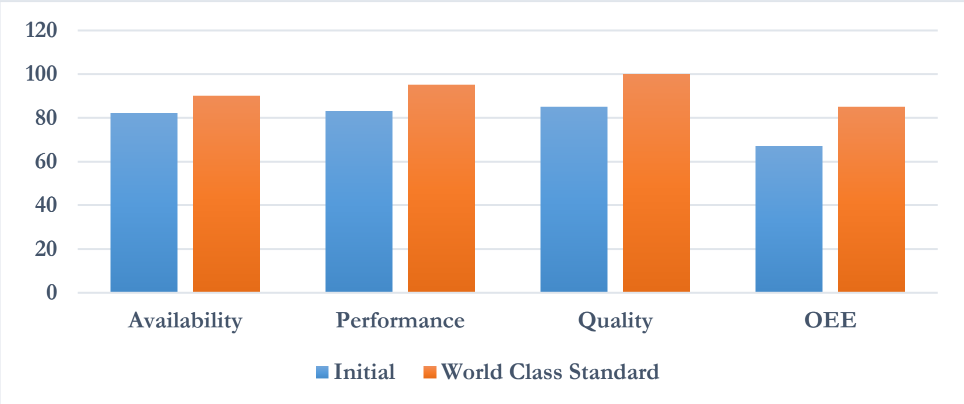

Fig. 3. OEE comparison with world-class standard.

4 | Root Cause Analysis

Root cause analysis is a systematic approach that aims to identify the underlying cause(s) of an event or problem, rather than just addressing its symptoms. It is a critical tool used in various fields, including engineering, medicine, aviation, and business management. The process of root cause analysis typically involves gathering data, identifying possible causes, evaluating evidence, and tracing the problem back to its fundamental cause(s). This process helps to uncover the root cause(s) and determine corrective actions that can prevent the problem from recurring. There are various techniques used for root cause analysis, such as the fishbone diagram, 5 whys, and Failure Modes and Effects Analysis (FMEA). The Fishbone Diagram, also known as the Ishikawa diagram, is used to identify the potential causes of a problem, while the 5 whys technique involves asking "why" questions repeatedly until the root cause(s) are identified. FMEA, on the other hand, is a proactive approach that involves identifying potential failure modes and evaluating their impact. Root cause analysis is a crucial process that helps organizations to learn from their mistakes and improve their processes. It can help to prevent similar problems from occurring in the future, improve efficiency, and increase productivity. By identifying the root cause(s) of a problem, organizations can make informed decisions on how to mitigate and prevent the problem from reoccurring.

4.1 | Fishbone Diagram

A fishbone diagram is a visual tool as *Fig. 4,* used to identify the potential causes of a problem or issue, also known as an Ishikawa diagram or cause-and-effect diagram. In this case, the problem or issue is low OEE on a selected production line. The major categories of potential causes are typically labeled on the diagram's branches. Each major category can be broken down further into sub-categories to identify more specific potential causes. Creating a fishbone diagram typically involves brainstorming potential causes with a team of relevant personnel to ensure that all possible causes are identified.

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By mapping out all potential causes in a fishbone diagram, the root causes of low OEE can be identified, and solutions to address them. The fishbone diagram for the selected production line is shown below:

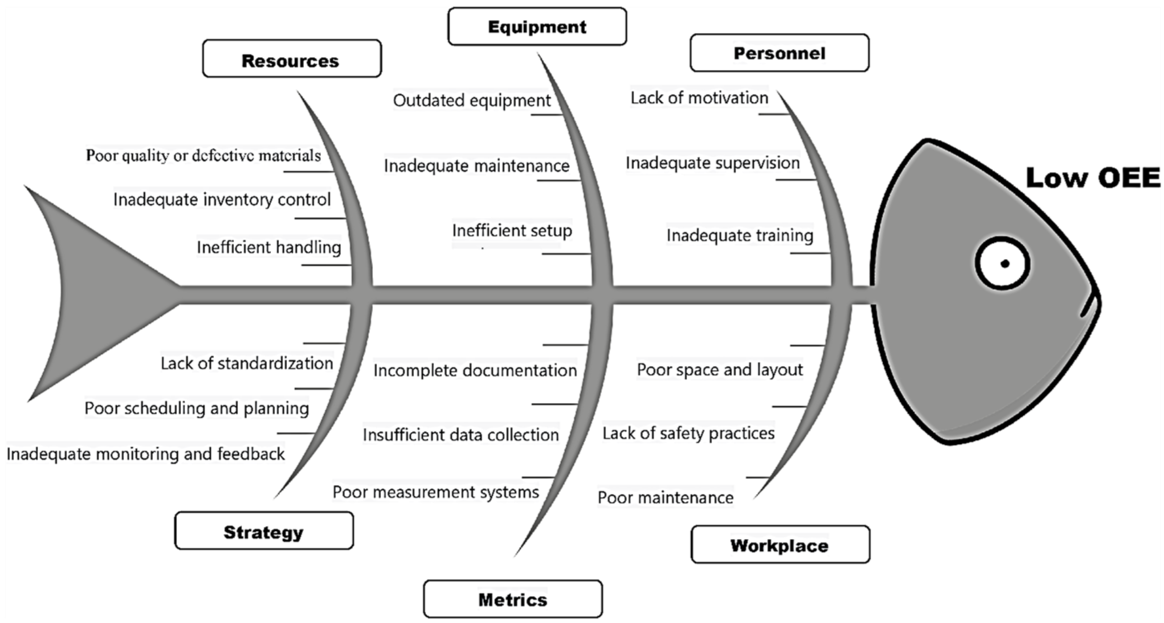

Fig. 4. Fishbone diagram for low OEE.

The following causes were found to be the root causes that resulted in low OEE for that production line:

I. Resources:

- *Material availability: insufficient or inconsistent supply of materials, or low-quality materials.*
- *Energy supply: inadequate or unreliable energy supply, which can lead to equipment breakdowns or reduced productivity.*
- *Capital investment: insufficient funding for new equipment, technology, or maintenance.*

II. Equipment:

- *Maintenance: inadequate or infrequent maintenance, which can lead to breakdowns, reduced capacity, or poor calibration.*
- *Technology: outdated or inefficient equipment, or lack of automation, which can lead to low productivity or reduced quality.*
- *Capacity: insufficient or mismatched equipment capacity, which can lead to bottlenecks or slow production.*

III. Personnel:

- *Training: insufficient or inadequate training, which can lead to errors, inefficiencies, or safety hazards.*
- *Staffing: insufficient or inexperienced staff, which can lead to overworked employees or poor quality.*
- *Motivation: poor morale or motivation, which can lead to decreased productivity or absenteeism.*

IV. Strategy:

- *Planning: inadequate or inflexible production planning, which can lead to inefficiencies or poor capacity utilization.*
- *Product design: poorly designed products or inadequate consideration of production requirements, which can lead to production problems or inefficiencies.*
- *Supply chain management: inadequate or unreliable supply chain management, which can lead to disruptions or delays in production.*

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V. Metrics:

- *Data collection: insufficient or unreliable data collection, can lead to inaccurate or incomplete OEE measurements.*
- *Performance measurement: inadequate or inappropriate performance metrics, which can lead to incorrect assessment of OEE or production problems.*
- *Analysis: inadequate or incomplete analysis of OEE data, can lead to missed opportunities for improvement or incorrect diagnosis of production problems.*

VI. Workplace:

- *Environment: poor or inadequate workplace environment, such as noise, temperature, or lighting, which can lead to safety hazards, decreased productivity, or absenteeism.*
- *Organization: poor organization or layout of the workplace, which can lead to inefficiencies, safety hazards, or decreased productivity.*
- *Cleanliness: poor or inadequate workplace cleanliness, which can lead to safety hazards, quality issues, or decreased productivity.*

The effectiveness of the entire plant is impacted by the fact that all of the aforementioned problems are lowering the overall equipment efficacy of the machines on the production floor. A thorough productive maintenance strategy needs to be implemented to address the aforementioned problems and improve OEE.

4.2 | Pareto Chart

A Pareto chart is a graphical representation of data that highlights the relative importance of different categories or factors. It is named after Vilfredo Pareto, an Italian economist who observed that 80% of the wealth in Italy was held by 20% of the population. In a Pareto chart, categories are arranged in descending order of importance, with the largest category on the left and the smallest on the right. The chart also includes a cumulative percentage line that shows the cumulative percentage of the total represented by each category.

The Pareto chart is often used in quality control and process improvement to identify the most significant causes of problems or defects. By focusing efforts on the few categories that account for the majority of the issues, organizations can make the most efficient use of their resources and achieve the greatest impact.

The Pareto analysis is a quality control tool used to identify the most significant issues affecting the quality of a product or service. The Pareto principle, also known as the 80/20 rule, states that 80% of the problems are caused by 20% of the causes.

One specific application of the Pareto chart is in identifying equipment failure. To do this, data is collected on all equipment failures over a certain period, and the causes of those failures are classified. The categories might include factors like design flaws, inadequate maintenance, operator error, or environmental factors. Once the categories have been established, they are arranged in order of frequency or severity, and a Pareto chart is created. The chart allows analysts to quickly see which categories account for the majority of the equipment failures, and to prioritize efforts to address those issues. By addressing the top few categories of equipment failure, organizations can reduce downtime, increase productivity, and improve safety.

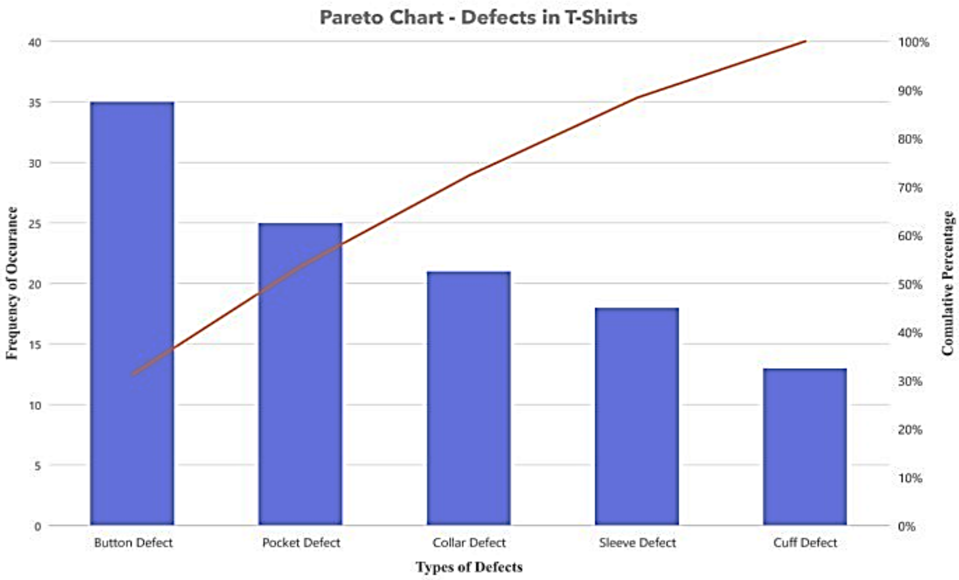

Fig. 5. Pareto analysis.

Pareto analysis of the selected production line is depicted in *Fig. 5* including button defect, pocket defect, collar defect, sleeve defect, and cuff defect with their frequency of occurrence and cumulative percentage.

Here are the defects and their frequency of occurrence for the production line:

- *Button defect: 25 occurrences.*
- *Pocket defect: 18 occurrences.*
- *Collar defect: 12 occurrences.*
- *Sleeve defect: 10 occurrences.*
- *Cuff defect: 5 occurrences.*

To perform the Pareto analysis, we need to calculate the cumulative percentage of the defects. The cumulative percentage is calculated by adding up the percentage of each defect to the percentage of the previous defects in *Table 3*.

Table 3. Defects analysis.

Defect	Frequency	Percentage	Cumulative Percentage
Button defect	25	36.2%	36.2%
Pocket defect	18	26.1%	62.3%
Collar defect	12	17.4%	79.7%
Sleeve defect	10	14.5%	94.2%
Cuff defect	5	7.2%	100%

From *Table 3*, we can see that the button defect and pocket defects account for over 60% of the total defects, which means they are the most significant issues affecting the quality of the production line. Therefore, the management should prioritize addressing these two issues first to improve the overall quality of the product. Here are some possible processes to reduce the rate of defects in each category:

I. Button defects:

- *Implement a process to test the buttons for durability and strength during production.*
- *Increase the training and monitoring of the workers responsible for attaching the buttons.*
- *Improve the quality of the buttons used in the production process.*

II. Pocket defects:

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- *Increase the training and monitoring of the workers responsible for sewing the pockets.*
- *Implement a process to test the strength and durability of the pockets during production.*
- *Use higher-quality fabric and thread for the pockets.*

III. Collar defects:

- *Increase the training and monitoring of the workers responsible for sewing the collar.*
- *Implement a process to test the strength and durability of the collar during production.*
- *Use higher-quality fabric and thread for the collar.*

IV. Sleeve defects:

- *Increase the training and monitoring of the workers responsible for sewing the sleeves.*
- *Implement a process to test the strength and durability of the sleeves during production.*
- *Use higher-quality fabric and thread for the sleeves.*

V. Cuff defects:

- *Increase the training and monitoring of the workers responsible for sewing the cuffs.*
- *Implement a process to test the strength and durability of the cuffs during production.*
- *Use higher-quality fabric and thread for the cuffs.*

In general, to reduce the rate of defects, it is essential to improve the quality control process at each step of the production line. This can involve increasing the training and monitoring of the workers responsible for each step, implementing quality checks during production, and using higher-quality materials where possible. Additionally, it is essential to track and analyze the defects to identify any patterns or common issues that can be addressed systematically to prevent future occurrences. TPM is a maintenance strategy aimed at maximizing equipment effectiveness and minimizing downtime. 5S is a workplace organization method that helps improve efficiency and productivity by creating a clean and organized work environment. Together, these strategies can help identify and eliminate this waste, reduce downtime, and improve OEE. Here are some possible steps to take for implementing TPM and 5S in the production line:

I. Create a team: assemble a team of employees who will be responsible for implementing TPM and 5S. This team should include representatives from all areas of the production line.

II. Conduct a thorough analysis: identify the root causes of the problems you have observed in your production line. Use tools like fishbone diagrams and Pareto charts to determine the most common causes.

III. Develop an action plan: based on your analysis, develop a plan for implementing TPM and 5S. This plan should include specific goals, timelines, and responsibilities for each team member.

IV. Implement 5S: start by implementing the 5S methodology. This involves creating a clean and organized work environment by sorting, simplifying, sweeping, standardizing, and sustaining. Make sure to involve all team members in this process and ensure that everyone understands the importance of maintaining a clean and organized workspace.

V. Implement TPM: once 5S is in place, begin implementing TPM. This involves creating a proactive maintenance program that focuses on preventing equipment breakdowns and improving OEE. Develop a maintenance schedule and ensure that all team members are trained to perform maintenance tasks.

VI. Monitor progress: regularly monitor progress to ensure that TPM and 5S are being implemented effectively. Use metrics like equipment downtime, productivity, and employee feedback to measure success.

These are ongoing processes that require continuous improvement and commitment from all team members.

5 | TPM Implementation

5.1 | Industrial Overview of the TPM Approach

I. Top Management has come to understand how the TPM tactics will benefit them.
II. Employing training, and spreading awareness of TPM among employees.
III. Establishing departmental and TPM committees, and specialist subcommittees, creating an organizational structure that will handle quality and AM.
IV. Fixing TPM's guiding principles, objectives, and operational process.
V. Creating a strategy for implementing TPM.
VI. To maximize the benefits of TPM, the production floor implements its eight pillars.
VII. To maintain progress over the long term, there must be constant monitoring and control.

5.2 | TPM Implementation

TPM should be applied properly and step-by-step to be successful. In *Fig. 6,* each step calls for the implementation of one TPM pillar per the needs of the business. The following diagram illustrates the progressive implementation.

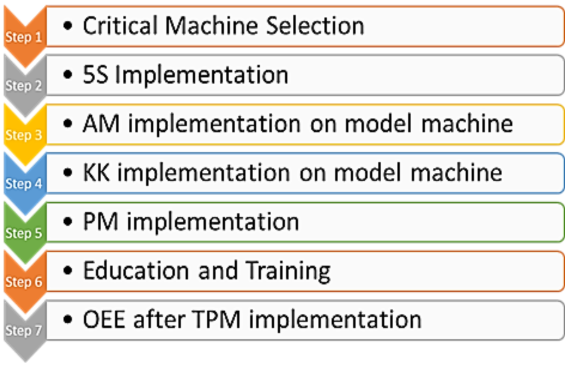

Fig. 6. TPM implementation steps.

5.3 | Pillar-Wise Steps to Adopt TPM

The introduction of the TPM program is based on the systematic application of a number of the eight TPM pillars. This would maximize plant and equipment efficiency by creating a flawless rapport between people and machinery. The *Fig. 7* below shows a typical TPM structure.

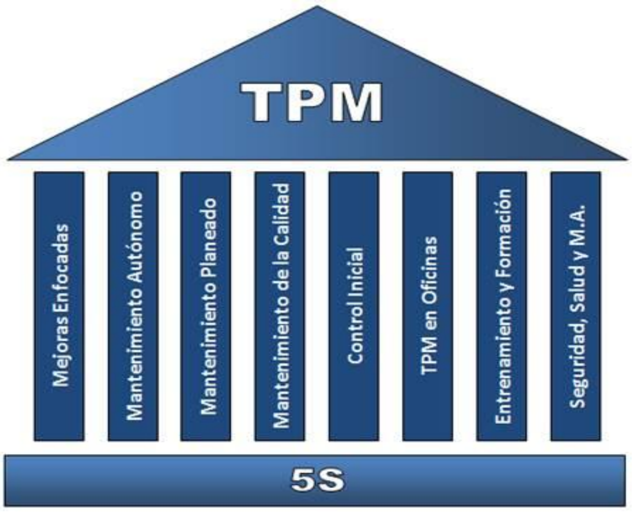

Fig. 7. TPM's 8 pillars.

5.4 | 5s Implementation

Table 4. 5S implementation.

5S Terms	Actions
Seiri (sort)	A list of the things that are not regularly used. Priority must be given to objects that are used frequently, and less frequently used items should be removed. Items that are not needed must be kept in a red-tagged area where they can be located when needed.
Seiton (set in order)	Initially, make sure that all extraneous items have been removed, and arrange the necessities such that they are accessible for use. The allocation of specific locations for necessary objects and the selection of sites based on frequency of use.
Seiso (clean)	Preserving a clean, clutter-free, and dust-free workplace. involving everyone in cleaning their machines, chairs, tables, etc.
Seiketsu (standardize)	Standardizing the activities that Ire carried out during the first three stages. In the plant, this can be accomplished by using color coding and standard operating procedures.
Shitsuke (sustain)	Providing people with various incentives and training to encourage appropriate housekeeping practices using a 5S tagline and poster to spread awareness among the public, as well as hosting monthly 5S meetings.

Table 4 elaborates the 5S terminologies and the effect can be seen in *Fig. 8* below:

Fig. 8. Scenery after 5S implementation on the factory floor.

5.5 | Implementation of AM on the Model Machine

After 5S, the model machine will go through an AM phase. This pillar is based on the notion that by delegating routine maintenance tasks to operators, skilled maintenance staff will have more time to concentrate on more complex tasks and technical repairs. Personnel must follow daily cleaning, lubrication, inspection, and tightening standards because of this CLIT instrument. Before a machine is unable to be properly identified due to a lack of maintenance, AM is performed. It increases quality and availability, avoids malfunctions, foresees failures, and prolongs equipment life. The business carried out AM by using run-to-failure mode regulation to allow the machine to run until it malfunctioned. One tool used on the assembly line to identify the machine component that appears to be malfunctioning is fugue mapping.

Machine abnormalities that put the operator in danger are referred to as fugue. Fuguai Tagging (F-Tagging) is a card with three categories—red, yellow, and blue—that is used to "tag" areas where machine anomalies exist. To understand the fundamental operations of the machine and locate the root cause, operators should receive machine function training and a component breakdown sheet. Determine the specific equipment that has a function for each component and how the components would fail using failure mode equipment analysis. The machines with the greatest risk are the axis and spindle subsystems. The five-axis system, which is the machine's critical area, should undergo AM, along with general cleaning, inspection, and F-Tagging. To show which abnormalities have been fixed and which have not, AM boards should be filled in. Machine function and likely causes of failure should be described on machine component sheets.

5.6 | Focused Improvement

The issues in WP-ATB 08 must now be resolved by all staff or employees, from the operator level to the top management. Starting with small group activities (a group made up of several operators), the problem is addressed by creating a report that will serve as the basis for discussion.

5.7 | Planned Maintenance

This phase attempts to keep an eye on the machine's malfunctioning parts. Components like a cutter, censors, and pusher lock can all be maintained. The business might switch its preventive maintenance program from periodic to routine maintenance.

5.8 | Quality Maintenance

Planning a maintenance system that delivers a high-quality, error-free product is the activity at this point (zero defects). The engineering team can now talk with quality control about the problems with the product quality. The maintenance staff should be aware of the maintenance activities, and standard operating procedures should be adequately documented.

5.9 | Education and Training

At this point, the staff or employees will be familiar with the machine. Before the implementation of OEE, businesses will need to develop several components, including awareness training, a clear definition of the operators' role, awareness of equipment losses, and basic equipment handling. A manager is in charge of ensuring that each maintenance worker has received the required training. They would become more knowledgeable, skilled, and capable as a result, improving their ability to make wise decisions when performing maintenance tasks. Later, I created a training program to advance our students' aptitude and knowledge in troubleshooting mechanical issues.

5.10 | Safety, Health, and Environment

All staff members will now receive training on workplace, environmental, and health safety. This knowledge includes wearing personal protection equipment, such as masks, shoes, and work attire when entering manufacturing areas. It also includes knowing how to evacuate in an emergency. Another skill might be upholding workplace environmental hygiene, such as refraining from bringing cosmetics or other foreign objects that contravene the operational standards of the company.

5.11 | Office TPM

At this stage, the company can develop TPM as a topic to be discussed regularly at every meeting in the company's activities.

5.12 | Development Management

The TPM department is currently designing an office to assist with administrative tasks that locate and eliminate waste to support production processes. Running AM, focused improvement, planned maintenance, and quality maintenance completes this level.

5.13 | OEE Calculation after TPM Implementation

After implementing the TPM methodology by the company, some new data from a certain production line was collected to calculate the OEE. The company has a 9-hour shift (8 AM to 5 PM), where the scheduled lunch break time is 1 hour/60 min. So, the planned production time is 8 hours/480min. Extra break = 20min. *Table 6* shows the new OEE calculation along with availability, performance, and quality.

Table 5. OEE calculation after TPM implementation.

Machine Name	Availability (%)	Performance (%)	Quality (%)	OEE (%)
Flat lock (front neck top)	90.00	94.00	99.00	83.00
Flat lock (sleeve hem)	89.16	91.22	99.00	80.82
Flat lock (side seam)	88.54	89.92	99.00	79.00
Flat lock (body hem)	90.00	86.00	99.00	77.00
Lock stitch (neck rib tuck)	91.25	89.00	99.80	81.05
Over lock (shoulder join)	90.62	89.37	99.50	80.00
Band knife	92.00	95.00	99.00	87.00
Metal detector	93.13	93.69	100	87.00
Thread suction	92.70	96.84	100	89.00
Iron machine	92.70	92.07	99.86	85.00
Production line OEE %	91.01	91.551	99.434	82.887

6 | Result and Discussion

Although implementing TPM successfully in any industrial setting is a difficult endeavor, the industry mentioned in the case study made every effort to complete the journey. According to the data gathered from the surveys, the industry has improved its performance in every area that concerns them, from January 2022 to February 2023. The corrective action plan increased the OEE value due to a decrease in the contributions of three major losses, confirming the plan's success. A comparison of the industrial environment scenario before and after TPM installation is shown in *Fig. 9*.

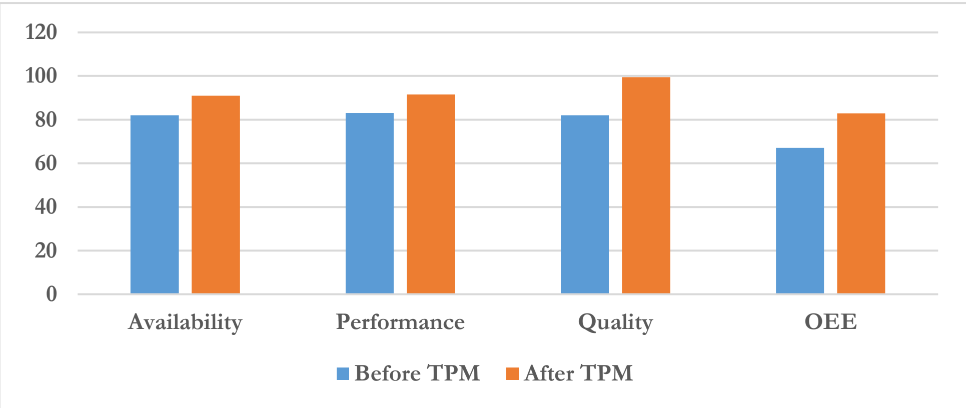

Fig. 9. OEE comparison.

By executing the TPM journey, the industry has reportedly made improvements in all relevant areas, including availability, performance efficiency, quality rate, OEE, breakdowns/accidents, customer complaints, etc. Additionally, an increasing number of managers and employees are currently expressing a desire to be hired by the industry, which is now regarded as a favorable omen for the future.

The current status of that production line is also compared with the world-class standard. This comparison is shown in the bellow chart:

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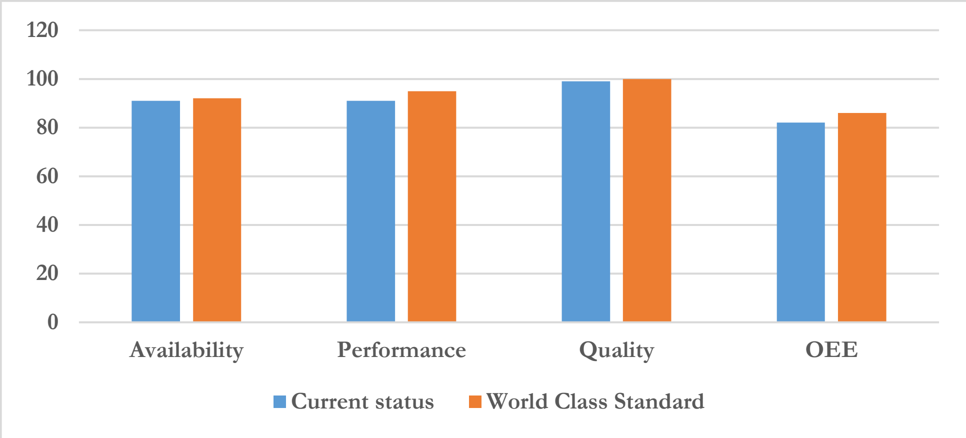

Fig. 10. OEE comparison with the world-class standard.

The industry-wide OEE is thus calculated based on the information shown in *Fig. 10*, and it is significantly lower than the global OEE level for process industries, which remains at about 85%. Hence, a successful TPM implementation can hold the industry's present OEE level closer to the worldwide average.

7 | Conclusions and Recommendation

7.1 | Conclusion

OEE was developed to reduce losses and increase value in the knitted textile sector. The following is ensured by the effective application of this sophisticated strategy:

- *The rate of availability rose to 2.66% as a result of the drop in setup and adjustment loss.*
- *The performance rate increases to 4.021% as a result of a decrease in minor stoppage loss.*
- *As a result of lower shortcomings and rework loss, the rate of quality rises to 0.224%.*
- *The OEE rate has increased to 6.117% due to higher availability, performance, and quality rates.*

The use of modern equipment and plant maintenance techniques is crucial in the age of globalization if you want to compete with other sectors. TPM is the best way for industries to keep up their effectiveness and competitiveness in terms of an organization's overall effectiveness. Continuous improvement is essential for industrial sectors to thrive and gain an advantage over rival industries. The textile spinning plant's OEE depends on both the efficiency of its machinery and the consistency of its processes because it is a continuous processing unit.

7.2 | Recommendation

Machines, as it offers logical suggestions to lower the proportion of each big loss attributed to OEE This study developed the OEE model to provide a comprehensive maintenance plan for the reduction of short stoppages, quality faults, and rework, setup, and adjustment loss. For each OEE loss, it is necessary to conduct a baseline investigation, analyze data using a Pareto chart and cause-and-effect diagrams, apply corrective action using checklists, collect data following the execution of the action plan, and compare the data. The proposed OEE model produces superior outcomes for enhancing the overall functionality of knitting causes.

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