Journal of
Production Research & Management

ISSN: 2249-4766 (Online)
ISSN: 2347-9930 (Print)
Volume 16, Issue 1, 2026
January–April
DOI (Journal): 10.37591/JoPRM

https://journals.stmjournals.com/joprm/

Research JoPRM

A Case Study on the Application of TPM Techniques in the Manufacturing Industry

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Abstract

The steel sector has developed dramatically during recent years, driven by technical breakthroughs, competitive challenges, and changing client requirements. Consumers now place increasing focus on cost effectiveness, shorter delivery lead times, and consistently excellent product quality, driving industrial organizations to continually strengthen their operational performance. Adopting structured quality and maintenance systems has become crucial for maintaining competitiveness and attaining operational excellence in response to these difficulties. With a focus on enhancing work quality, equipment dependability, and overall productivity via the methodical implementation of total productive maintenance (TPM) pillars, this research assesses the effects of TPM efforts on Power & Steel Limited manufacturing performance. By incorporating workers at all organizational levels, TPM aims to maximize equipment effectiveness and promote a culture of proactive maintenance and continuous development. The goal of the study is to investigate how TPM techniques affect important performance metrics, including production efficiency, defect minimization, and downtime reduction. An extensive case study was carried out at Power & Steel Limited production site to verify the efficacy of the suggested strategy. Production records, maintenance logs, and quality reports were used to gather data both before and after TPM installation to evaluate changes in operational performance. The implementation of TPM pillars showed promising results, such as decreased equipment failures, higher overall productivity, better process stability, and improved product quality. The findings suggest that rather than being seen as an extra operational expense, maintenance should be seen as a strategic expenditure meant to increase productivity. Effective maintenance procedures help businesses to maximize asset utilization, decrease waste, and increase process dependability, consequently increasing their competitive position in the market. Additionally, TPM helps create a workplace that is safer, cleaner, and more organized, all of which have a favorable impact on employee engagement and morale. The report also cites a number of crucial success criteria for TPM adoption, such as the active participation of top management, strong leadership commitment, and the integration of traditional maintenance procedures with complete TPM programs. The success of TPM programs was shown to be further enhanced by employee training, cross-functional coordination, and ongoing performance monitoring. All things considered, the results validate TPM as a workable and successful approach to attaining sustainable manufacturing competitiveness in the Indian steel sector, providing insightful information for researchers and practitioners looking to enhance operational performance via structured maintenance excellence.

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Received Date: January 22, 2026
Accepted Date: February 02, 2026
Published Date: February 13, 2026

Citation: Sibabrata Mohanty, Faisal Sagiruddin Shaikh, Fahad Al Akram, Sipu Gochhayat, Pappu Mandal. A Case Study on the Application of TPM Techniques in the Manufacturing Industry. Journal of Production Research & Management. 2026; 16(1): 1–9p.

Keywords: Total productive maintenance (TPM), manufacturing systems, industrial performance, productive maintenance, and overall equipment effectiveness (OEE).

INTRODUCTION ABOUT MAINTENANCE

An organization that works in tandem with production must prioritize maintenance. The final product is the principal output of production, but it also creates a secondary output: the need for maintenance. Maintenance involves preventing equipment failure from regular wear and tear and fixing equipment after it has failed. According to the definition, maintenance is "the work of keeping something in proper condition, upkeep," which suggests that it includes both repairs and preventive steps to keep the equipment working. Every piece of equipment has a limited operational life and needs to be maintained to continue operating as intended.

Initially, maintenance took a "breakdown" or remedial approach. The primary goal of mass manufacturing was to keep machinery operating, and maintenance was only performed in response to malfunctions. Because the operations staff prioritized fulfilling daily output objectives, this frequently resulted in longer idle times on the shop floor. Preventive maintenance was developed as a solution to this problem, enabling maintenance crews to foresee malfunctions and make adjustments to increase equipment reliability. The concept of productive maintenance ultimately resulted from a combination of preventive maintenance, maintenance prevention, and maintainability enhancement. Productive maintenance aims to optimize the life cycle cost of manufacturing equipment while maximizing its effectiveness. Nippon Denso concurrently created quality circles to engage staff in maintenance tasks. Total productive maintenance (TPM) emerged as a result of encouraging full employee engagement in productive maintenance implementation. The Toyota group's Nippon Denso was the first business certified by the Japanese Institute of Plant Engineers (JIPE) for the development and application of TPM.

Objectives of the Work

Focusing on the application of TPM, this study examines the variables that impact maintenance practices in manufacturing businesses. This study focuses on how TPM helps businesses stay competitive in a rapidly changing market while supporting effective maintenance systems.

This study's goals are to:

1. Evaluate the degree to which manufacturing firms have adopted TPM.
2. Determine and describe the main TPM techniques used by manufacturing companies.
3. Analyze the connection between maintenance performance and TPM procedures.
4. Examine the connection between the adoption of TPM procedures and corporate culture.
5. This study examined how TPM helps reduce waste and improve operational effectiveness in a changing economic climate.
6. Examine how TPM may save production costs without sacrificing product quality.
7. Evaluate how well TPM supports low-batch manufacturing with the minimum lead time.
8. Examine how TPM guarantees that customers receive items free of defects.

LITERATURE REVIEW

The definition of maintenance in industry is given by S. Borris [1]. He classifies maintenance into four groups. The goals of maintenance are explained by S.A. Kumar and N. Suresh [2]. They claim that equipment is a crucial resource for enhancing the value of goods. It needs to be maintained in a functional state. Inadequate maintenance causes quality problems, production disruptions, and downtime. In mass production lines, this is particularly true. Upkeep must be cost-effective. To reduce expenses, an integrated strategy is required.

Three forms of maintenance are identified by Kumar and Suresh [2]: predictive, preventive, and breakdown. They describe each type's benefits and drawbacks. TPM and reliability-centered maintenance (RCM) are two popular approaches, according to S. Borris [1]. They both began in the United States. Later, TPM moved to Japan, where it continued to grow. It was referred to as preventive maintenance (PM) in the United States. PM concentrated on enhancing equipment dependability. TPM is similar to total quality management (TQM) and is more comprehensive [2]. It makes use of instruments like documentation, benchmarking, and employee empowerment. TPM increases competitiveness, according to studies. TPM initiatives improved an Indian organization's production

ISSN: 2249-4766 (Online), ISSN: 2347-9930 (Print)

performance [3]. Additionally, TPM enhances product quality [4]. Using TPM, a small manufacturing facility found equipment issues and decreased defects. Together with TPM, the Kanban method decreased inventory, improved flexibility, and cut operating expenses [4]. Agriculture has also used TPM [5]. Its objectives are to increase output, avoid errors, and efficiently handle equipment.

In addition to the above studies, several researchers have investigated how maintenance techniques can enhance manufacturing efficacy. One of the forerunners of TPM, Nakajima [6], describes it as an all-encompassing strategy that aims to maximize overall equipment effectiveness (OEE) by including every employee, from shop floor workers to top management. He emphasized that the eight core pillars of TPM—autonomous maintenance, planned maintenance, targeted improvement, quality maintenance, and training and education—all help to achieve zero malfunctions, zero faults, and zero accidents. Nakajima's work provided the groundwork for the broad adoption of TPM in numerous industrial sectors.

Muchiri et al. [7] stress that good maintenance management greatly affects productivity, cost savings, and equipment availability. Their analysis reveals that businesses employing organized maintenance frameworks have increased asset performance and decreased life cycle costs. According to Eti, Ogaji, and Probert [8], inadequate maintenance procedures are a significant contributor to low productivity in the industries of developing nations, underscoring the need for preventive and predictive maintenance strategies for long-term industrial development. The link between TPM implementation and manufacturing performance has been examined in a number of empirical investigations. After conducting a thorough analysis of TPM techniques in Indian manufacturing organizations, Ahuja and Khamba [9] came to the conclusion that TPM adoption significantly boosts employee morale, productivity, quality, and safety.

Additionally, their results show that ongoing training, employee participation, and management commitment are essential for successful TPM adoption. In a different study, Cooke [10] highlighted the behavioral and cultural shifts necessary for TPM effectiveness, pointing out that TPM should be seen as an organizational transformation project rather than just a maintenance strategy. Additionally, a favorable correlation between TPM techniques and manufacturing performance characteristics, including cost, quality, delivery, and flexibility, was empirically demonstrated by McKone, Schroeder, and Cua [11].

According to their study, TPM improves process stability and equipment dependability, which enhances lean manufacturing and just-in-time (JIT) systems. This perspective is also supported by Swanson [12], who contends that combining TPM with lean methods produces better operational results. In recent studies, TPM research has expanded beyond typical manufacturing. In his discussion of the strategic significance of maintenance management in gaining a competitive edge, Tsang [13] argued that proactive maintenance practices strongly correspond with long-term corporate goals. Al-Najjar and Alsyouf [14] showed that TPM implementation lowers operational risks and increases equipment efficacy in the service and process sectors.

These results demonstrate that TPM is a flexible and adaptive strategy that can be used in various industrial settings. The usefulness of TPM as a strategic maintenance philosophy that improves productivity, quality, safety, and organizational competitiveness is generally well supported by the research now in publication. Nevertheless, additional industry-specific case studies in the Indian steel business are still needed despite a great deal of international research. By analyzing the effects of TPM implementation at Power & Steel Limited, this study aims to close this gap and offer actual data to expand the TPM literature.

TPM FOLLOWED IN THE STEEL INDUSTRY

The TPM team, management, and union representatives determine the program's scope, choose equipment, establish objectives, and gather baseline performance data in a master plan that serves as the foundation for the TPM implementation. While maintenance personnel offer training and assistance in creating safety protocols, operators of autonomous maintenance are in charge of cleaning, inspecting, and carrying out routine maintenance. To prevent conflicts, planned maintenance entails tracking performance, assessing equipment data, and integrating maintenance plans with production. To improve future equipment design, arrange spare parts, schedule periodic analyses, and carry out proactive replacements, maintenance reduction uses data and lessons learned. To simplify activities and maintain the program, holding the gains guarantees that new TPM practices are integrated with production systems, integrated into standard operations, and constantly enhanced. The various pillars of TPM are shown in Figure 1.

Process Carried Out in a Steel Industry

As shown in Figure 2, the process begins with hot-rolled (HR) coils, which are made at high temperatures and have comparatively greater thickness and surface oxide scale.

To prepare them for further processing, these coils are first delivered to the HR slitter, where they are chopped into smaller widths. In the pickling and cold rolling processes, slitting guarantees dimensional appropriateness and seamless handling. Following slitting, the material moves onto the pickling line, where acid solutions, typically hydrochloric acid, are used to remove the oxide scale created during hot rolling. This step is essential for obtaining a clean steel surface for cold rolling. The acid regeneration plant (ARP) recovers and reuses spent acid, making the process economical and environmentally sustainable.

Subsequently, the descaled strip is processed in cold rolling mills, such as 4-Hi or 6-Hi cold rolling mills, where the thickness is drastically decreased at room temperature. While the 6-Hi mill offers superior control for narrower gauges and better flatness, the 4-Hi mill is often used for modest reductions. To preserve the roll surface quality and guarantee consistent thickness and surface polish, roll grinding is performed regularly during this phase. At this point, the product is referred to as a cold rolled full-hard (CRFH) coil, which has minimal ductility but great strength.

The CRFH coil travels through an electrolytic cleaning line (ECL), which uses electric current and alkaline solutions to eliminate any remaining rolling oils and surface impurities before the material is annealed. Consistent material characteristics and efficient heat treatment depend on a clean surface. The cleaned strip then undergoes annealing, a heat treatment technique that restores ductility by reducing internal tensions caused during cold rolling. The grain structure of steel can recrystallize after annealing, enhancing its softness and formability, which are required for subsequent processing and end-use applications.

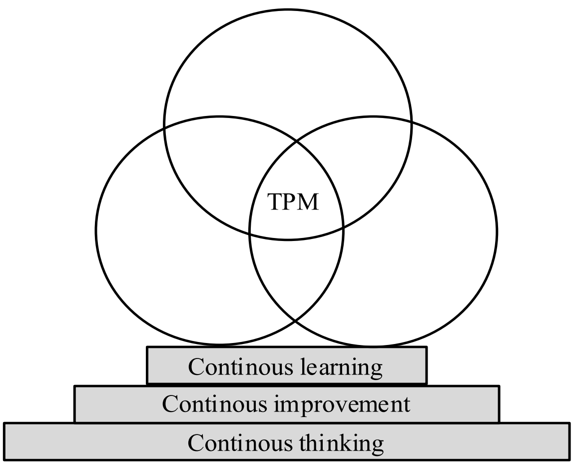

Figure 1. Pillar of TPM.

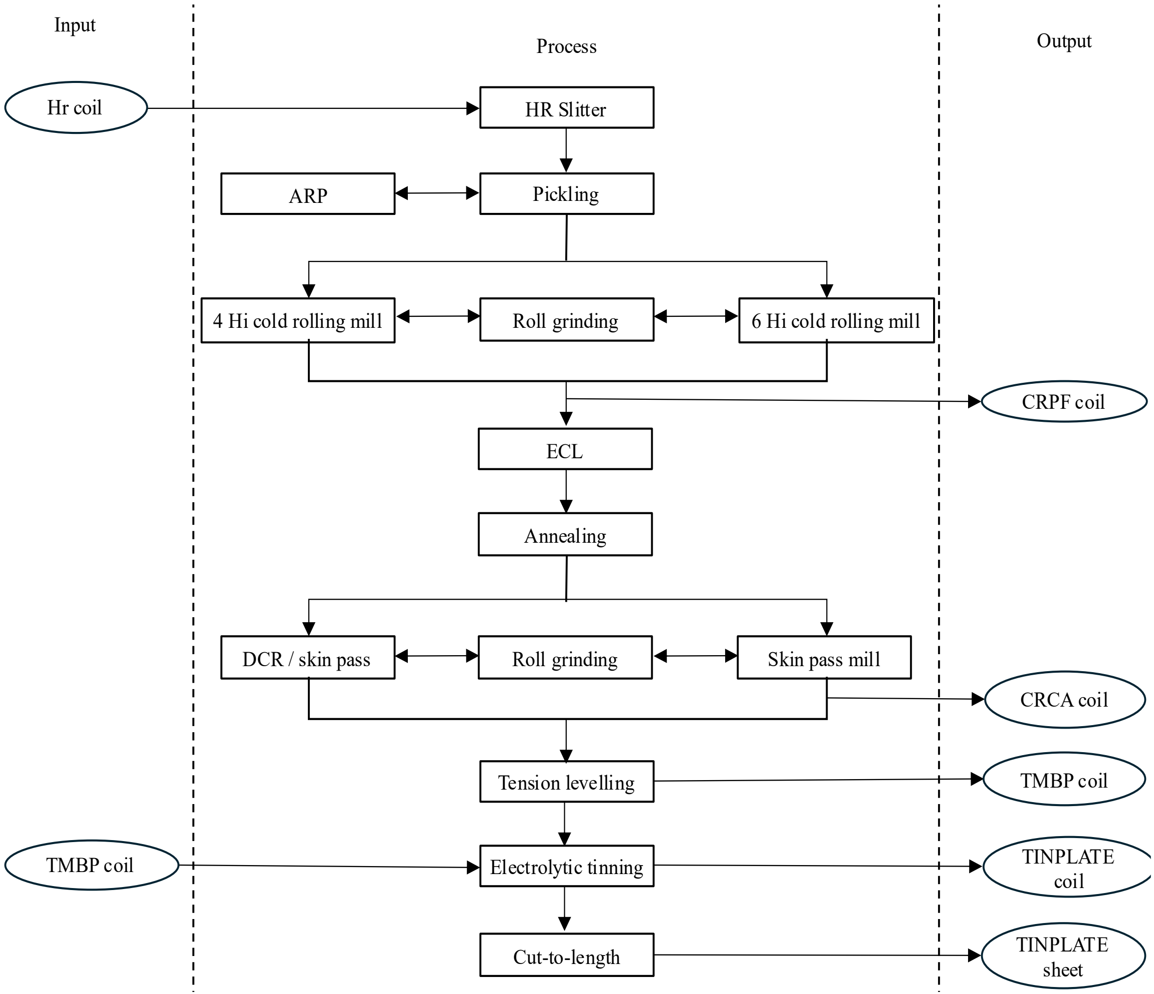

Figure 2. The detailed process in a steel power plant.

Double cold reduction (DCR) or skin pass rolling is applied to the strip following annealing. While DCR adds extra strength where needed, skin pass rolling uses a very slight decrease to improve surface smoothness, flatness, and reduce yield point elongation. Once more, roll grinding is employed to preserve accuracy and surface quality. The output from this step is cold rolled close annealed (CRCA) coil. After that, the CRCA coil goes through tension leveling, which eliminates form flaws, including coil set, edge waves, and buckles, by applying controlled tension and bending. This results in Tin Mill Black Plate (TMBP) coil, a stable, flat product that is used as the foundation for tinplate manufacturing.

The TMBP coil is then treated in an electrolytic tinning line, where an electrolytic procedure is used to deposit a thin, consistent layer of tin on both sides of the steel strip. The material is appropriate for food packaging and container applications because of its tin coating, which also offers superb surface attractiveness and exceptional corrosion resistance. Tinplate coils are the current products.

The tinplate coil is then delivered to the cut-to-length machine, where it is cut into sheets that meet the client's specifications. The finished product is tinplate sheets, which are frequently used in cans, containers, and other packaging applications.

OBSERVATIONS ON MAINTENANCE OF THE STEEL INDUSTRY

- For any type of maintenance problem, whether small or big, people are called to solve the problem.
- The concept of Autonomous maintenance is not followed closely.

- The record-keeping procedure requires modification.
- The placement of tools and tackles vis-à-vis maintenance activities requires modification.
- Operational inefficiency due to old technology leads to a high cost of production.
- Ageing of equipment requires replacement or renovation.

METHODOLOGY

The primary reasons for time wastage and output losses in the industrial sector were found and examined over the study period. OEE was employed as a key performance metric to measure the effect of these losses on equipment performance and overall output. OEE is a commonly used indicator in TPM that assesses how well manufacturing equipment is used by combining three crucial elements: product quality, availability, and performance efficiency. For the analysis, a 24-hour shift duration was considered. This was used to compute projected production time by removing planned production breaks. The actual operating time was then calculated by subtracting machine downtime, which is defined as times when the equipment was not in use because of malfunctions, maintenance, or other stoppages, from the scheduled production time. The total number of units produced each day and the number of units rejected because of flaws, were considered while evaluating production performance. Rejected units were subtracted from the overall output to determine the final quantity of high-quality products. By dividing the overall operating time by the total number of units produced, cycle time—which is the amount of time needed to generate one unit—was determined. To represent optimal equipment usage, the planned production time was also used to calculate the valuable operating time per unit. The degree to which the equipment was available for production was determined by calculating the ratio of operating time to scheduled production time. By comparing the actual cycle time with the useful operating time per unit, which indicates the production process's efficiency, the performance rate was assessed. The percentage of good units produced in relation to the total number of units manufactured was used to calculate the quality rate, which indicated how well the machinery produced goods free of flaws. Lastly, availability, performance rate, and quality rate were multiplied to determine OEE. By highlighting the main regions of loss and offering a clear picture of equipment use, this comprehensive statistic made it possible to identify chances for improvement through TPM adoption.

RESULT AND DISCUSSION

Calculation of OEE Before Implementing TPM

Using the above-mentioned variables and equations, we calculated the OEE of this industry from October 2022 to December 2022, as shown in Table 1. After calculating the OEE of this industry, it was observed that the OEE of this industry was not acceptable according to the industry's profit. Therefore, it is advisable to implement TPM pillars in this industry.

Calculation of OEE for October 2022

Total shift time: 24 hrs. = 24×31 = 44640 min
Machine downtime: 8220 min
Total units manufactured: 4424.95 MT
Total units rejected: 135 MT
Total planned production time: 44640 min
Total operating time: (44640 – 8220) min = 36420 min
Final goods = 4429.95 – 135 = 4289.95 MT
Cycle time (time taken to produce one unit): 36420/4424.95 = 8.23
Valuable operating time per unit: 44640/4424.95 = 10.09
Availability = 36420/44640 = 81%
Performance rate = 8.23/10.09 = 81%
Quality rate = (4429.95 – 135)/4429.95 = 97%
OEE = 0.81×0.81×0.97 = 64%

Table 1. Calculation of OEE before implementation of TPM.

Parameters/months	October 2022	November 2022	December 2022
Shift time	44640 min	43200 min	44640 min
Breakdown time	8220 min	6000 min	6900 min
Units manufactured	4424.95 MT	3681 MT	4009.39 MT
Units rejected	135 MT	123 MT	90 MT
Final goods	4289.95	3558	3919.39
Planned production time	44640 min	43200 min	44640 min
Operating cost	36420 min	37200 min	37740 min
Cycle time	8.23	10.10	9.41
Valuable operating times per unit	10.09	11.74	11.13
Availability	81%	86%	84%
Performance rating	81%	86%	84%
Quality rate	97%	96%	98%
OEE	64%	71%	70%

Similarly, for November and December 2022, OEE can be calculated, and the results are shown in the corresponding columns of Table 1.

SUGGESTIONS AND IMPLEMENTATION OF TPM

After TPM Implementation

Calculation of OEE for January 2023

Total shift time: 24 hrs. = 24×31 = 44640 min
Machine down time: 2340 min
Total units manufactured: 4711.89 MT
Total units rejected: 82 MT
Total planned production time: 44640 min
Total operating time: (44640 – 2340) min = 42300
Final goods = (4711.89 – 82) MT = 4629.89
Cycle time (time taken to produce one unit): 42300/4711.89 = 8.98
Valuable operating time per unit: 44640/4711.89 = 9.47
Availability = 42300/44640 = 95%
Performance rate = 8.98/9.47 = 95%
Quality rate = (4711.89 – 82)/4711.89 = 98%
OEE = 0.95 × 0.95 × 0.98 = 88%

Similarly, OEE for the other two months (February and March) can also be calculated according to the above method, and the results are specified in the corresponding columns of Table 2.

COMPARATIVE STUDY OF BOTH IMPLEMENTATIONS

Figure 3 compares the OEE, performance rate, quality rate, and availability prior to and after the installation. This shows that the proper utilization of resources increases, and the OEE, performance rate, quality rate, and availability decrease when TPM is properly applied.

Therefore, the performance rate, quality rate, and availability were lower before TPM implementation OEE and increased after implementation OEE, as Figure 3.

The plot demonstrates that the OEE, performance rate, quality rate, and availability all increased after TPM adoption. The OEE increased by approximately 20% after three months of adoption.

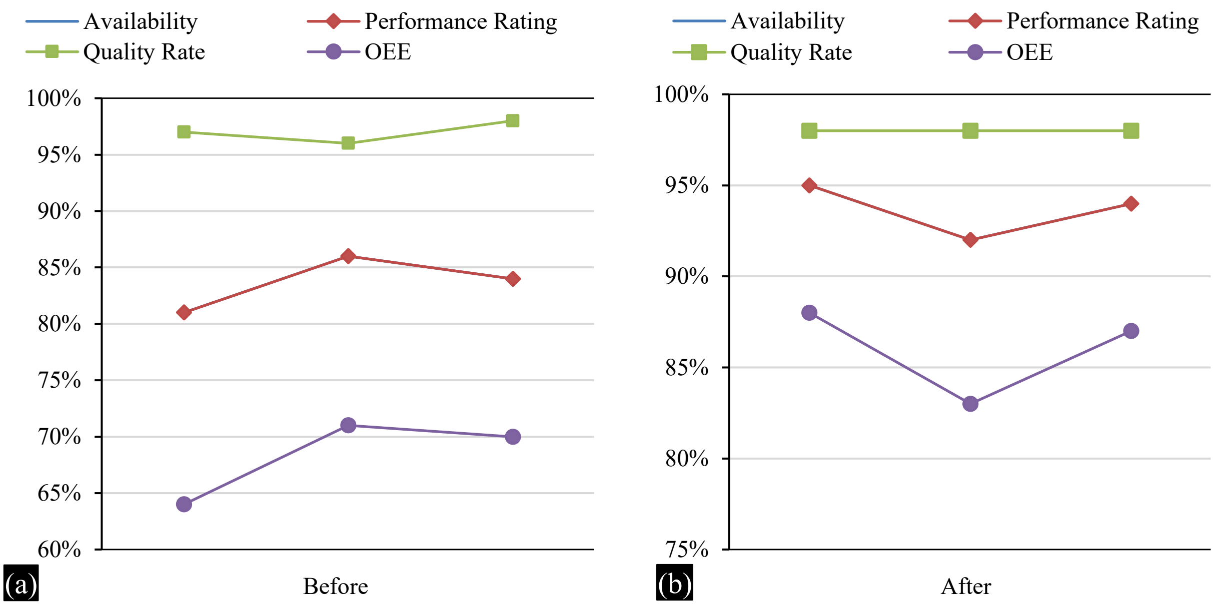

Figure 3. (a) to (b) Comparison of implementing TPM.

Table 2. OEE after implementation.

Parameters/months	**January 2023**	**February 2023**	**March 2023**
Shift time	44640 min	41760 min	44640 min
Breakdown time	2340 min	3300 min	2820 min
Units manufactured	4711.89 MT	5203.11 MT	5314.68 MT
Units rejected	82 MT	95 MT	92 MT
Final goods	4629.89	5108.11	5222.68
Planned production time	44640 min	41760 min	44640 min
Operating time	42300	38460	41820
Cycle time	8.98	7.39	7.87
Valuable operating times per units	9.47	8.02	8.40
Availability	95%	92%	94%
Performance rating	95%	92%	94%
Quality rate	98%	98%	98%
OEE	88%	83%	87%

CONCLUSION

A manufacturing facility was studied to analyze TPM implementation issues, the roadmap followed, and key benefits achieved. This research highlights how TPM initiatives in the Indian industry provide strategic advantages to meet global competition. The study shows that TPM has a greater impact on manufacturing performance than traditional maintenance practices, helping build organizational capabilities for sustained competitive advantage.

Systematic TPM interventions improve productivity, quality, safety, and workforce morale while ensuring cost-effective manufacturing. Effective TPM initiatives can support strategic manufacturing improvements in a dynamic global market.

In a three-month study at the Power & Steel Industry, the initial OEE was approximately 70%. Several operational and worker-related weaknesses were identified, and specific measures were implemented to address them. After TPM implementation, the OEE increased to an average of 86%, indicating substantial improvements in productivity, the working environment, and profitability.

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