

Total Productive Maintenance: Enhancing Overall Equipment Efficiency in the Steel Industry of Bangladesh

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Abstract

Optimizing operational effectiveness while maintaining product quality is essential in the changing steel companies. This study explores Total Productive Maintenance (TPM) in the context of steel production, highlighting how it contributes to increased Overall Equipment Efficiency (OEE) by removing inefficiencies. The most significant losses, mostly Chemistry/Scrap, and a few others are identified by PARETO analysis. This research uses in-depth analysis of the steel manufacturing process to not only identify significant causes of total delays and faults but also to identify the root causes with countermeasures of significant losses using the WWBLA (Why-Why Because Logical Analysis) method. The countermeasures found in the WWBLA have reduced overall delays and total faults, resulting in an increase in OEE from 79.5% to 80.5%. This study emphasizes the importance of TPM as an important tool for improving productivity, sustainability, and competitiveness in the steel manufacturing industry by integrating it with structured analytical methods.

Keywords

Total Productive Maintenance, TPM Pillar, Overall Equipment Effectiveness, Autonomous preventive maintenance

1. Introduction

The steel melting sector in Bangladesh, which is a dynamic and ever-evolving field, must prioritize operational efficiency to remain competitive in the global market. Total Productive Maintenance (TPM) is an aggressive method that focuses on improving the function and design of manufacturing equipment. Seiichi Nakajima in the 1960s pioneered a quantitative metric called Overall Equipment Effectiveness (OEE) is a Key Performance Indicator (KPI) in any manufacturing to accelerate productivity and help to identify the actual loggers. OEE was developed by three important aspects availability, performance, and quality. Availability identifies the quantity of time when the machine is running is determined by subtracting machine downtime from the projected operating time, performance is described as the comparison of the speed at which the machine runs to the ideal cycle time, and quality is defined as the number of good components produced and also comprises flaws made during startup as well as those produced while the machine is in stable production. Total Productive Maintenance (TPM) is at the vanguard of this endeavor, a complete system that goes beyond standard maintenance procedures to improve total equipment efficacy. Saureng

Kumar et al (2017) explained that TPM aims to optimize zero breakdowns, zero accidents, and zero loss. Managing and maintaining the machinery in steel melting plants is critical to comply with the rising demand for high-quality steel. This publication tries to explore the subtle interplay between TPM principles and their direct influence on the efficiency and productivity of machinery in the steel melting factory of Bangladesh. Almeanazel (2010) mentioned The fundamental principle behind maintenance is to have the parts and machine ready to accomplish what is needed within the time and space constraints while using fewer resources. The Japanese TPM strategy emphasizes effective equipment utilization, a comprehensive preventive maintenance system, full departmental engagement, involvement of everyone from the shop floor to top management, and the development of autonomous, small group-based preventive maintenance. Our goal, through this holistic perspective, is to contribute not just to the understanding of TPM, but also to provide industry stakeholders with the information to improve equipment efficacy and strengthen the basics for long-term growth in Bangladesh's thriving steel melting sector.

1.1 Objectives

The purpose of this study is to identify and analyze significant production losses, delays, and quality issues relating to Total Predictive Maintenance (TPM) implementation. The objective is to calculate the rise in Overall Equipment Effectiveness (OEE) as a result of TPM methods. The study contributes to the advancement of the OEE tool by proving its usage in industries and presenting practical examples. The conclusion offers particular solutions for improving OEE and overcoming disruptions in industrial operations.

2. Literature Review

TPM definitions were presented by Bamber et al. (1998), in his assessment of TPM literature, he presented two definitions, one based on the Japanese approach and the other on the Western perspective. Wireman (1991), another US advisor of TPM, believes that TPM is maintenance that encompasses all employees in the organization and so includes everyone from high management to the line employee and indicates: “. . . it encompasses all departments including, maintenance, operations, facilities, design engineering, project engineering, instruction engineering, inventory and stores, purchasing, accounting finances, plant /site management". Ahuja (2011) stated that in today's world market, TPM may be a successful worldwide strategy for manufacturing organizations, allowing enterprises to consistently improve their performance. Saureng Kumar et al. (2017) analyzed how nonproductive work can be minimized after section-wise and process-wise analysis. The Total Productive Maintenance practices, developed by S. Nakajima (1998) at the Japan Institute of Plant Maintenance, were the inspiration for Overall Equipment Effectiveness. The goals of TPM are to achieve the ideal performance and achieve Zero loss demonstrated by McKone et al (1999), which means no production scrap or defect, no breakdown, no accident, no waste in the process running or changeover [6]. TPM, as outlined by McKone et al. (1999), presents a complete company-wide approach to maintenance management that may be separated into long-term and short-term parts. A case study was taken from Steel Company in Jordan to estimate the OEE to optimize their maintenance practices and productivity which was developed by Almeanazel and O. T. R. (2010).

3. Pillars of TPM

TPM consists of 8 pillars with a base of 5S which is depicted in Figure 3. All pillars are equally important when launching any TPM program.

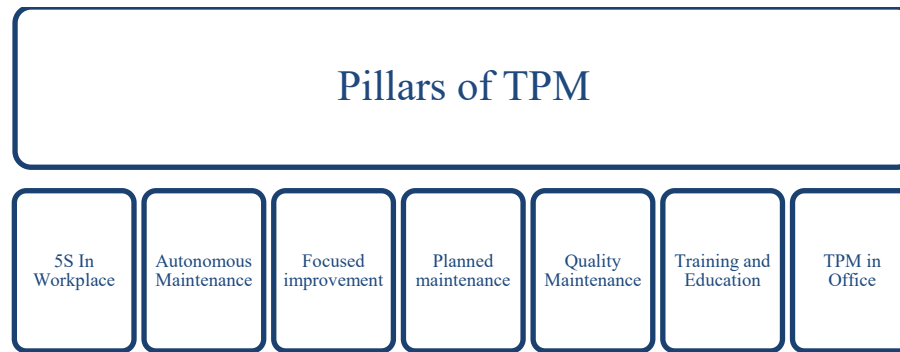


Figure 3. TPM Pillars.

Pillar -1: 5S

Typically, the introduction of 6S or workplace organization comes before the deployment of a TPM program.

1. SORT: Eliminate all unnecessary things and determine all tools and equipment required to complete the task.
2. SET-IN-ORDER: Organize all usable items near the facility and identify less important items.
3. SHINE: Cleaning is such a manner that everything is in perfect working order.
4. STANDARDIZE: Create a method for doing activities and operations that is consistent. Achieved by consistent use of the SORT, SET-IN-ORDER, and SHINE processes.
5. SUSTAIN: This step ensures that everyone must follow the previous four steps.

Pillar-2: Autonomous Maintenance

Jishu Hozen, or Autonomous maintenance is a pillar of TPM that emphasizes the operators' capability to maintain any equipment. It contains several steps:

1. Define Objectives: Clearly outline goals for Jishu Hozen in TPM, focusing on improving equipment reliability and performance.
2. Create Teams: Form cross-functional teams that will be in charge of carrying out Jishu Hozen activities, assuring a broad set of talents and viewpoints.
3. Training: Give all team members participating in the process extensive training on Jishu Hozen concepts and procedures.
4. Equipment Evaluation: Conduct rigorous equipment assessments to detect possible problems and create a baseline for future improvements.
5. Implement Autonomous Maintenance: Give operators the authority to do routine equipment maintenance, instilling a feeling of ownership and preventing small difficulties from becoming large concerns.
6. Continuous Improvement: Create a feedback loop for continuous improvement, assessing and modifying Jishu Hozen procedures based on outcomes and feedback on a regular basis.
7. Documentation: To measure progress and guarantee consistency, keep extensive documentation of Jishu Hozen operations, such as standard operating procedures, checklists, and performance indicators.

Pillar-3: Focused improvement

Focused improvement fully depends on the theory of Kaizen. Kaizen is a Japanese phrase that means "continuous improvement" or "change for the better." It is a concept and technique centered on incremental and ongoing improvements to processes, goods, or services. Kaizen stresses employee participation at all levels in developing and implementing modest, incremental improvements to improve productivity, quality, and overall performance. The objective is to foster a culture of continual improvement in which even little enhancements contribute to long-term success. Kaizen is a key idea in Total Productive Maintenance (TPM) and Lean management.

Pillar-4: Planned maintenance

TPM's planned maintenance focuses on proactively arranging and carrying out maintenance tasks to avoid failures and maximize equipment effectiveness. It entails responsibilities such as frequent inspections, cleaning, lubrication, and predictive maintenance to keep machinery in good working order. We can measure the maintenance system by following formulas:

Mean Time Between failure (MTBF) is the measurement of reliability and continuous development of any maintenance work.

$MTBF = \text{Total operating time} / \text{Number of failures over a given period}$

Another one is Mean Time to Repair (MTTR) which indicates the performance quality of the maintenance team and the reliability of a system or product from a repair standpoint.

$MTTR = \text{Total downtime} / \text{Total number of failures over a specific time}$

Pillar-5: Quality Maintenance

The Quality Maintenance pillar, Total Productive Maintenance (TPM), focuses on avoiding and eliminating problems across the whole manufacturing process (Early Equipment Management) this entails taking quality into account throughout the design and procuring of new equipment. TPM grapples to prevent problems from arising in the first place by addressing possible quality concerns early on.

Pillar-6: Training and Education

Provide all personnel with the knowledge and abilities needed to do basic machine maintenance. This process of empowering operators frees up maintenance professionals to participate in the investigation and root cause of downtime issues, allowing them to be more proactive in building up measures to prevent future occurrences. Improves operators' ability to routinely maintain production equipment; trains operators to clean and maintain their equipment daily; frees up maintenance personnel to focus on proactive improvement activities such as preventive maintenance; and trains managers to mentor and coach employees on TPM techniques.

Pillar-7: TPM in Office

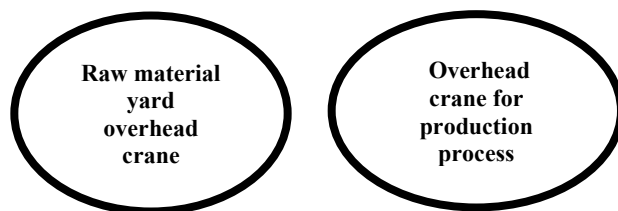
Administrative and support departments can be viewed as process plants, with the primary duties of collecting, processing, and distributing information. Process analysis should be used to improve information flow and eliminate unnecessary procedures. Waste in administrative and support functions can easily be addressed. Through using TPM approaches to support operations in order to minimize waste and streamline processes. This will increase production efficiency by decreasing issues produced by administrative chores such as raw material acquisition, order entry, and order release to production.

Pillar-8: Safety and Environmental Management

Identifies possible hazards and implements actions to minimize or at least lessen the risk. Improves the working environment by eliminating potential safety risks Ensures that all protections and PPEs are in place to limit the possibility of operator harm.

4. Methods

In the melting unit plant, an induction furnace is used to melt the scraps and generate molten metal. Scraps are delivered by Raw material yard by the help of overhead crane. The overhead crane loads the transfer car according to running recipe. Then the operator of production process takes scraps from transfer car and load the vibro feeder with the scraps. Vibro feeder take into place in front of induction furnace and start to charge scraps into the induction furnace. After the completion, full filled induction furnace with molten metal called "heat" in the melting unit. The production flow is depicted in the Figure 1.



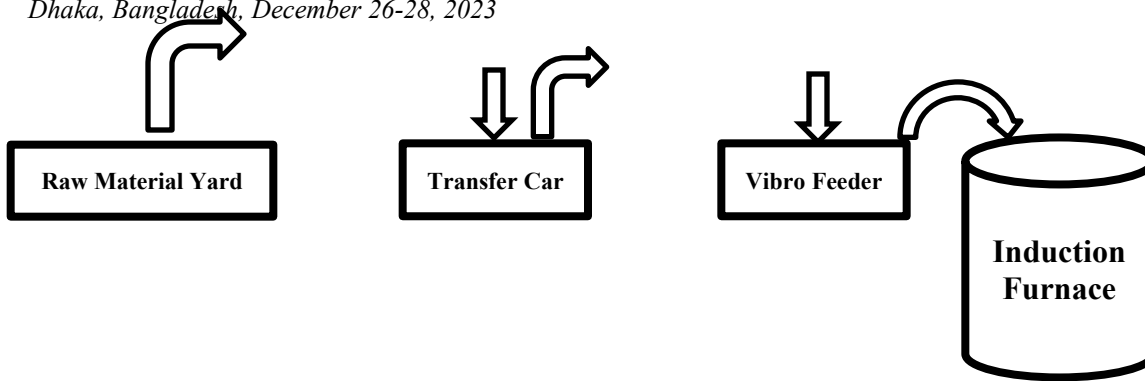


Figure 1. Process Flowchart

To launch TPM ideas in plant maintenance tasks, workers must first discover that it is a team-based project and it requires different stages. Figure 2 demonstrates the steps as below:

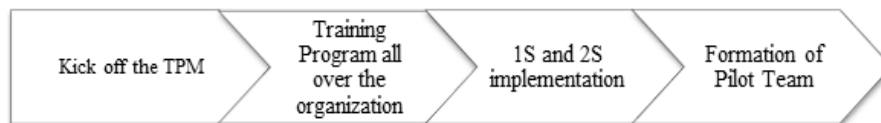


Figure 2. Launching TPM in any manufacturing unit

Step 1: Kick Off the TPM

While launching any TPM program, the whole organization must be concerned about the topic of Total Productive Maintenance and everyone's participation is mandatory.

Step 2: Training Programs all over the organization

The efficacy of training can impact the success of implementing a TPM (Total Productive Maintenance) program. TPM procedures are better implemented and sustained by well-trained teams, resulting in increased equipment dependability, maintenance efficiency, and overall productivity. To guarantee a seamless program rollout, training should cover TPM concepts, problem-solving strategies, and teamwork abilities. Ongoing training also aids in maintaining momentum and adapting to changing conditions.

Step-3: 1S and 2S implementation

"1s & 2s" often refers to the first stages in the 5S approach, which is a vital part of Total Productive Maintenance (TPM). The 5S concept entails arranging the workplace to maximize efficiency and effectiveness. To begin implementing the "1s & 2s" program in TPM, sort and organize the workplace to lay the groundwork for a more efficient and productive working environment.

Step-4: Formation of Pilot Team

A pilot team is very much needed while implementing TPM. The team will evaluate the progression of the program. 5S audit, training and education, awareness about TPM, etc. will be conducted by this team. Forming a pilot team is a strategic and essential step in the TPM implementation process before scaling them across the entire organization.

5. Data Analysis

Before the analysis, 10 days survey was held in the steel melting industry to identify the major losses with respective downtime. The purpose of maintenance management is to improve equipment efficiency and output. It tries to achieve and maintain optimal equipment conditions to avoid unexpected breakdowns, speed losses, and process quality problems. Overall efficiency, including economic efficiency, is accomplished by lowering maintenance costs and maintaining optimal equipment conditions during the life of the equipment.

So the steps can be classified as:

1. Identification of relevant losses by Pareto analysis.
2. Calculation of Overall Equipment Efficiency (OEE).
3. Reduction of losses with analytical techniques.
4. Root cause analysis with Why-Why Because Logical Analysis (WWBLA).

Pareto analysis involves identifying and focusing on the most significant factors that influence a particular outcome. The "80/20 rule" is a common expression of this idea, suggesting that roughly 80% of effects come from 20% of causes. Cumulative measurement is shown at Table 1 to plot the result in bar chart to visualize the criteria of losses.

Table 1. Significant losses among 11 losses.

Category	Total delays(mins)	Cumulative	% Cumulative
Chemistry/Scrap	600	600	51%
Material unavailability	102	702	59%
Transfer car	75	777	66%
Crane problem	70	847	72%
Shearing machine	68	915	77%
Electrical related	67	982	83%
Ground Leakage Detector (GLD)	64	1046	89%
Mechanical related	55	1101	93%
Continuous Casting Machine (CCM) related	34	1135	96%
Vibro Feeder	30	1165	99%
High-temperature issue	16	1181	100%

Figure 4 demonstrates the results by which the actual productivity is hampered. Mainly 3 major factors were identified that significantly have an impact on the reduction of OEE improvement in this melting unit. Now some analytical tools such as WWBLA (Why-Why-Because Logical Analysis), Why-Why analysis, Fishbone analysis etc. can be used to analyze the actual root cause.

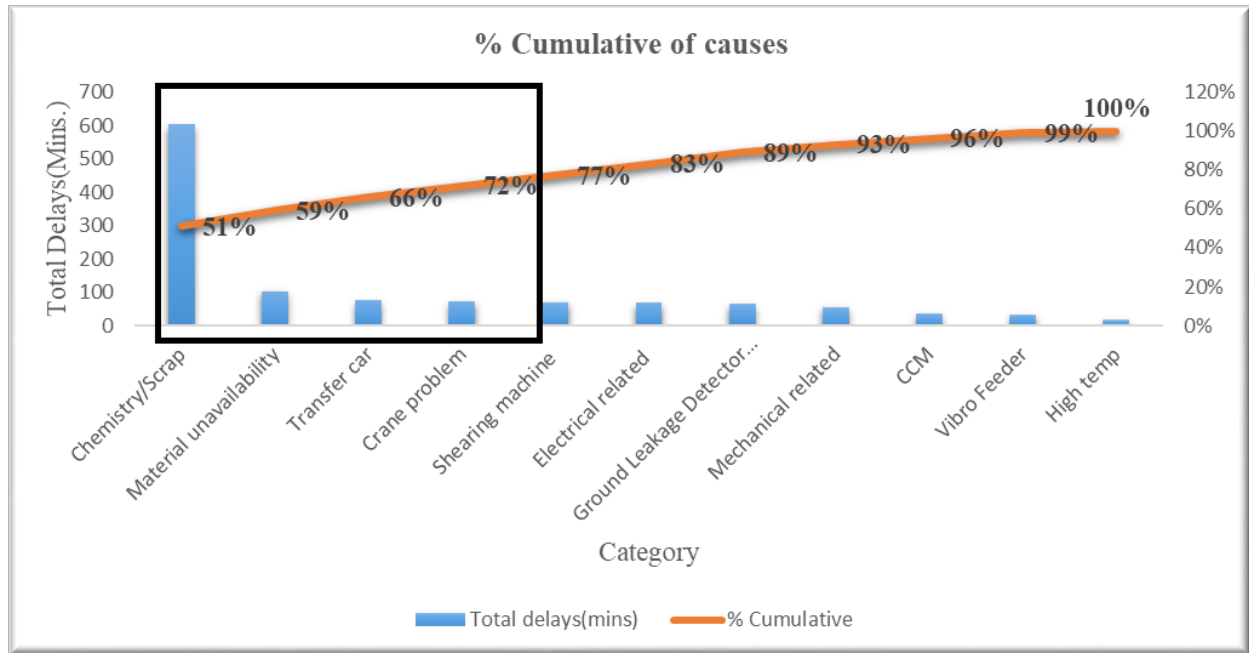


Figure 4. Pareto chart showing reason contributing to most delays

WWBLA is used in this quantitative study. The WWBLA approach is a worksheet for determining the fundamental root causes of an issue. Each main problem is studied separately in this method, and a worksheet is created. A causal factor is found and referred to as the main reason for any important issue. Then, an analysis is carried out to see whether it can be further broken down into more fundamental reasons. Should this division be possible, it is denoted by G, where G stands for "Go." After then, a second major portion to the issue is identified and confirmed. The third and fourth challenges are identified by repeating this methodical technique. When more identification is not feasible, the verification is marked with NG, which stands for "No Go." In the end, countermeasures are identified for every underlying source of the problems.

According to Pareto analysis, the four major losses—Chemistry/Scrap, Material unavailability, Transfer car, and crane problem—now comprise around 72% of the overall loss. Therefore, in order to raise the OEE, these losses must be eliminated first. The WWBLA approach is now employed to determine countermeasures that reduce the issue of significant losses.

The root cause analysis of these four major reasons are analyzed in the Table 2, Table 3, Table 4 and Table 5 to complete the investigation of the breakdown.

Table 2. Factors and Countermeasures of delay regarding Chemistry/scrap

Problem	1st Factor of problem	Verification	2nd Factor for problem	Verification	3rd Factor for problem	Verification	Countermeasures
Chemistry/Scrap	1. Abnormal chemistry	G	1.1 Improper charge mixing	G	1.1.1 Responsible Charging crane	NG	What: Recipe should be informed to crane operators; Who: Shift In-Charge; When: Every toolbox talk
	2. High Slag	G	2.1 Dust in scraps	G	2.1.1 Not cleaning properly 2.1.1 Dust mixed sponge iron	NG	What: Proper cleaning of scraps and good quality sponge iron sacks should be ensured; Who: Raw material yard; When: During shearing machine running time;
			2.2 Low quality sponge iron	G		NG	
3. Scrap jam	G	3.1 Lots of wire cutting and rod cutting	NG			What: A Poker machine should be installed; Who: Plant maintenance; When: During project period	

From the Table-2 we found that proper communication regarding the running recipe with crane operator can help to reduce chemistry related downtimes and also cleaning of scraps during shearing machine run time can prevent slag formation which lead to reduction of breakdown. A poker machine can be used to poke the light scraps to utilize the generated power inside the furnace.

Table 3. Factors and Countermeasures of delay regarding Material Unavailability

Problem	1st Factor for problem	Verification	2nd Factor for problem	Verification	3rd Factor for problem	Verification	Countermeasures
Material Unavailability	1. Heavy weighted scraps unavailability	NG					What: Heavy weighted scraps should be provided after first sample; Who: Raw material yard and supply chain management; When: Each shift
	2. Loose sponge iron	G	2.1 There is no sacks of sponge iron in stock 2.2 Lots of loose DRI in inventory	NG			What: Sponge iron sacks should be provided; Who: Supply chain management; When: During procurement

To reduce the breakdown related to material unavailability we incurred from Table-3 the causes which are heavy weight scraps cannot be provided after taking the first sample that's why power loss is higher which lead to higher cycle time. Sponge iron availability must be continuous with sack.

Table 4 : Factor and countermeasures of delay regarding Transfer Car

Problem	1st Factor for problem	Verification	2nd Factor for problem	Verification	3rd Factor for problem	Verification	Countermeasures
Transfer car	1. Scrap stuck into TT	G	1.1 Operator was not concerned	G	1.1.1 Raw material yard crane operator hip the scraps	NG	What: Proper training and increasing the awareness Who: Both operator; When: During filling the TT & driving the TT
	2. Tearing electrical cable	G	2.1 Scraps fallen into cable pit	G	2.1.1 Not cleaning properly	NG	What: Proper cleaning of scraps from pit; Who: Raw material yard helper; When: After falling scraps

Transfer car related issue is one of the major issues affecting the productivity. The root causes were identified in Table 4 as proper training and awareness among the crane operators to supply in limit and cable pit must be cleaned after scraps fallen into pit by field worker.

Table 5. Factor and countermeasures of delay regarding the Crane problem

Problem	1st Factor for problem	Verification	2nd Factor for problem	Verification	3rd Factor for problem	Verification	Countermeasures
Crane problem	1. Trip occurred due to overflow of current	G	1.1 Operator was not fully trained to rectify to save time	G	1.1.1 Proper training and evaluation needed	NG	What: Proper training and increasing the awareness Who: Operators; When: Training session need to organize
	2. Hydraulic oil leakage	G	2.1 Overweight of scraps	G	2.1.1 The weight scale was not properly calibrated	NG	What: Proper calibration of weight scale; Who: Electrical team and crane operator; When: Starting of every shift.

As per the pillar autonomous maintenance proper training and evaluation are needed to overcome the primary level maintenance to reduce the breakdown which is investigated in Table 5. The actual weight needed to show when operator handle the scraps to avoid any unwanted delays.

Table -6. Reduced Delay

Category	Before (Delay)	After (Delay)
Chemistry/Scrap	600	540
Material unavailability	102	91.8
Transfer car	75	67.5
Crane problem	70	63
Shearing machine	68	68
Electrical related	67	67
Ground leakage detector (GLD)	64	64
Mechanical related	55	55
CCM	34	34
Vibro Feeder	30	30
High temp	16	16
Total Defects	19	17
Total delays after reduction		18.27

After the identification of root causes of four major issues, these identified causes were considered seriously to see the result. The results depict in Table-6.

Table 7. Revised OEE Calculation:

Total available time(hrs)	240
Cycle time(hrs)	1.53
Total heats	290
Total delays (hrs)	18.27
Total defects	17
Availability	92%
Performance	93%
Quality	94%
New OEE	80.50%

Now we observed changes in the availability rate, performance ratio and also quality. The comparison is given below in the table 8:

Table 8. Comparison of OEE calculation

Comparison	New	Old
Availability	92%	92%
Performance	93%	93%
Quality	94%	93%
OEE	80.50%	79.50%

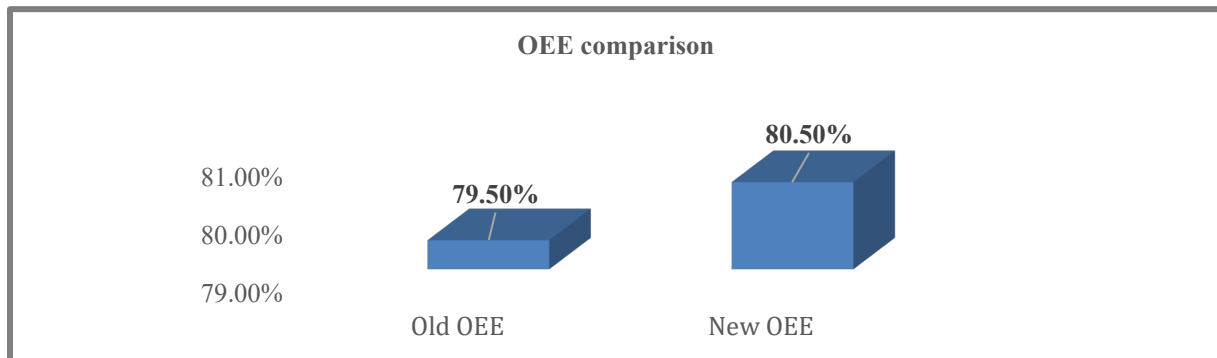


Figure 5. Comparison of OEE

The results show the increment of OEE is 1.26% which is significant for the implementation stage.

6. Results and Discussion

To achieve all Predictive Maintenance (TPM) excellence, a thorough Pareto analysis revealed that the main causes of almost 72% of all losses in a steel melting unit were Chemistry/Scrap, Material Unavailability, Transfer Car, and Crane Problem. Strategic countermeasures, including improved communication procedures, proactive cleaning measures, continual sponge iron availability, and focused training activities, were quickly put into place using the WWBLA approach for root cause analysis. The observable efficacy of these interventions was demonstrated by a noteworthy 1.26% enhancement in Overall Equipment Effectiveness (OEE), underscoring the influential function of TPM techniques in addressing key operational obstacles and enhancing efficiency. This research demonstrates the value of methodical analysis and focused interventions in bringing about significant improvements in industrial processes, which is in line with the overarching objective of maximizing equipment performance and guaranteeing long-term efficiency in the steel production plant.

7. Conclusion

In conclusion, this research pointed to the application of Total Productive Maintenance (TPM) within the context of a steel-making melting plant. The utilization of the 80/20 rule proved instrumental in pinpointing critical issues affecting the unit's availability, performance, and quality. After the identification of these major factors, strategic countermeasures were implemented to address and rectify the root causes. The success of this approach is reflected in the improved efficiency of the steel plant's equipment. By focusing on preventive and predictive maintenance, the study underscores the significance of proactive strategies in minimizing downtime and maximizing productivity. This research not only points to the knowledge of TPM but also provides practical insights for industrial practitioners seeking to optimize their operational processes. In essence, the findings highlight the transformative potential of TPM as a methodology for achieving sustainable improvements in equipment reliability and overall operational effectiveness within steel manufacturing units.

8. References

- Ahuja, I. S., Total productive maintenance practices in manufacturing organizations: a literature review. *International Journal of Technology, Policy and Management*, 11(2), 117-138,2011.
- Almeanazel, O. T. R., Total productive maintenance review and overall equipment effectiveness measurement. *Jordan Journal of Mechanical and Industrial Engineering*, 4(4),2010.
- Bamber, C. J., Sharp, J. M., & Hides, M. T., Factors affecting successful implementation of total productive maintenance: a UK manufacturing case study perspective. *Journal of Quality in Maintenance Engineering*, 5(3), 162-181,1999.
- Kumar, S., Raj, B., & Shubham, S., Study of total productive maintenance & it's implementation approach in steel manufacturing industry: A case study of equipment-wise breakdown analysis, *International Research Journal of Engineering and Technology (IRJET)*, 4(8), 608-613, 2017.
- McKone, K. E., Schroeder, R. G., & Cua, K. O., Total productive maintenance: a contextual view. *Journal of operations management*, 17(2), 123-144,1999.
- Nakajima S., Introduction to TPM, Productivity Press, Portland, 1988.
- Wireman, T. (1994). *Computerized maintenance management systems*. Industrial Press Inc...