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# ACCESSING THE LEVEL OF TOTAL PRODUCTIVE MAINTENANCE IMPLEMENTATION: THE CASE OF A NIGERIAN FABRICATION COMPANY

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**Abstract**

The maintainability and reliability of manufacturing systems plays an important role in accessing both the quality and quantity of the products. However, practicing unscheduled preventive maintenance approach can pose high cost to the firm which can adversely minimize the reliability of the manufacturing line. This work is aimed at optimizing the overall total productive maintenance of a manufacturing system. A model was proposed to optimize the OEE value for the fabrication company. The OEE of the firm factor by factor before and after implementation of the MINLP and TPM-TQM-OEE model was assessed. After six months of implementation, the availability is 87% which is about 10.2% improvement, the performance ratio is 91% which is about 10.4% improvement and the quality ratio is 93% which is about 9.6% improvement as compared to the values of OEE factors before implementation. The OEE value also increased from 56% to 75% which is about 33% improvement. This research also tried to identify the most significant factor of OEE using the TPM-TQM-OEE model. The result showed that the OEE is mostly influenced by Availability (about 88%), followed by Performance rate (about 85%) and finally by Quality rate (about 82%). Reliability analysis among other analysis should always be considered during optimization maintenance practices.

**Keywords:** Overall Equipment effectiveness (OEE), Total productive maintenance (TPM), Total Quality management (TQM).

## Introduction

The characteristics and circumstances of the organization's facilities and equipment are becoming increasingly important in today's industrial and service sectors for the improvement of products and services. Every industry must work to increase productivity across all activity domains if it is to thrive (Sethia et al., 2014). Therefore, it makes sense to make the best use of resources like equipment, labour, and material. To reach a certain level of quality and reliability and to operate efficiently, it is crucial to keep facilities and equipment in good operating order. An effective production system must perform critical service functions, including plant maintenance. It aids in maintaining and enhancing the operational performance of plant facilities, which increases revenue by lowering operating expenses and improving production efficiency.

The effectiveness of TPM in boosting equipment effectiveness and production has been established. Japanese scientists introduced and developed TPM concepts in 1971. The core concept of TPM is total plant maintenance. The underlying ideas are that machine breakdowns, safety issues, and quality issues will significantly decrease with proper maintenance of plant machinery. In the Nigerian sector, there is a growing requirement for TPM implementation and a need to create TPM implementation practices and procedures. Given that the operator would be assisting the maintenance team in their duties, TPM should encourage improved teamwork at the workplace.

In an increasingly competitive global context, the cost of operating and maintaining equipment has grown to be a significant component in the production of goods. Consumers today expect manufacturers to produce products of the greatest quality at competitive prices. This necessitates extremely reliable machinery and machining techniques from the producer. Highly reliable machines require a smooth production process in order to be maintained. Total Productive Maintenance (TPM) has been used by numerous businesses as a means of maximizing the efficiency of machinery by establishing and upholding the ideal rapport between workers and their equipment (Aroor et al. 2015). Over the past few decades, the maintenance function has seen a number of changes. The traditional understanding of maintenance's function is that it should respond as soon as a breakdown occurs.

To achieve optimum efficacy, the goal is to continuously increase the availability of the equipment and avoid its deterioration. To achieve these goals, the shop floor needed constant utilization of work teams and small group activities in addition to strong managerial support. Maintenance is regarded as a vital and significant resource in TPM. By continually enhancing the functionality of the equipment and establishing the practice of effective maintenance, the maintenance group may now contribute to the improvement of the production system's competitiveness and profitability (Aroor et al. 2015).

## Literature Review

When performance and product quality are important to the business, overall equipment effectiveness (OEE) is crucial (Patel and Deshpande, 2016). Large amounts of waste are lost owing to breakdowns, operator-related problems, process-related problems, and maintenance problems, all of which have an impact on the company's overall OEE. Therefore, the assembling sector must have zero tolerance for waste, flaws, and breakdown. To increase productivity and OEE of machines, workers are given the skills, knowledge, and procedures for timely machine maintenance (Mahajan et al., 2018). The equipment's overall performance is evaluated using the OEE approach. Only by reducing six major losses could the OEE be improved incrementally (Burhan and Sari, 2019).

Mwanza and Mbohwa (2015) created a powerful TPM model to enhance the maintenance procedure at a Zambian chemical manufacturing business. Reviewing that the maintenance department used 67.6% breakdown maintenance, 24.3% preventative maintenance, and 8.1% not applicable revealed the research's dual findings. According to the research, only 14% of the time did operators participate in maintenance tasks, leaving them out of the process 78% of the time. 19% of the maintenance technique(s) employed were found to be ineffective, 65% to be fair, 8% to be good, and 8% to be not relevant. OEE, or overall equipment effectiveness, was assessed at 37%, which was more than 50% below the global average.

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In a study with the aim of improving overall equipment effectiveness (OEE) in a manufacturing company, Patel and Deshpande (2016) came to the following conclusions:

- The Secret The elimination of three OEE loss categories, such as Downtime Loss, Speed Loss, and Quality Loss, is necessary for a successful improvement of Overall Equipment Effectiveness (OEE). Employee buy-in and top management support are crucial for successful execution.
- Improving manufacturing system performance is crucial for boosting productivity. High equipment availability, which is determined by equipment dependability and maintainability, is necessary to achieve the target production output.
- OEE, despite being widely used over the years, is not a statistically significant parameter.
- An organized approach for continuous improvement called OEE tries to increase production efficacy by discovering and eliminating equipment and production efficiency losses during the course of the production system.

Humiras, Erwin, and Niko (2018) conducted research on a manufacturer of filter air conditioners for four wheels. Through the use of the OEE (Overall Equipment Effectiveness) approach as a factor in the deployment of TPM in the organization, the research attempted to determine the degree of effective use of machine/production equipment. Braglia, Frosolini, and Gallo (2017) optimized the switch process time by combining the SMED approach with the 5Y analysis. In the end, a higher OEE value was attained by reducing the changeover time. By using TPM, it was possible to identify unproductive time loss, availability loss, performance loss, and quality loss. Additionally, it was confirmed that a steel mill uses SMED and 5-Y analysis to acquire the superior value of OEE (Rimawan and Irawan, 2017). The Jute Mill's Major Losses Were Analysed and identified by Rahman, Islam, and Rabby (2018), and Work Was Done to Reduce These Losses to Improve OEE and Other KPI. By putting TPM into practice, the jute mill's OEE went from 51.93% to 75.35%.

Ahmad, Hossen and Ali (2018) used Pareto analysis, 5Y analysis, and Cause and Effect analysis to investigate the six major losses of ring frames in a spinning facility. It was proposed that operators undergo well-planned training sessions to cut down on these losses. By implementing Kaizen and minimizing the six significant losses, the OEE in the ring frame increased from 75.09% to 86.02%. The pillars of TPM were thoroughly analyzed by Okpala et al. (2018), and tools and techniques including Pareto analysis were used to assess their effects on quality and productivity. Researchers Rusman, Parenreng, Setiawan, Asmal, and Wahid (2019) used the OEE model to quantify the effectiveness of numerical control (NC) router machines and investigate the factors that contribute to their poor performance.

**Methodology**

Before implementing TPM there is need to develop a model that will serve as foot print for implementation. The proposed model takes into consideration TQM as a pillar among other pillars of TPM (Aroor et al., 2015). The TQM-TPM-OEE model is presented in Figure 1. TQM being one Pillar with other 6 pillars of TPM (5S, Autonomous maintenance, planned maintenance, Kaizen, Training and Office TPM) are directly influencing

TPM and those pillars helps to increase the level of TPM for any industry. From the model TPM have a direct influence on OEE and as TPM level increases OEE value will also increase.

**Pillar 1-5S**

Prior to the introduction of TPM, 5S serves as a foundation program. This 5S implementation needs to be done in stages. To start, a 5S audit of the workplace's existing state must be performed.

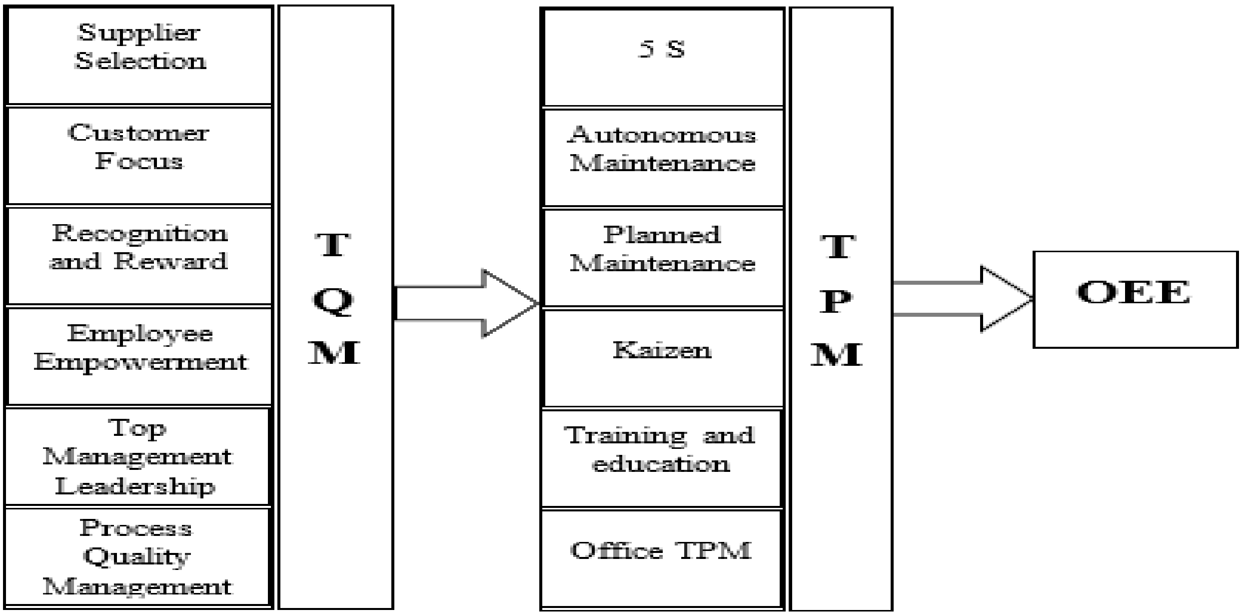


Figure 1: TQM – TPM – OEE Model.

**Pillar 2 - Autonomous maintenance (AM)**

This pillar aims to train operators to be accountable for maintaining their machinery to keep it from breaking down. The goal of using this pillar is to keep the machine in brand-new condition. The tasks at hand are of a pretty straightforward kind. This involves lubricating, cleaning, checking visually, tightening loose bolts, etc. The preparation of staff, first machine clean-up, taking preventative action, fixing provisional AM standards, general inspection, autonomous inspection, and standardization are all steps in AM.

**Pillar 3-Planned maintenance (PM)**

It aims to deliver fault-free machinery and tools for making items without flaws for complete client satisfaction. Preventive maintenance, breakdown maintenance, corrective maintenance, and maintenance prevention are the four "families" or groupings that are divided up into here. The six steps of planned maintenance are: equipment evaluation and recoding current status; repairing deterioration and strengthening weaknesses; building information management system; creating time-based information system; choosing equipment and creating a plan; creating a predictive maintenance system by introducing equipment diagnostic techniques; and assessing planned maintenance.

**Pillar 4-Kaizen**

"Kai" denotes change, while "Zen" denotes goodness. By utilizing various kaizen approaches, this pillar seeks to reduce workplace losses that have an impact on efficiencies. Zero losses are sustained in terms of minor stops, measurements, adjustments, defects, and unavoidable downtimes, and the Kaizen target is met.

Additionally, a 30% reduction in production costs is a goal. The Why-Why analysis, mistake proofing, summary of losses, kaizen register, and kaizen summary sheet are tools used in kaizen.

**Pillar 5-Training and Education**

Training goals include achieving and maintaining zero losses owing to knowledge, skills, or technique deficiencies, zero losses due to lost time injuries on important machines, and 100% involvement in recommendation schemes.

**Pillar 6-Office TPM**

After the other four TPM pillars—5S, AM, Kaizen, and PM—have been successfully activated, this one should be launched. To boost administrative function productivity and effectiveness, office TPM must be adhered to. All employees participating in support roles to focus on improved plant performance and a pleasant work environment are among the advantages of office TPM.

**Overall Equipment Effectiveness (OEE)**

OEE is a measure that is used independently to compare the equipment's actual production capacity to its theoretical production capacity. It is crucial to monitor machine health and performance in manufacturing in order to assess TPM's effectiveness. OEE assesses machine effectiveness thoroughly and intuitively identifies production issues as opposed to efficiency. According to Garza-Reyes, Eldridge, Barber, and Soriano-Meier (2010), the six major losses of equipment identified by OEE.

Three parameters are used to calculate OEE. Availability, Performance Ratio, and Quality Ratio are these characteristics. Equation (1) can be used to calculate OEE's value.

$$\text{OEE} = \text{Availability} \times \text{Performance ratio} \times \text{Quality ratio} \tag{1}$$

Also, the value of Availability can be computed as shown in Equation (2).

$$\text{Availability} = \frac{\text{Shift duration} - \text{Breaks} - \text{Downtime}}{\text{Shift duration} - \text{Breaks}} \tag{2}$$

The value of performance ratio can be computed using Equation (3).

$$\text{Performance ratio} = \frac{(\text{Total output} - \text{Scrap}) \times \text{cycle time}}{\text{Shift duration} - \text{Breaks} - \text{Downtime}} \tag{3}$$

The value of quality ratio can be computed using Equation (4).

$$\text{Performance ratio} = \frac{\text{Total output} - \text{Scrap}}{\text{Total output}} \tag{4}$$

**Results and Discussion**

The fabrication company is accessed to determine the level of implementation of the TQM-TPM-OEE Model. The questionnaire built to access the performance of the six (6) key factors of TQM considered and three (3) factors of TPM was responded by twenty staffs of the company before the implementation of the TQM-TPM-OEE model and after implementation. The results factor by factor are presented in Table 1 and Table 2. The factors of TQM pillars and response result are presented in Table 1. In all, the level of TQM implementation is 29% before the implementation and 82% after implementation of the TQM-TPM-OEE model which is an 184% improvement.

Table 1. Factor by Factor Analysis of TQM Implementation.

| S/N | Factors and Questions | Before | | After | |
|---|---|---|---|---|---|
| **Factor: Supplier Selection** | | **% of YES** | **% of No** | **% of YES** | **% of No** |
| 1 | In this plant quality is key criterion for selecting suppliers. | 0 | 100 | 100 | 0 |
| 2 | Suppliers who are certified are giving preference. | 25 | 75 | 70 | 30 |
| 3 | Plant management will select a supplier who gives raw material with least cost. | 70 | 30 | 15 | 85 |
| **Factor: Customer Focus** | | | | | |
| 1 | Plant collects feedback from customer regarding quality of products. | 30 | 70 | 80 | 20 |
| 2 | Management often establishes close contact with customers and regularly survey their customer requirements. | 35 | 65 | 100 | 0 |
| 3 | This Plant is highly responsive to customer’s complaints. | 30 | 70 | 80 | 20 |
| **Factor: Recognition and Reward** | | | | | |
| 1 | Employees are rewarded for quality improvement | 0 | 100 | 30 | 70 |
| 2 | There is a reward system for employee(s) that improves quality by management. | 0 | 100 | 30 | 70 |
| **Factor: Employee Empowerment** | | | | | |
| 1 | Employees have the authority to halt the production process when any problem arrives in production line. | 15 | 85 | 75 | 25 |
| 2 | Independent decision making by employees are encouraged in the company. | 0 | 100 | 50 | 50 |
| **Factor: Process Quality Management** | | | | | |
| 1 | In this plant causes for Scrap and Reworks are identified. | 0 | 100 | 35 | 65 |
| 2 | Corrective action is taken immediately when a quality problem is identified. | 70 | 20 | 85 | 15 |
| 3 | Key processes are systematically improved to achieve better product quality and performance. | 25 | 75 | 35 | 65 |
| **Factor: Top Management Leadership** | | | | | |
| 1 | Top management strongly encourage employee involvement. | 40 | 60 | 80 | 20 |
| 2 | Plant management communicates a vision focused on quality improvements. | 50 | 50 | 100 | 0 |
| 3 | All major departmental heads within this plant accept their responsibility for quality. | 60 | 40 | 100 | 0 |

Table 2. Factor by Factor Analysis of TPM Implementation.

| S/N | Factors and Questions | Before % of YES | Before % of No | After % of YES | After % of No |
|---|---|---|---|---|---|
| | **Factor: Planned Maintenance** | | | | |
| 1 | In this plant they have a separate shift or a part of shift reserved only for maintenance activities. | 0 | 100 | 0 | 100 |
| 2 | In this plant machine breakdowns and stoppages are very less. | 25 | 75 | 80 | 20 |
| 3 | In this plant preventive maintenance schedule is determined for every machine. | 30 | 70 | 90 | 10 |
| 4 | In this plant maintenance department uses most of its time to improve the equipment and advanced inspection. | 35 | 65 | 15 | 85 |
| 5 | The lubrication points/surfaces are identified on the equipment and serviced as per the specified standard. | 40 | 60 | 80 | 20 |
| | Factor: Autonomous Maintenance | | | | |
| 1 | In this plant the production personnel are responsible for most of the maintenance inspections on their machines. | 35 | 65 | 85 | 15 |
| 2 | What is to be done, who is responsible and when it was last time checked/ repaired is clearly communicated to all operators. | 40 | 60 | 90 | 10 |
| 3 | In our plant Production personnel are well trained for trouble shooting and maintenance job. | 45 | 55 | 75 | 25 |
| 4 | In this plant operators are held responsible for up keep of their equipment to prevent it from deteriorating. | 35 | 65 | 85 | 15 |
| | Factor: Training and Education | | | | |
| 1 | Employees at this plant trained to perform multiple tasks/jobs. | 80 | 20 | 85 | 15 |
| 2 | Is there a formal quality training program for employees. | 30 | 70 | 75 | 25 |
| 3 | Employees are capable of performing variety of jobs. | 80 | 20 | 85 | 15 |

In the TQM – TPM – OEE model presented in the previous section, only three pillars of TPM were considered. They are planned maintenance, Autonomous maintenance and training. These TPM pillars and response result were presented in Table 2. in summary, the level of TPM implementation is 51% before the implementation and 84% after implementation of the TQM-TPM-OEE model which is an 65% improvement.

Using TPM as a pillar with planned maintenance, autonomous maintenance and education and training as other pillars of the TQM – TPM – OEE model, the graphical representation of the level of implementation of the pillars are presented in Figure 2. The most notable improvement is seen in the TQM as a pillar, followed autonomous maintenance, planned maintenance and with the least improvement seen in training and education.

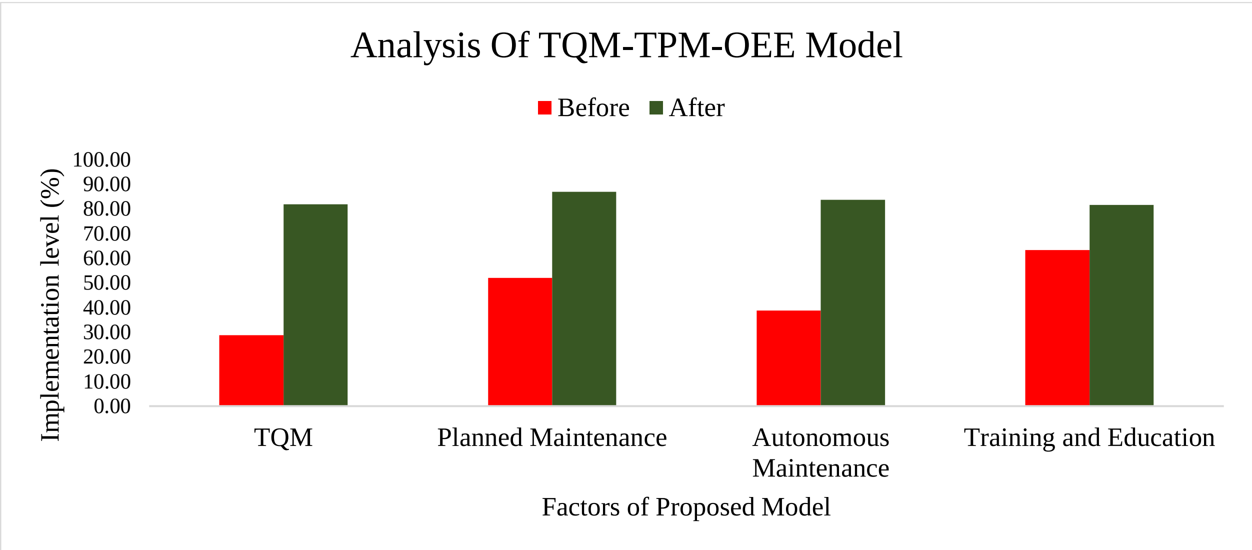


Figure 2: Analysis Of TQM-TPM-OEE Model.

## OEE Results Before Implementation of TQM-TPM-OEE model

OEE depends on Availability, Performance and Quality rate and as such, it is important to analyse these three parameters to identify hidden problems. The data from the company before implementation of the model is presented in Table 3. Figure 3 Shows the availability for the 20 shifts as computed from Table 3. The values of availability are constantly varying between 0.70 and 0.90 with mean value of 0.79 (79%) which is clearly below the standard value of 0.90 (90%).

Figure 4 represents the 20 shifts values for machine performance rate as computed from table 4.8. From Figure 4 it can be observed that performance rate also continuously fluctuating between 0.72 and 0.93 with a mean value of 0.83 (83%) which is also below the standard value of 0.95 (95%). Figure 5 represents the 20 shifts values for quality ratio as computed with Table 3. Mainly it gives the ratio of accepted production to total production. From Figure 5, it can be observed that quality ratio is continuously fluctuating between 0.78 and 0.93 with a mean value of 0.85 (85%) which is obviously below the world standard value of 0.95 (95%).

Table 3. OEE parameter value calculation before implementation the model.

| Shift no. | Shift time | Breaks | Downtime | Cycle time | Total Output | Net Output | Scrap | Availability | Performance ratio | Quality Ratio | OEE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 240 | 30 | 42.00 | 12 | 12.04 | 1.63 | 13.67 | 0.80 | 0.86 | 0.88 | 0.61 |
| 2 | 240 | 30 | 41.79 | 12 | 12.21 | 2.81 | 15.02 | 0.80 | 0.87 | 0.81 | 0.57 |
| 3 | 240 | 30 | 21.63 | 12 | 12.87 | 1.67 | 14.54 | 0.90 | 0.82 | 0.89 | 0.65 |
| 4 | 240 | 30 | 43.26 | 12 | 12.23 | 3.23 | 15.46 | 0.79 | 0.88 | 0.79 | 0.55 |
| 5 | 240 | 30 | 46.20 | 12 | 10.92 | 1.93 | 12.85 | 0.78 | 0.80 | 0.85 | 0.53 |
| 6 | 240 | 30 | 38.64 | 12 | 12.14 | 2.45 | 14.59 | 0.82 | 0.85 | 0.83 | 0.58 |
| 7 | 240 | 30 | 43.26 | 12 | 10.46 | 1.92 | 12.38 | 0.79 | 0.75 | 0.85 | 0.51 |
| 8 | 240 | 30 | 37.17 | 12 | 11.95 | 1.18 | 13.14 | 0.82 | 0.83 | 0.91 | 0.62 |
| 9 | 240 | 30 | 42.21 | 12 | 11.33 | 2.62 | 13.95 | 0.80 | 0.81 | 0.81 | 0.53 |
| 10 | 240 | 30 | 54.18 | 12 | 12.08 | 0.91 | 12.99 | 0.74 | 0.93 | 0.93 | 0.64 |
| 11 | 240 | 30 | 45.36 | 12 | 9.88 | 2.77 | 12.65 | 0.78 | 0.72 | 0.78 | 0.44 |
| 12 | 240 | 30 | 36.12 | 12 | 11.88 | 1.47 | 13.35 | 0.83 | 0.82 | 0.89 | 0.60 |
| 13 | 240 | 30 | 31.29 | 12 | 11.91 | 2.94 | 14.86 | 0.85 | 0.80 | 0.80 | 0.55 |
| 14 | 240 | 30 | 33.60 | 12 | 12.50 | 2.15 | 14.64 | 0.84 | 0.85 | 0.85 | 0.61 |
| 15 | 240 | 30 | 39.06 | 12 | 11.54 | 1.11 | 12.65 | 0.81 | 0.81 | 0.91 | 0.60 |
| 16 | 240 | 30 | 58.59 | 12 | 10.35 | 2.06 | 12.41 | 0.72 | 0.82 | 0.83 | 0.49 |
| 17 | 240 | 30 | 55.99 | 12 | 10.24 | 0.96 | 11.21 | 0.73 | 0.80 | 0.91 | 0.53 |
| 18 | 240 | 30 | 56.91 | 12 | 10.70 | 1.82 | 12.53 | 0.73 | 0.84 | 0.85 | 0.52 |
| 19 | 240 | 30 | 39.90 | 12 | 11.64 | 2.56 | 14.20 | 0.81 | 0.82 | 0.82 | 0.55 |
| 20 | 240 | 30 | 62.56 | 12 | 10.81 | 2.18 | 13.00 | 0.70 | 0.88 | 0.83 | 0.51 |

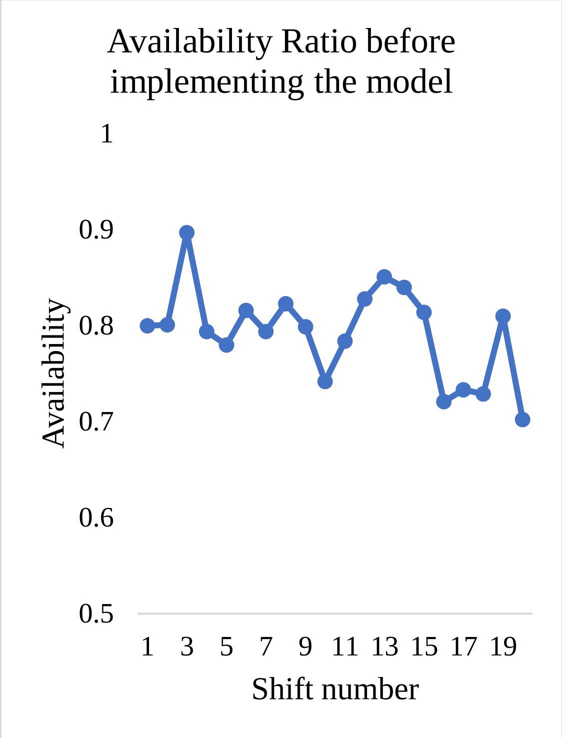


Figure 3: Availability Ratio before implementing the model.

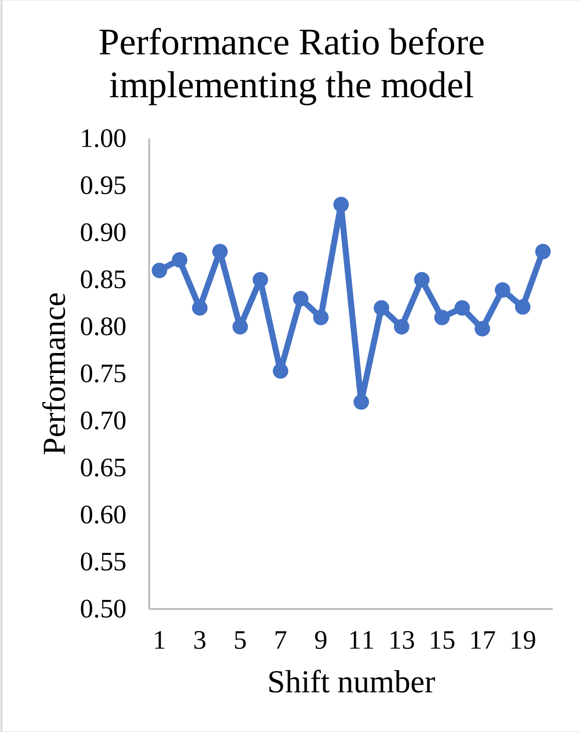


Figure 4: Performance Ratio before implementing the model.

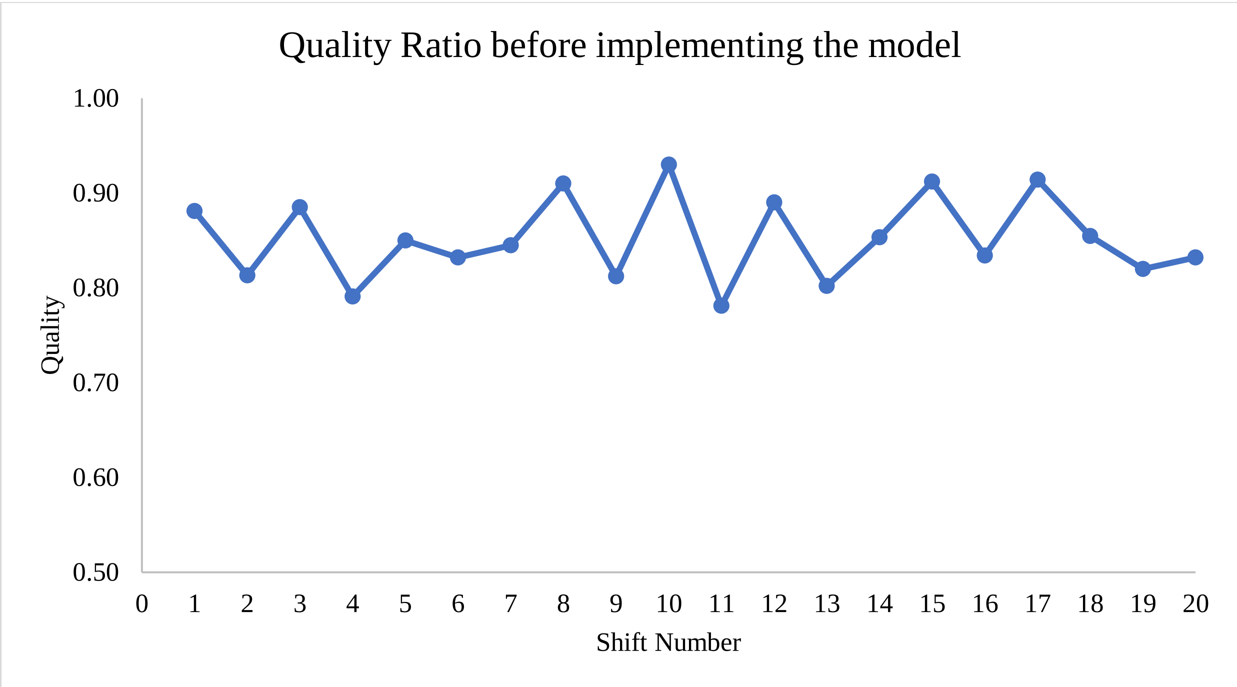


Figure 5: Quality Ratio before implementing the model.

Figure 6 shows the values of OEE as a function of availability ratio, performance ratio and quality ratio for 20 shifts before the implementation of TPM and MINLP schedules as computed from Table 3. It can be observed that OEE values are continuously fluctuating between 0.44 and 0.65 with a mean value of 0.56 (56%) which is obviously below the standard value of 0.95 (95%). With these values of OEE it is indeed clear justification for this research to implement and optimize these values by implementing total productive maintenance.

**OEE Results After Implementation of TQM-TPM-OEE Model**

Six months after the implementation of TPM, the parameters such as shift downtimes, breaks, cycle time, shift output, shift defect/scrap for 20 shifts of 4 (four) hours each are presented in Table 4. Table 4 is used to compute the Availability, the Performance ratio and the Quality ratio. The graphical representation of the Availability is presented in Figure 5. From Figure 7 it can be clearly seen that the values of availability are constantly varying between 0.83 and 0.90 with mean value of 0.87 (87%) which is about 10.2% improvement as compared to the values of availability without proper implementation of TPM and MINLP schedules and a standard deviation of 0.023. Although this value of availability still lags as compared to the standard value of 0.90 (90%) by 2.9% which is a very good value for just 6 months of implementation.

Table 4. OEE value calculation after implementation of TPM and MINLP.

| Shift no. | Shift time | Breaks | Downtime | Cycle time | Total Output | Net Output | Scrap | Availability | Performance ratio | Quality Ratio | OEE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 240 | 30 | 42.00 | 12 | 14.00 | 1.38 | 15.38 | 0.86 | 0.93 | 0.91 | 0.73 |
| 2 | 240 | 30 | 41.79 | 12 | 14.35 | 1.08 | 15.43 | 0.90 | 0.91 | 0.93 | 0.76 |
| 3 | 240 | 30 | 21.63 | 12 | 13.97 | 0.74 | 14.71 | 0.89 | 0.90 | 0.95 | 0.76 |
| 4 | 240 | 30 | 43.26 | 12 | 13.60 | 1.35 | 14.95 | 0.85 | 0.91 | 0.91 | 0.71 |
| 5 | 240 | 30 | 46.20 | 12 | 13.47 | 1.01 | 14.49 | 0.87 | 0.89 | 0.93 | 0.72 |
| 6 | 240 | 30 | 38.64 | 12 | 14.74 | 0.46 | 15.20 | 0.90 | 0.94 | 0.97 | 0.82 |
| 7 | 240 | 30 | 43.26 | 12 | 14.55 | 1.21 | 15.76 | 0.89 | 0.93 | 0.92 | 0.77 |
| 8 | 240 | 30 | 37.17 | 12 | 13.21 | 0.99 | 14.21 | 0.84 | 0.90 | 0.93 | 0.70 |
| 9 | 240 | 30 | 42.21 | 12 | 13.52 | 0.56 | 14.08 | 0.85 | 0.91 | 0.96 | 0.74 |
| 10 | 240 | 30 | 54.18 | 12 | 14.35 | 1.08 | 15.44 | 0.88 | 0.93 | 0.93 | 0.76 |
| 11 | 240 | 30 | 45.36 | 12 | 14.07 | 1.39 | 15.46 | 0.87 | 0.92 | 0.91 | 0.73 |
| 12 | 240 | 30 | 36.12 | 12 | 13.99 | 1.73 | 15.72 | 0.90 | 0.89 | 0.89 | 0.71 |
| 13 | 240 | 30 | 31.29 | 12 | 13.55 | 0.99 | 14.54 | 0.85 | 0.91 | 0.93 | 0.72 |
| 14 | 240 | 30 | 33.60 | 12 | 14.52 | 1.06 | 15.58 | 0.90 | 0.92 | 0.93 | 0.77 |
| 15 | 240 | 30 | 39.06 | 12 | 14.55 | 1.21 | 15.76 | 0.89 | 0.93 | 0.92 | 0.77 |
| 16 | 240 | 30 | 58.59 | 12 | 13.83 | 0.98 | 14.81 | 0.84 | 0.94 | 0.93 | 0.74 |
| 17 | 240 | 30 | 55.99 | 12 | 13.72 | 0.66 | 14.38 | 0.83 | 0.94 | 0.95 | 0.75 |
| 18 | 240 | 30 | 56.91 | 12 | 13.38 | 0.78 | 14.16 | 0.86 | 0.89 | 0.95 | 0.72 |
| 19 | 240 | 30 | 39.90 | 12 | 14.38 | 0.29 | 14.67 | 0.90 | 0.91 | 0.98 | 0.81 |
| 20 | 240 | 30 | 62.56 | 12 | 13.72 | 1.00 | 14.72 | 0.89 | 0.88 | 0.93 | 0.73 |

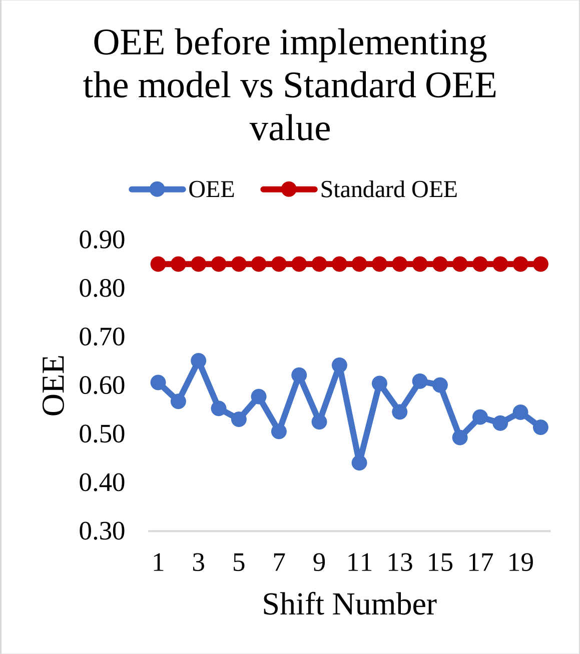


Figure 6. OEE before implementing the model vs Standard OEE.

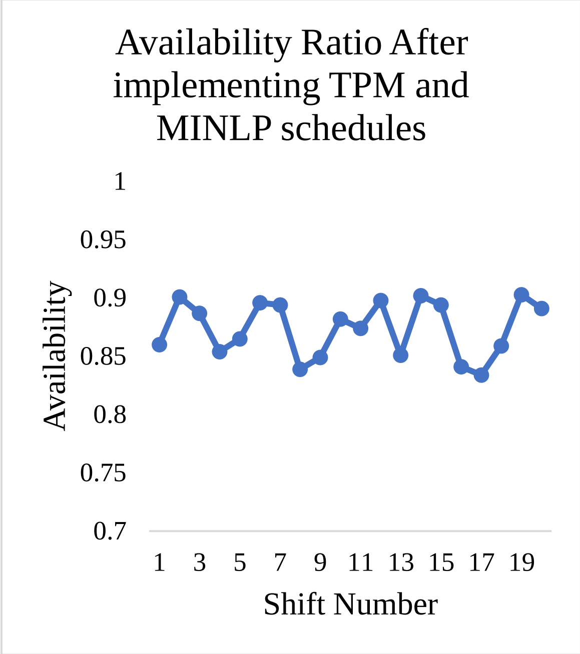


Figure 7. Availability Ratio After implementing the model.

The values of performance for 20 shifts after implementation of the TPM and MINLP model schedule as computed from Table 4 are presented in Figure 8. From Figure 8, it is clearly obvious that the values of performance ratio are constantly varying between 0.88 and 0.94 with mean value of 0.91 (91%) which is about 10.4% improvement as compared to the values of availability without implementation of the model and a standard deviation of 0.018. Although this value of performance ratio still lags as compared to the standard value of 0.95 (95%) by 3.8% which is a very good value for just six (6) months of implementation.

The values of Quality ratio for 20 shifts after implementation of the model schedule as computed from Table 4 are presented in Figure 9. From Figure 9, it can be clearly seen that the values of quality ratio are constantly varying between 0.89 and 0.98 with mean of about 0.93 (93%) which is about 9.6% improvement as compared to the values of quality ratio without proper implementation of TPM and MINLP schedules and standard deviation of 0.022. Although this value of quality ratio still lags as compared to the world standard value of 0.99 (99%) by about 6% which is an acceptable value for six (6) months of implementation.

The values of OEE as a function of availability ratio, performance ratio and quality ratio for 20 shifts after implementation of the TPM and MINLP model schedule as computed from Table 4 were presented in Figure 10. From Figure 10, it can be clearly seen that the values of OEE for 20 shifts are constantly varying between 0.70 and 0.82 with mean of about 0.75 (75%) which is 33.3% improvement as compared to the values of OEE without proper implementation of the model and standard deviation of 0.031.

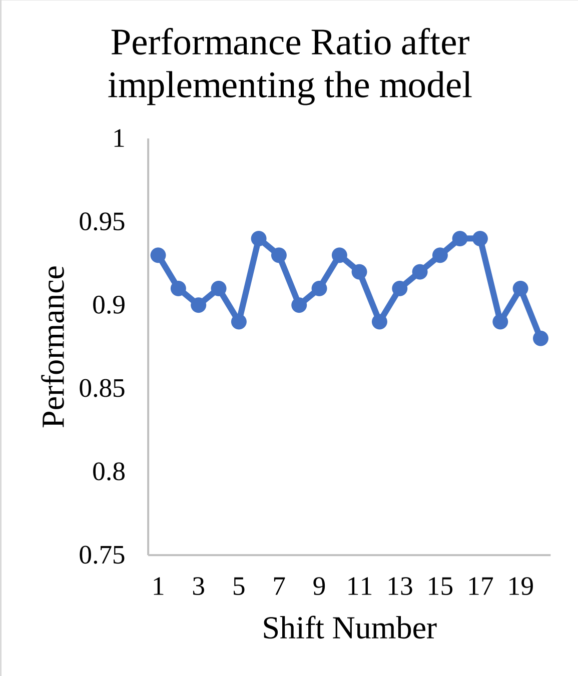


Figure 8. Performance Ratio after implementing.

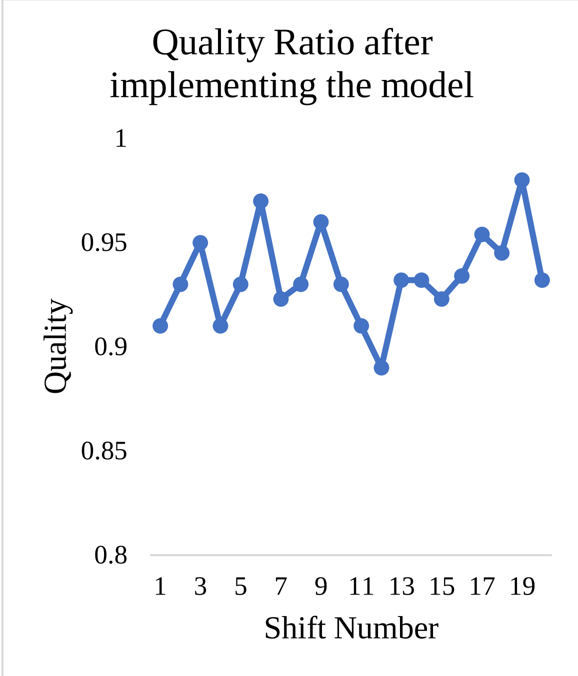


Figure 9. Quality Ratio after implementing the model.

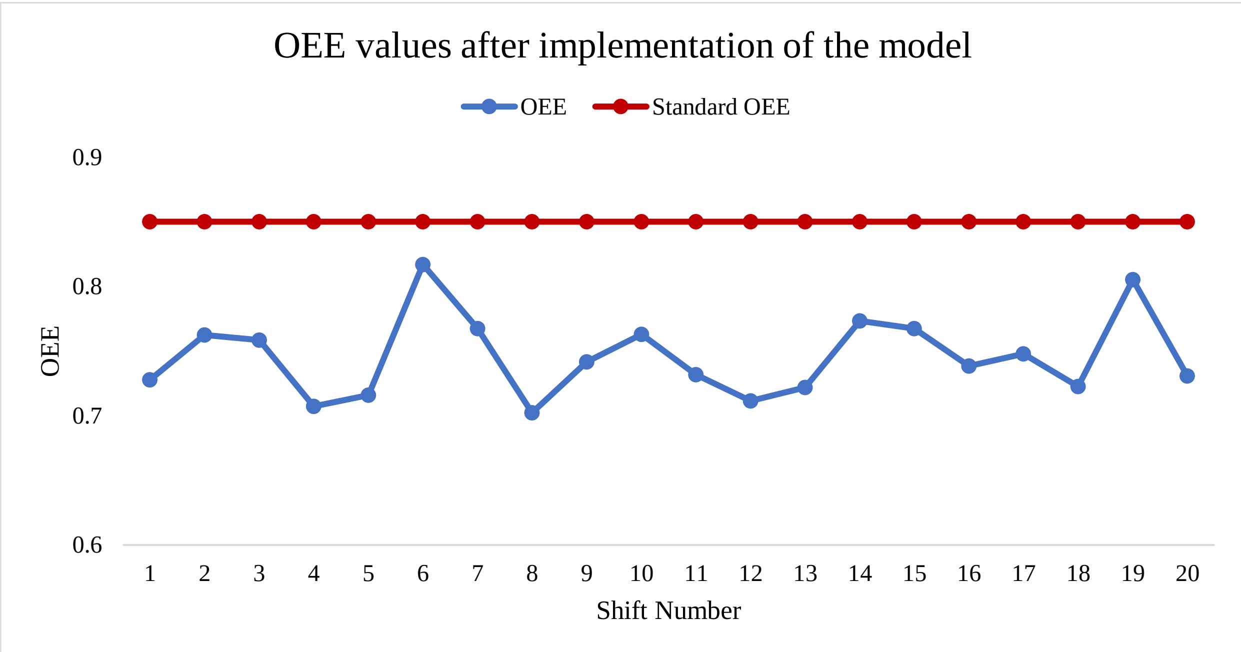


Figure 10. OEE values after implementation of TPM and MINLP Schedules.

Although this value of OEE still lags as compared to the standard value of 0.85 (85%) by 11.9%. Notwithstanding, there is total improvement in OEE after implementation of the MINLP model schedules and TPM for the fabrication company.

In summary, it is necessary to visualize the comparison of the values of Availability, Performance, Quality and OEE of the fabrication company before and after implementation of the model. This will also help to measure the level of TPM (before and after implementation) and access deviation of values from world standard parameters. Also Figure 11 was used as a graphic representation of the comparison between values of machine availability, performance ratio, quality ratio and OEE before and after implementation of TQM-TPM-OEE model computed from Table 4 presented in Table 4.10. Hence, it can easily be deduced that overall performance level or TPM level of the fabrication company is better after implementation of the model.

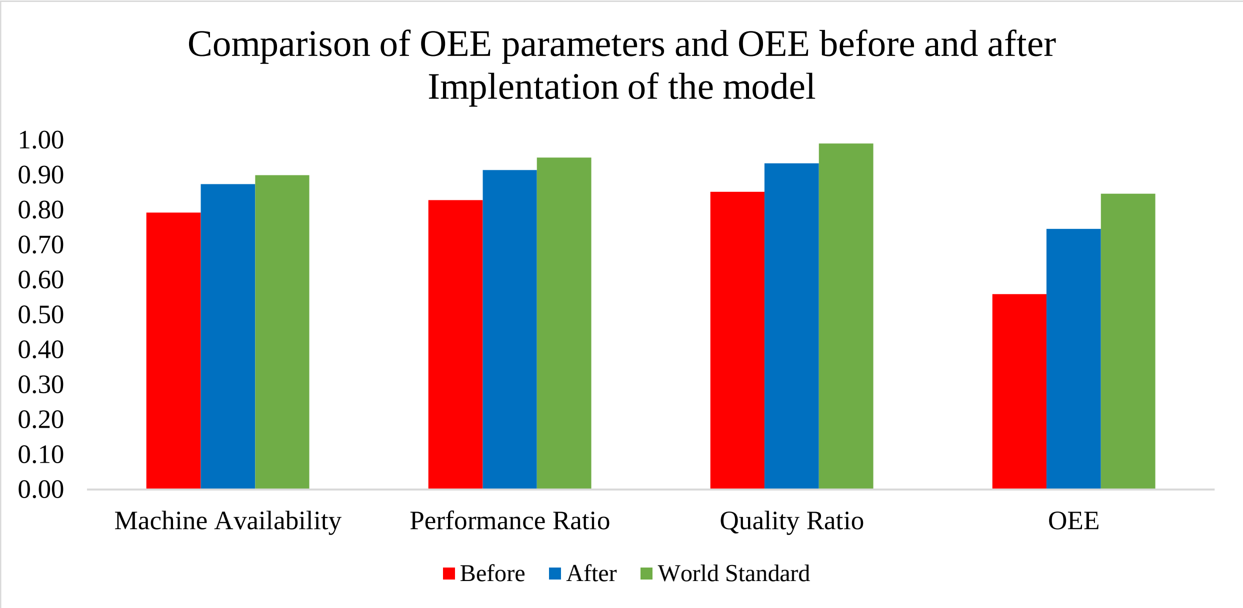


Figure 11. Comparison of OEE parameters and OEE before and after Implementation of the model.

**Correlation Analysis**

Karl Pearson's coefficient of correlation equation was used for finding the relationship between the variables. This research considered OEE as a dependent variable and other three parameters (Availability, Performance and Quality) were considered as independent variables. For calculation of correlation all 40 shifts values (before and after implementation) were used as a sample size.

The parameters OEE and availability were positively correlated with a correlation coefficient of 0.876. This means that, any action taken to improve machine availability also improves the OEE value. The parameters OEE and performance are positively correlated with a correlation coefficient of 0.853 which means that, any action taken to improve performance ratio of the firm also improves the OEE of the firm. The parameters OEE and quality ratio were positively correlated with a correlation coefficient of 0.822 and as such, any action taken to improve quality ratio also improves OEE. In summary, OEE is mostly influenced by Availability (about 88%), followed by Performance ratio (about 85%) and finally by Quality rate (about 82%).

**Conclusion**

This research studied the level of TPM implementation in a fabrication company. It proposed a model for implementation of TPM to optimize the OEE of the company. The values of OEE before and after implementation of the model were computed for the fabrication firm and comparisons made to world standard values. As a result of the model's implementation, the OEE value increased. OEE has a positive link with availability, performance, and quality rate, according to the analysis of the correlation coefficient. Additionally, by examining the relationship between the values, we can deduce that OEE has the greatest correlation with availability, followed by the Performance ratio and the Quality ratio. Therefore, it is important to make an effort to reduce the losses in the following order.

- Increase Availability by reducing Downtime losses.
- Increase Performance Rate by reducing Speed losses.
- Increase Quality Loss by reducing startup and production rejections.

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