THE EFFECT OF TOTAL PRODUCTIVE MAINTENANCE AND RELIABILITY CENTERED MAINTENANCE ON OPERATIONAL PERFORMANCE THROUGH OVERALL EQUIPMENT EFFECTIVENESS OF POWER PLANT AT PT PLN INDONESIA POWER UBP PLTU BANTEN 1 SURALAYA

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Abstract

This study aims to improve the performance of maintenance management at PT PLN Indonesia Power Unit Bisnis Pembangkitan PLTU Banten 1 Suralaya by implementing Total Productive Maintenance (TPM), Reliability Centered Maintenance (RCM), and Overall Equipment Effectiveness to support the reliability and efficiency of power plant operations. The causal descriptive quantitative research method was conducted through a survey of 255 operations and maintenance division employees, using a questionnaire via Google Forms. The results showed a significant and positive effect of implementing these methods on improving operational performance, aligning with the need to increase electricity consumption for households and industry. The study was conducted for four months, from April to July 2024 at the PLTU Suralaya location, Cilegon.

Keywords: Total Productive Maintenance (TPM), Reliability Centered Maintenance (RCM), Overall Equipment Effectiveness (OEE), Operational Performance (OP)

INTRODUCTION

In the modern era, electricity plays an irreplaceable role in supporting daily life, industrial development, and economic growth. With increasing dependence on technology and electrical devices, meeting the need for electricity has become essential for the continuity of human activities and the progress of the nation. Given the great benefits of electrical energy, the demand for electricity customers has increased rapidly over time, as seen in the national electricity customer statistics for the period 2019-2023. Along with the increasing electricity demand, it is important for power generation companies to not only focus on increasing operational efficiency but also consider the sustainability and environmental impact of the energy production process (Syahrial & Nusraningrum, 2022). The implementation of sustainable maintenance practices such as Total Productive Maintenance (TPM) can help reduce waste and increase the efficient use of resources, thereby supporting sustainable development goals. In other industries, such as the sugar sector, research shows that the implementation of TPM can improve Overall Equipment Effectiveness (OEE) to achieve world standard targets, which reflects similar potential in the electricity sector (Priyono et al., 2019).

At PT PLN Indonesia Power, especially at the Suralaya Banten 1 Generation Unit (UBP Banten 1 Suralaya), a subsidiary of PT. PLN (Persero), one of the main objectives is to maintain the reliability of power plants and excellent electricity supply. The generation unit is an investment asset that requires large funds for its construction. In this context, it is important to note that the implementation of Total Productive Maintenance (TPM) and Reliability Centered Maintenance (RCM) not only focuses on increasing equipment effectiveness but also on developing a proactive maintenance culture among employees. By involving operators in the maintenance process through training and empowerment, companies can reduce downtime due to machine damage and increase awareness of the importance of machine cleanliness and condition (Yohanes & Ekoanindiyo, 2021). In addition, it is important to explore the role of technology in supporting more effective TPM and RCM implementation. The implementation of TPM and RCM not only increases Overall Equipment Effectiveness (OEE) but also reduces operational costs by minimizing unplanned downtime (Salmi et al., 2019).

With a large investment, it is expected that the generating unit can operate satisfactorily. The success of the generating unit is often assessed from the Equivalent Availability Factor (EAF), with a target to achieve an optimal EAF value with high efficiency (low heat rate) in the average operating range. EAF measures the readiness of the generating unit to supply electricity to the consumer's high-voltage grid, reflecting the operational performance and source of income for the unit (Pratiwi, 2019). In addition, data analysis obtained from this system can provide valuable insights for continuous improvement, allowing the management team to identify patterns and trends that may not have been previously visible. The achievement of the EAF target of 85% is in line with the target outlined in the Company's Long-Term Plan (RJPP) for 2019-2024. However, the achievement of EAF from 2018 to 2023 has consistently been lower than the company's standards and the North American Electric Reliability Corporation (NERC). This is a concern because the low EAF indicates that the power plant is not ready to operate according to the needs of the PLN Load Regulator Center (P2B). Addressing these challenges involves implementing effective maintenance strategies such as Total Productive Maintenance (TPM), Reliability Centered Maintenance (RCM), and Overall Equipment Effectiveness (Campos & Simon, 2019). TPM in particular is a scientific technique used to evaluate equipment performance against product quality and identify critical instrumental elements for improvement (Sahoo & Yadav, 2020). By increasing the effectiveness of TPM through a maintenance system that focuses on the entire product life cycle, operational disruptions can be minimized and overall efficiency can be increased (Ahm et al., nd)

The results and research gaps indicate that although TPM has a significant impact on operational performance, there is still potential for further research to explore its broader impact on financial, social, and environmental performance. In the context of improving operational performance, the implementation of Total Productive Maintenance (TPM) and Reliability Centered Maintenance (RCM) not only focuses on machine efficiency but also includes aspects of human resource development. Training and empowerment of employees in preventive maintenance are very important to ensure that each team member has adequate knowledge of maintenance procedures and equipment care, to reduce the risk of damage and downtime that are detrimental to the company (Danguche & Taifa, 2023). Thus, this holistic approach is expected to produce better synergy between humans and machines, increase Overall Equipment Effectiveness (OEE), and achieve the ultimate goal of operational reliability of the power plant (Gubin et al., 2023)

Based on the background description, several problems related to operational performance were identified, seen from parameters such as Equivalent Availability Factor (EAF), Equivalent Forced Outage Rate (EFOR), Suddenly Outage Frequency (SdOF), and Pareto Loss Energy. The average value of EAF in the last four years is still below the company standard (< 85%) and international standards (NERC <86.36%). Meanwhile, the average values of EFOR and SdOF are also still below the company standard, below 4% and 3%, respectively. Pareto Loss Energy shows a high average value, indicating a gap in previous research that will be sharpened in this study. In dealing with various problems that occur at PT PLN Indonesia Power PLTU Banten 1 Suralaya, this study is limited to operational analysis at the power plant. The unit of analysis chosen is the operations and maintenance division, considering that these two divisions are directly related to the achievement of operational performance. The Operational Performance targets set include increasing EAF, decreasing EFOR, and reducing SdOF, which will be measured using the Overall Equipment Effectiveness (OEE) method in accordance with the Total Productive Maintenance (TPM) and Reliability Centered Maintenance (RCM) concepts.

REVIEW OF LITERATURE

Total Productive Maintenance and Overall Equipment Effectiveness

Total Productive Maintenance (TPM) is a maintenance concept that involves all workers in the company. The goal is to achieve effectiveness in the entire production system through participation and productive maintenance activities, in TPM the involvement of everyone is emphasized (Gianfranco et al., 2022). According to Mandal et al., (2019), total productive maintenance (TPM) is a process to optimize the effectiveness of machines and equipment, eliminate damage and breakdowns, and establish autonomous maintenance activities by operators in the daily operations of machine maintenance.

H1: TPM implementation has a positive impact on OEE.

Reliability Centered Maintenance and Overall Equipment Effectiveness

RCM is a methodical and organized approach to improve the reliability and efficiency of machine maintenance and reduce maintenance costs and downtime. (Hussain, nd). In several studies, RCM has been found to improve OEE by identifying and addressing potential failure modes in the system, as well as optimizing maintenance intervals for critical components (Khasanah, nd).

H2: Reliability Centered Maintenance has a positive impact on Overall Equipment Effectiveness

Total Productive Maintenance and Operational Performance

Total Productive Maintenance (TPM) is a proactive approach that aims to identify problems as early as possible and plan to avoid problems before they occur. It emphasizes proactive and preventative maintenance to maximize equipment's operational efficiency. Implementing a TPM program creates shared responsibility for the equipment that encourages greater operator involvement, which can be very effective in increasing productivity.

H3: Total Productive Maintenance has a positive impact on Operational Performance.

Reliability Centered Maintenance and Operational Performance

Reliability Centered Maintenance (RCM) has a direct and significant impact on operational performance. This methodology focuses on identifying critical assets and potential failure modes, prioritizing maintenance tasks, and optimizing maintenance strategies to ensure smooth and efficient equipment operation.

H4: Reliability Centered Maintenance has a positive impact on Operational Performance.

Overall Equipment Effectiveness and Operational Performance

Overall Equipment Effectiveness (OEE) has a significant influence on operational performance in manufacturing systems. OEE is a method for monitoring and improving the efficiency of manufacturing processes. The research conducted (Sandy & Wathoni, 2022) shows that the OEE method is used to optimize the production process in industry, especially the pharmaceutical industry, because this method can increase production efficiency and produce the quality as expected.

H5: Overall Equipment Effectiveness has a positive impact on Operational Performance.

H6: Overall Equipment Effectiveness mediates the relationship between Total Productive Maintenance and Operational Performance.

H7: Overall Equipment Effectiveness mediates the relationship between Reliability Centered Maintenance and Operational Performance.

RESEARCH METHOD

This study involves a quantitative descriptive approach basis intended for the purpose of studying the relationship between variables and explaining why the relationship exists, so confirmatory studies and exploratory studies are used. The variables in question are Total Productive Maintenance and Reliability Centered Maintenance as exogenous variables, Overall Equipment Effectiveness as an intervening variable and Operational Performance as an endogenous variable. The population of this study were employees of PT. Indonesia Power UBP PLTU Banten 1 Suralaya. This study involved 54 indicators in the four variables used for further analysis of the influence of Total Productive Maintenance on Operational Performance, Reliability Centered Maintenance, and Overall Equipment Effectiveness. Based on the formula (Hair et al., 2017), a sample of 225 employees was determined as respondents. Respondents in this study were employees of PT. Indonesia Power UBP PLTU Banten 1 Suralaya who work in the operations, maintenance and engineering divisions. The respondents were selected because the divisions are directly related to the achievement of Operations performance targets.

Data Collection and Research Variables

This study uses primary data, which is data that is directly obtained by researchers from the initial source or obtained for the first time. Primary data sources can be obtained from surveys, observations, experiments, questionnaires, interviews and others. However, primary data in this study were obtained from the results of distributing questionnaires. The data was collected using a questionnaire specifically designed to measure variables referring to TPM, RCM, OEE, and Operational Performance. The research variables include independent variables: TPM and RCM. Mediating variables: OEE. Dependent variables: Operational Performance

Data Processing and Research Process

This study uses PLS to estimate the relationship between the components specified in the research model. This study uses descriptive data analysis to provide a comprehensive description of the research variables, namely transformational leadership, organizational climate, knowledge sharing and product innovation.

This study will apply Total Productive Maintenance, Reliability Centered Maintenance through Overall Equipment Effectiveness to operational performance and equipment effectiveness in this unit. By utilizing data and information from UBP BSLA, the study aims to provide in-depth insight into the management and optimization of power plant performance at PT Indonesia Power.

RESULTS AND DISCUSSION

This study involved 255 employees as respondents, with various characteristics categorized into five parts: gender, age, position, length of service, and department. Respondent profile data is described as follows: Respondent characteristics based on gender. The results show the dominance of male employees, with 253 people (99%) compared to 2 female employees (1%). This data reflects significant gender inequality among employees involved in this study.

Respondent characteristics based on age show a varied distribution. Most respondents, namely 125 people (49%), are between 25-35 years old, while 70 people (27%) are in the 36-50 year age range. Respondents under 25 years old are only 47 people (18%), and those over 50 years old are 13 people (5%). This distribution provides an illustration that the majority of employees are in the middle productive age range.

Data on respondents' last education. It can be seen that most respondents have a vocational high school/high school education background, namely 143 people (56%). In addition, 50 people (20%) have a D3 education, and 60 people (24%) have a S1 education. These data show that most employees have quite diverse levels of education, with a dominance at the secondary education level.

Analysis of this data provides insight into the profile of employees participating in the study. Information on employees’ gender, age, and highest education level can help in understanding demographic characteristics and their potential influence on the research results. This data also forms the basis for further analysis of the relationship between these variables and their influence on the main research variables.

The Operational Performance variable in this study was measured using 9 questions asked to 256 respondents. Descriptive statistics of this variable revealed that question coded OP8 received the highest average score, which was 4.17, indicating that respondents strongly agreed with the statement. Conversely, question coded OP5 had the lowest average score, which was 3.97, indicating a slightly lower level of agreement compared to other questions. Overall, the average value for the Operational Performance variable was 4.05, indicating that the majority of respondents tended to agree with the statements in this questionnaire.

These results indicate that in general, employees feel that their operational performance is at a good level, although there are some areas with lower levels of agreement. The relatively high mean scores indicate that employees feel positive about the various aspects measured by this variable, while variations in the mean scores of the questions indicate differences in the assessment of the various dimensions of operational performance.

This data can provide important insights into employee perceptions of the company's operational performance. These findings can be used to evaluate which areas may require further attention or improvement, as well as to assess the effectiveness of the strategies and policies implemented in improving operational performance in the company. This information will be a useful basis for further analysis and planning of appropriate corrective actions.

Testing the measurement model or Outer Model is a crucial step in Partial Least Squares Structural Equation Modeling (PLS-SEM) analysis. This model functions to connect latent variables with their indicators, and Outer Model evaluation is carried out to assess the validity and reliability of these indicators. This test uses the PLS algorithm to ensure that the indicators effectively measure the latent variables to confirm the theory and explain the relationship between latent variables. This evaluation includes reflective and formative measurement models, each of which requires a different approach to analysis.

In this study, Outer Model testing was conducted using the Confirmatory Factor Analysis (CFA) technique, which focuses on the validity and reliability of the indicators.

Convergent validity was tested by ensuring that the factor loading value was greater than 0.7 and the average variance extracted (AVE) was more than 0.5, while construct reliability was measured through Composite Reliability and Cronbach's alpha. A construct is considered reliable if the Composite Reliability value is more than 0.7 and Cronbach's alpha is more than 0.6. This evaluation aims to ensure that the measurement model used in the study has adequate validity and reliability.

Validity Test

Based on the Partial Least Squares (PLS) method, the validity of the reflective indicator is carried out in two main stages. The first stage is the convergent validity test, which aims to ensure that the indicators used to measure a construct actually measure the construct validly and consistently. In this test, the loading factors of each indicator are examined to ensure that the indicators are highly correlated with each other, indicating that they measure the same construct. This first stage utilizes Confirmatory Factor Analysis (CFA) to identify how well the indicators measure the intended construct.

The next step is the discriminant validity test, which measures the extent to which indicators of a construct differ from indicators of other constructs. In the convergent validity test, the two main metrics used are Outer Loadings and Average Variance Extracted (AVE). Outer Loadings measures how much each indicator contributes to the construct it represents, with an ideal value of more than 0.70, although a value of 0.50-0.60 is also acceptable in earlier studies. Meanwhile, AVE shows the proportion of variance that can be explained by the construct to the variance of its indicators. A higher AVE value indicates better convergent validity, confirming that the indicators are indeed relevant in measuring the same construct.

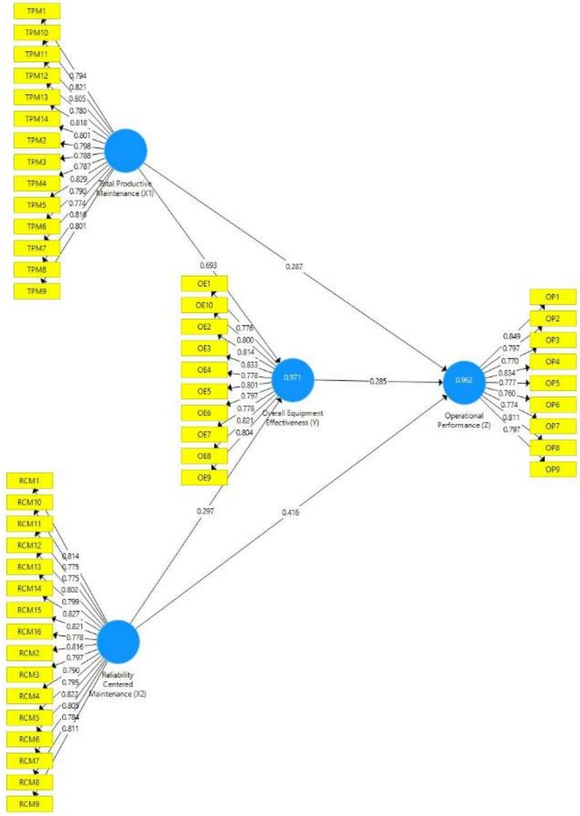

Figure 1.
Loading Factor Value of Total Productive Maintenance Variable
Source: Results of analysis using SmartPLS 3.3.3

Table 1.
Loading Factor Value

Dimensions	Indicator Code	Outer Loading Value	Condition	Information
Total Productive Maintenance	TPM1	0.794	> 0.5	**Valid**
	TPM2	0.798	> 0.5	**Valid**
	TPM3	0.788	> 0.5	**Valid**
	TPM4	0.787	> 0.5	**Valid**
	TPM5	0.829	> 0.5	**Valid**
	TPM6	0.790	> 0.5	**Valid**
	TPM7	0.774	> 0.5	**Valid**
	TPM8	0.816	> 0.5	**Valid**
	TPM 9	0.801	> 0.5	**Valid**
	TPM 10	0.821	> 0.5	**Valid**

	TPM11	0.805	> 0.5	**Valid**
	TPM12	0.780	> 0.5	**Valid**
	TPM13	0.818	> 0.5	**Valid**
	TPM14	0.801	> 0.5	**Valid**
Reliability Centered Maintenance	RCM1	0.814	> 0.5	**Valid**
	RCM2	0.816	> 0.5	**Valid**
	RCM3	0.797	> 0.5	**Valid**
	RCM4	0.790	> 0.5	**Valid**
	RCM5	0.795	> 0.5	**Valid**
	RCM6	0.822	> 0.5	**Valid**
	RCM7	0.805	> 0.5	**Valid**
	RCM8	0.784	> 0.5	**Valid**
	RCM9	0.811	> 0.5	**Valid**
	RCM10	0.775	> 0.5	**Valid**
	RCM11	0.775	> 0.5	**Valid**
	RCM12	0.802	> 0.5	**Valid**
	RCM13	0.799	> 0.5	**Valid**
	RCM14	0.827	> 0.5	**Valid**
	RCM15	0.821	> 0.5	**Valid**
	RCM16	0.778	> 0.5	**Valid**
	Indicator Code	Outer Loading Value	Condition	Information
	OEE1	0.776	> 0.5	Valid
	OEE2	0.814	> 0.5	Valid
	OEE3	0.833	> 0.5	Valid
	OEE4	0.778	> 0.5	Valid
	OEE5	0.801	> 0.5	Valid
	OEE6	0.797	> 0.5	Valid
	OEE7	0.778	> 0.5	Valid
	OEE8	0.821	> 0.5	Valid
	OEE9	0.804	> 0.5	Valid
	OEE10	0.800	> 0.5	Valid
	OP1	0.849	> 0.5	Valid
	OP2	0.797	> 0.5	Valid
	OP3	0.770	> 0.5	Valid
	OP4	0.834	> 0.5	Valid
	OP5	0.777	> 0.5	Valid

	OP6	0.760	> 0.5	Valid
	OP7	0.774	> 0.5	Valid
	OP8	0.811	> 0.5	Valid
	OP9	0.797	> 0.5	Valid

Based on the Figure and table, it can be seen that all loading factor values for each TPM, RCM, OEE, and OP variable have met the criteria, namely >0.5, so it can be said that they have met convergent validity.

Reliability Test

Reliability testing aims to assess the extent to which a measuring instrument is reliable and consistent in providing results. A survey is considered reliable if the responses to the statements given are consistent over time. In this study, the reliability of the indicator is determined based on the combined reliability value and Cronbach's alpha for each indicator block. In general, Cronbach's alpha value or combined reliability must be more than 0.7 to be considered good, although a value of 0.6 is still acceptable. In the first stage, construct reliability is measured by Composite Reliability, where a construct is considered reliable if its Composite Reliability value is more than 0.7. The results of the Composite Reliability measurement can be seen in Table 2.

Table 2.
Composite Reliability Value of Research Model

Composite Variable	Reliability	Condition	Information
Operational Performance (Z)	0.940	> 0.70	**Reliable**
Overall Equipment Effectiveness (Y)	0.947	> 0.70	**Reliable**
Reliability Centered Maintenance (X2)	0.966	> 0.70	**Reliable**
Total Productive Maintenance (X1)	0.961	> 0.70	**Reliable**

Based on the Table showing the Composite Reliability value of the research model, all variables in this model have a Composite Reliability value above 0.7. The lowest value was recorded in the Operational Performance variable with 0.940, while the highest value was found in the Reliability Centered Maintenance variable with 0.966. Thus, these results conclude that the research model has met the expected Composite Reliability reliability criteria.

In the next stage of reliability testing, namely testing the Cronbach's Alpha value, the construct is considered reliable if the Cronbach's Alpha value is more than 0.6. The test results show the Cronbach's Alpha value for all variables in the research model. With values exceeding the threshold, it can be concluded that all constructs in the research model show an adequate level of reliability.

Table 3.
Cronbach's Alpha Value of the Research Model

Variables	Cronbach's Alpha	Condition	Information
Operational Performance (Z)	0.928	> 0.6	**Reliable**
Overall Equipment Effectiveness (Y)	0.938	> 0.6	**Reliable**
Reliability Centered Maintenance (X2)	0.963	> 0.6	**Reliable**
Total Productive Maintenance (X1)	0.957	> 0.6	**Reliable**

In the table above, it can be seen that each variable has a Cronbach's alpha value above 0.6 with the lowest value being the Operational Performance variable of 0.928 and the highest value being the Reliability Centered Maintenance variable of 0.963. Based on the statement above, it can be concluded that the research model has met the value of Cronbach's alpha and is declared reliable. From all the statements above, we can conclude that the model has met the criteria for composite reliability and Cronbach's alpha, so that the research model has met the criteria for reliability and is a measuring instrument that can be trusted and is reliable.

Direct Effect Test

Hypothesis testing is carried out based on the results of the Inner Model evaluation (structural model), which includes r-square output, parameter coefficients, and t-statistics. To determine whether a hypothesis is accepted or rejected, the significance value between constructs, t-statistics, and p-values are considered. Hypothesis testing in this study was carried out using SmartPLS (Partial Least Square) 4.0 software. These values were obtained from bootstrapping results. The rule of thumb used in this study is t-statistics> 1.96 with a significance level of p-value 0.05 (5%) and a positive path coefficient.

Table 4.
Direct Influence Test Results

Relationship Between Constructs	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	P Values
OEE -> OP	0.285	0.270	0.109	2.616	0.009
RCM -> OP	0.416	0.431	0.111	3,743	0.000
RCM -> OEE	0.297	0.312	0.107	2,767	0.006
TPM -> OP	0.287	0.286	0.117	2,442	0.015
TPM -> OEE	0.693	0.678	0.106	6,516	0.000

Source: Smartpls 3.3 Processed Data

Based on the test results presented in Table 4, it can be explained that the first hypothesis that tests the effect of Overall Equipment Effectiveness on Operational Performance shows significant results. The beta coefficient of 0.285 and the t-statistic of 2.616 indicate that Overall Equipment Effectiveness has a positive and significant effect on Operational Performance, with a p-value of 0.009 which is smaller than 0.05. This proves that the first hypothesis is accepted, confirming the importance of Overall Equipment Effectiveness in improving Operational Performance.

The second hypothesis, which tests the effect of Reliability Centered Maintenance on Operational Performance, also shows significant results. The beta coefficient of 0.416 and t-statistic of 3.743 prove that Reliability Centered Maintenance has a positive and significant effect on Operational Performance, with a p-value of 0.000 which is far below 0.05. These results confirm that Reliability Centered Maintenance has a significant contribution to improving operational performance.

Furthermore, the third hypothesis that tests the effect of Reliability Centered Maintenance on Overall Equipment Effectiveness produces a beta coefficient value of 0.297 and a t-statistic of 2.767. With a p-value of 0.006 which is smaller than 0.05, this result indicates that Reliability Centered Maintenance has a positive and significant effect on Overall Equipment Effectiveness. This confirms that Reliability Centered Maintenance plays an important role in increasing the overall effectiveness of the equipment.

Finally, the fourth hypothesis that tests the effect of Total Productive Maintenance on Operational Performance shows a beta coefficient value of 0.287 and a t-statistic of 2.442. With a t-statistic greater than 1.96 and a significant p-value, these results prove that Total Productive Maintenance also has a positive and significant effect on Operational Performance. This confirms that Total Productive Maintenance plays an important role in improving operational performance.

Indirect Effect Test

Hypothesis testing is done using an internal model (structural model) which includes R-squared output, parameter coefficients, and t-statistics to determine whether the hypothesis can be accepted or rejected. In this study, testing was done using SmartPLS (Partial Least Squares) 4.0 software, and bootstrap results were used to assess the significance between constructs. The general principle applied is that the t-statistic must be greater than 1.96 and the p-value must be less than 0.05 (5%) with a positive beta coefficient to prove a significant effect. The values of the hypothesis testing results are presented in Table.

Table 5.
Indirect Effect Test Results

Relationship Between Constructs	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	P Values
RCM ->OEE -> OP	0.085	0.078	0.035	2.413	0.016
TPM -> OEE -> OP	0.197	0.190	0.093	2.197	0.028

Based on the test results shown in the following table, it can be concluded that the sixth hypothesis, which tests whether Reliability Centered Maintenance affects Operational Performance through Overall Equipment Effectiveness, shows significant results. With a beta coefficient value of 0.085 and a t-statistic of 2.413, which is greater than 1.96 and a p-value of 0.016 which is less than 0.05, these results prove that Overall Equipment Effectiveness functions as an effective mediator in the relationship between Reliability Centered Maintenance and Operational Performance.

In addition, the seventh hypothesis, which tests whether Total Productive Maintenance affects Operational Performance through Overall Equipment Effectiveness, also shows significant results. The beta coefficient value of 0.197 and t-statistic of 2.197, which is greater than 1.96, and p-value of 0.028 which is less than 0.05, indicate that Overall Equipment Effectiveness successfully mediates the effect of Total Productive Maintenance on Operational Performance. These results confirm the important role of Overall Equipment Effectiveness as a mediator in both relationships tested.

The Influence of Total Productive Maintenance on Overall Equipment Effectiveness.

The test results show that Total Productive Maintenance (TPM) has a positive and significant effect on Overall Equipment Effectiveness (OEE). The beta coefficient value for the effect of TPM on OEE is 0.693 with a t-statistic of 6.516, which exceeds the threshold of 1.96, and a p-value of 0.000 which is less than 0.05. This proves that TPM implementation significantly increases equipment effectiveness, consistent with research by Tonny et al. (2023) which emphasizes that full integration of TPM contributes to increased equipment performance and efficiency.

The Influence of Reliability Centered Maintenance on Overall Equipment Effectiveness.

The test results show that Reliability Centered Maintenance (RCM) has a positive and significant effect on Overall Equipment Effectiveness (OEE), with a beta coefficient value of 0.297 and a t-statistic of 2.767. A t-statistic value greater than 1.96 and a p-value smaller than 0.05 prove that RCM significantly increases OEE. This finding is in line with research by(Mkalaf et al., 2023), which shows that RCM has a significant impact on OEE practices in organizations. The implementation of structured RCM can help reduce machine downtime by identifying and maintaining critical components, which has a positive impact on OEE values.

The Influence of Total Productive Maintenance on Operational Performance

The test results show that Total Productive Maintenance (TPM) has a positive and significant effect on Operational Performance. The beta coefficient value of 0.287 and t-statistic of 2.442, with a p-value of 0.01, indicate that TPM significantly affects the company's operational performance. This study is consistent with the findings of Efri et al. (2023) which show that the implementation of TPM can increase the efficiency, effectiveness, and productivity of the production process and product quality. By involving employees in maintenance and repair, companies can reduce operational costs and achieve competitive advantage.

The Influence of Reliability Centered Maintenance on Operational Performance

The test results show that Reliability Centered Maintenance (RCM) has a positive and significant effect on Operational Performance, with a beta coefficient value of 0.416 and a t-statistic of 3.743, and a p-value of 0.000. This finding indicates that RCM significantly affects operational performance, in line with the research of Shannon et al. (2023) which also found a positive impact of RCM on Operational Performance. RCM focuses on equipment and system maintenance to ensure optimal operations, emphasizing the identification and handling of equipment failure risks to improve operational performance.

The Influence of Overall Equipment Effectiveness on Operational Performance

The test results show that Overall Equipment Effectiveness (OEE) has a positive and significant effect on Operational Performance, with a beta coefficient value of 0.285 and a t-statistic of 2.616. These results indicate that OEE significantly affects operational performance, with a t-statistic greater than 1.96 and a p-value of 0.009 which is less than 0.05. These findings indicate that OEE, which measures the availability, performance, and quality of equipment, plays an important role in improving Operational Performance.

The Influence of Total Productive Maintenance on Operational Performance Through Overall Equipment Effectiveness

The test results show that Total Productive Maintenance (TPM) has an effect on Operational Performance through Overall Equipment Effectiveness (OEE), with a beta coefficient value of 0.197 and a t-statistic of 2.197. These results indicate that the t-statistic is greater than 1.96 and the p-value of 0.028 is less than 0.05, so that OEE significantly mediates the effect of TPM on Operational Performance. This proves that OEE plays a significant role as a mediator in the relationship between TPM and operational performance.

The Influence of Reliability Centered Maintenance on Operational Performance Through Overall Equipment Effectiveness

The sixth hypothesis tests whether Reliability Centered Maintenance affects Operational Performance through Overall Equipment Effectiveness. The test results show that the beta coefficient value is 0.085 and the t-statistic is 2.413. From these results, a significant t-statistic is obtained. because 2.413 > 1.96 with a p-value of 0.016 <0.05, so it proves that through Overall Equipment Effectiveness it is able to mediate the effect of Reliability Centered Maintenance on Operational Performance.

CONCLUSION

Based on the analysis and testing of data on the influence of Total Productive Maintenance (TPM) and Reliability Centered Maintenance (RCM) on Operational Performance (OP) through Overall Equipment Effectiveness (OEE) at PT PLN Indonesia Power UBP PLTU Banten 1 Suralaya, several key findings can be concluded. First, Overall Equipment Effectiveness (OEE) shows a positive and significant influence on Operational Performance with a beta coefficient value of 0.285 and a t-statistic of 2.616, and a p-value of 0.009. This indicates that OEE plays an important role in improving operational performance. Second, Reliability Centered Maintenance (RCM) is proven to have a significant positive influence on Operational Performance with a beta coefficient of 0.416 and a t-statistic of 3.743, and a p-value of 0.000. In addition, RCM also shows a significant positive influence on OEE, with a beta coefficient value of 0.297 and a t-statistic of 2.767, and a p-value of 0.006. Finally, Total Productive Maintenance (TPM) has a positive and significant effect on Operational Performance with a beta coefficient value of 0.287 and a t-statistic of 2.442, and a p-value of 0.01. This finding indicates that both TPM and RCM significantly affect operational performance both directly and through OEE.

REFERENCES

Anwar, M., & Ahmed, E. (2024). *Optimizing operational performance through industry 4 . 0 : a comprehensive model for data reliability and OEE enhancement*. 1–16. DOI: https://doi.org/10.21203/rs.3.rs-3893505/v1

Chopra, A., Sachdeva, A., & Bhardwaj, A. (2016). Productivity enhancement using reliability centred maintenance in process industry. *International Journal of Industrial and Systems Engineering*, *23*(2), 155–165. https://doi.org/10.1504/IJISE.2016.076397

Chowdhury, A. H. M. Y., & Mridha, N. A. (2020). The Impact of Total Productive Maintenance Practices on Operational Performance : A Case Study in Footwear Industry of Bangladesh. *International Journal of Applied Business and Management Sciences*, *1*(1), 125–134.

Chattopadhyay, G., Parida, A., & Kumar, U. (2019). Remote asset management for Reducing Life cycle costs (LCC) risks and enhancing asset performance. In *Proceedings of the 5th International Workshop and Congress on eMaintenance: Trends in Technologies & methodologies, challenges, possibilities and applications* (pp. 74-80). SBN: 978-91-7790-475-5 (pdf) Available at http://ltu.diva-portal.org

Hair, J. F., Hult, G. T. M., Ringle, C. M., & Sarstedt, M. (2017). A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM). Thousand Oaks. *Sage*, 165.

Kebede Adem, M., & Virdi, S. S. (2021). The effect of TQM practices on operational performance: an empirical analysis of ISO 9001: 2008 certified manufacturing organizations in Ethiopia. *TQM Journal*, *33*(2), 407–440. https://doi.org/10.1108/TQM-03-2019-0076

Laulita, N. B., & Setyawan, A. (2016). Pengaruh Penerapan Tpm Sebagai Manajemen Perawatan Strategik Terhadap Kinerja Operasional Departemen Fpm Industri Pertambangan. *Change Agent For Management Journal (CAM)*, *4*(2), 18–29. http://jurnal.stiemtanjungredeb.ac.id/index.php/camjournal

Makara, S. (2014). *Maintenance Management and operational performance of service Parastatals in Kenya*. *May*, 52.

Meslameni, W. (2021). Comparison of the effectiveness of two monitoring techniques based on maintenance times OEE and RCM Case of a blow molding machine. *International Journal of Applied Research and Technology*, *3*, 2021. https://www.researchgate.net/publication/349968402

Mkalaf, K. A., Rami Hikmat Al-Hadeethi, & Peter Gibson. (2023). Application of Overall Equipment Effectiveness for Optimizing Ventilator Reliability in Intensive Care Units and Emergency Departments. *Journal of Techniques*, *5*(2), 187–196. https://doi.org/10.51173/jt.v5i2.1419

Priono, I., Wildan Nuryanto, U., & Basrowi. (2023). Implementasi Metode Just in Time Dalam Pengendalian Bahan Baku Pt. Alliance Consumer Products Indonesia. *Faletehan Jurnal Ekonomi Dan Bisnis*, *2*(1), 69–81. https://doi.org/10.61252/fjeb.v2i1.82

Rosario Lopez, A. M., & Nigaglioni, R. (2022). Total Productive Maintenance (TPM) to Improve Laboratory Performance. *Politechnê*, *21*(2), 54–58. http://hdl.handle.net/20.500.12475/1752

Sandy, P. M., & Wathoni, N. (2022). Review: Implementation of Overall Equipment Effectiveness (OEE) Based on Lean Manufacturing Tools in the Indonesian Pharmaceutical Industry. *IDJP*, *4*(1), 158–167. https://jurnal.unpad.ac.id/idjp/article/view/38707/pdf

Terdpaopong, K., Puapradit, A., & Malisuwan, U. (2021). The effect of lean on the operational performance of medium-sized Thai manufacturing companies. *Uncertain Supply Chain Management*, *9*(3), 647–658. https://doi.org/10.5267/j.uscm.2021.5.005

Uddin, M. M., Sakaline, G., & Khan, M. M. A. (2021). Enhancing OEE as a Key Metric of TPM Approach-A Practical Analysis in Garments Industries. *European Journal of Engineering and Technology Research*, *6*(2), 142–147. https://doi.org/10.24018/ejers.2021.6.2.2376

Ullah, M. R., Molla, S., Siddique, I. M., Siddique, A. A., & Abedin, M. M. (2023). Optimizing Performance: A Deep Dive into Overall Equipment Effectiveness (OEE) for Operational Excellence. *Journal of Industrial Mechanics*, *8*(3), 26–40. https://doi.org/10.46610/joim.2023.v08i03.004

Virk, S. I., Khan, M. A., Lakho, T. H., & Indher, A. A. (2020). Review of Total Productive Maintenance (TPM) & Overall Equipment Effectiveness (OEE) Practices in Manufacturing Sectors. *Proceedings of the International Conference on Industrial & Mechanical Engineering and Operations Management Dhaka*.

Syahrial, T. R., & Nusraningrum, D. (2022). Improving Performance and Electricity Production with the Overall Equipment Effectiveness Method as the Basis for the Proposed Application of the Total Productive Maintenance Concept on the PLTS Equipment System at Soekarno-Hatta Airport. *European Journal of Business and Management Research*. https://doi.org/10.24018/ejbmr.2022.7.4.1603

Priyono, S., Machfud, M., & Maulana, A. (2019). *Penerapan Total Productive Maintenance (TPM) Pada Pabrik Gula Rafinasi di Indonesia (Studi Kasus: PT. XYZ)*. https://doi.org/10.17358/JABM.5.2.265

Yohanes, A., & Ekoanindiyo, F. A. (2021). *IMPLEMENTASI TOTAL PRODUCTIVE MAINTENANCE SEBAGAI PENUNJANG PRODUKTIVITAS DENGAN MENGGUNAKAN METODE OVERALL EQUIPMENT EFFECTIVENESS (studi kasus PT. Metta Boga)*. https://doi.org/10.30587/MATRIK.V21I2.1973

Salmi, S., Nazrin, M. Z., & Norlena, H. (2019, May 17). *Applied Of Total Productive Maintenance Concepts In Energy Industry: Organizations Practices*. https://doi.org/10.15405/EPSBS.2019.05.02.33

Pratiwi, I. (2019). *Usulan Penerapan Total Productive Maintenance pada Mesin Turbin Gas*. https://doi.org/10.25077/JOSI.V18.N1.P37-47.2019

Campos, R. S. de, & Simon, A. T. (2019). Insertion of sustainability concepts in the maintenance strategies to achieve sustainable manufacturing. *Independent Journal of Management & Production*. https://doi.org/10.14807/IJMP.V10I6.939

Sahoo, S. (2019). Assessment of TPM and TQM practices on business performance: a multi-sector analysis. *Journal of Quality in Maintenance Engineering*, *25*(3), 412-434. https://doi.org/10.1108/JQME-06-2018-0048

Chowdhury, A. H. M. Y., Mridha, N. A., & Ratna, S. A. (2020). The impact of total productive maintenance practices on operational performance: a case study in footwear industry of Bangladesh. *International Journal of Applied Business and Management Sciences*, *1*(1), 125-134

Danguche, I., & Taifa, I. (2023). Factors influencing total productive maintenance implementation for thermal generation plants. *Tanzania Journal of Engineering and Technology*, *42*(1), 97-112. DOI: 10.52339/tjet.v42i1.892

Gubin, P. Y., Kamel, S., Safaraliev, M., Senyuk, M. D., Hussien, A. G., & Zawbaa, H. M. (2023). Optimizing generating unit maintenance with the league championship method: A reliability-based approach. *Energy Reports*. https://doi.org/10.1016/j.egyr.2023.06.024

Gianfranco, J., Taufik, M., Hariadi, F., & Fauzi, M. I. (2022). Pengukuran total productive maintenance (tpm) menggunakan metode overall equipment effectiveness (oee) pada mesin reaktor produksi. *Jurnal Lebesgue*. https://doi.org/10.46306/lb.v3i1.109

Schindlerová, V., Šajdlerová, I., Michalčík, V., Nevima, J., & Krejčí, L. (2020). Potential of using TPM to increase the efficiency of production processes. *Tehnicki Vjesnik-Technical Gazette*. https://doi.org/10.17559/TV-20190328130749

Hussain, Z., & Jan, H. (2019). Establishing simulation model for optimizing efficiency of CNC machine using reliability-centered maintenance approach. *International Journal of Modeling, Simulation, and Scientific Computing*, *10*(06), 1950034. https://doi.org/10.1142/S179396231950034X

Khasanah, R. (2012). Reliability-centered maintenance (RCM) evaluation in the industry application, case study: fertilizer company, Indonesia. *Penelitian dan Aplikasi Sistem dan Teknik Industri*, *10*(1), 182866. Lopez, A. R., & Nigaglioni, R. (n.d.). *Total Productive Maintenance TPM to Improve Laboratory Performance*.

Alseiari, A. Y., Farrell, P., & Osman, Y. Z. (2020). *Technical and operational barriers that affect the successful total productive maintenance (TPM) implementation: case studies of Abu Dhabi power industry*. https://doi.org/10.1007/978-3-030-57745-2_110

Moscoso, C., Fernandez, A., Viacava, G., & Raymundo, C. (2020). Integral model of maintenance management based on TPM and RCM principles to increase machine availability in a manufacturing company. In *Human Interaction and Emerging Technologies: Proceedings of the 1st International Conference on Human Interaction and Emerging Technologies (IHIET 2019), August 22-24, 2019, Nice, France* (pp. 878-884). Springer International Publishing. https://doi.org/10.1007/978-3-030-25629-6_137

Suryaprakash, M., Gomathi Prabha, M., Yuvaraja, M., & Rishi Revanth, R. V. (2021). Improvement of overall equipment effectiveness of machining centre using tpm. *Materials Today: Proceedings*. https://doi.org/10.1016/J.MATPR.2020.02.820

Anwar, M., Ahmed, E. N., & Abdelhamid, Z. (2024). Optimizing operational performance through industry 4.0: a comprehensive model for data reliability and OEE enhancement. DOI: https://doi.org/10.21203/rs.3.rs-3893505/v1

Sugiyono. (2015). Metode Penelitian Kuantitatif, Kualitatif, dan R&D. Bandung: ALFABETA

Ghozali, Imam. (2014). *Structural Equation Modeling, Metode Alternatif dengan Partial Least Square (PLS).* Edisi 4. Semarang: Badan Penerbit Universitas Diponegoro.

Ghozali, Imam. (2021). *Aplikasi Analisis Multivariate dengan Program IBM SPSS 26*. Semarang: Badan Penerbit Universitas Diponegoro.

Sugiyono. (2017). *Metode Penelitian Bisnis (Pendekatan Kuantitatif, Kualitatif, dan R&D)*. Bandung: Alfabeta.

Sugiyono. (2013). *Metode Penelitian Pendidikan (Pendekatan Kuantitatif, Kualitatif, dan R&D)*. Bandung: Alfabeta.

Slamet Riyanto dan Aglis Andhita Hatmawan. (2020). Metode Riset Penelitian Kuantitatif Penelitian di Bidang Manajemen, Teknik, Pendidikan, dan Eksperimen. Yogyakarta: CV BUDI UTAMA.

Ismail Nurdin, dan Hartati, Sri. (2019). Metodologi Penelitian sosial. Surabaya: Media Sahabat Cendikia