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Analysis of Availability Efficiency, Performance Efficiency, And Quality Efficiency Using the Overall Equipment Effectiveness (OEE) Method
(Case Study in the Service Unit of Orya Hydro Power Plant of Jayapura Regency)

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ABSTRACT

This study investigates the Orya Jayapura Hydroelectric Power Plant in Indonesia. The plant suffers from high machine downtime, resulting in low production and profits. Analyze the plant's efficiency using the Overall Equipment Effectiveness (OEE) method. OEE considers availability, performance, and quality metrics. A mixed method combining a case study with quantitative data analysis (OEE formula) and a qualitative approach (cause-and-effect diagrams) to prioritize improvement recommendations. The average OEE for 2019-2022 was only 32.76%, indicating significant equipment inefficiency and low profits. High equipment failure losses were identified as the main culprit. The study confirms a correlation between technical efficiency and financial performance: higher availability leads to higher profits. The plant needs to improve its overall quality in terms of people, machinery, materials, and methods. This includes staffing with qualified personnel, providing employee training, enhancing equipment maintenance, and implementing strategies for asset optimization and innovation.

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1. INTRODUCTION

Hydroelectric power plants (HPP) are one of the important renewable energy sources to meet electricity needs in Indonesia. HPP performance is highly influenced by several factors, one of which is machine efficiency. High machine efficiency will result in more optimal electricity production and reduce downtime. This study aims to improve the efficiency of HPP machines using the Overall Equipment Effectiveness (OEE) method. This method is chosen because OEE encompasses three important efficiency variables, namely availability efficiency, performance efficiency, and quality efficiency. Previously, [1] conducted a study showing that efficiency and equipment effectiveness are closely related. [2] Also explained that availability efficiency calculates the percentage of active equipment time, performance efficiency is obtained by multiplying the ratio of the quantity of products produced to the ideal cycle time by the time available to run the production process, and quality efficiency is obtained from the percentage of Processed amount and Defect amount factors. Based on these studies, the authors believe that the OEE method can be applied to improve HPP machine efficiency and produce more optimal electricity production.

2. LITERATURE REVIEW

In this study, the researcher employs a theoretical framework as a foundational support. The subsequent section will delve deeper into relevant theories, such as Digital Transformation, Cloud Computing, Change Management, Project Management and Success Factor of Cloud Project.

2.1 Strategic Management

According to [3] the strategy of large companies is divided into three interrelated levels that evolve with the company's business. First, corporate strategy, which focuses on the overall growth of the company, with three strategic choices: growth strategy, stability strategy, and retrenchment strategy. Second, business strategy, which focuses on the competitive position of products/services in a particular market segment, with three strategic choices: cost leadership strategy, differentiation strategy, and focus strategy. Third, functional strategy, which focuses on improving functional areas such as operations, marketing, finance, and HR to support business and corporate strategy, and ultimately, achieve competitive advantage.

2.2 Business Strategy

Hydroelectric power plants (HPP) can employ three main business strategies to achieve competitive advantage, enhance profitability, and contribute to sustainable development: cost leadership, differentiation, and focus. Among the three business strategies, the author applies the cost leadership strategy in the implementation of this paper, where operational efficiency is dominant in Orya HPP. Competitive advantage is a condition that distinguishes a company or organization from its competitors in the market. Competitive advantage can encompass various aspects, such as superior technology, a strong brand, production efficiency, effective distribution, access to scarce resources, and product or service innovation. Competitive advantage enables a company to achieve a stronger position in the market, increase market share, and generate higher profits [4].

2.3 Functional Strategy

Functional strategy plays a crucial role in enabling business units to gain a competitive edge by fostering and maintaining specialized competencies. It serves as a supporting strategy that complements the success of other strategies, namely business and corporate strategies. Functional strategy encompasses various functions, including finance, production/operations, marketing, human resources, and research and development. It must align with the overall business strategy, and its primary focus lies in determining the most effective implementation approach [5].

2.4 Machine Maintenance

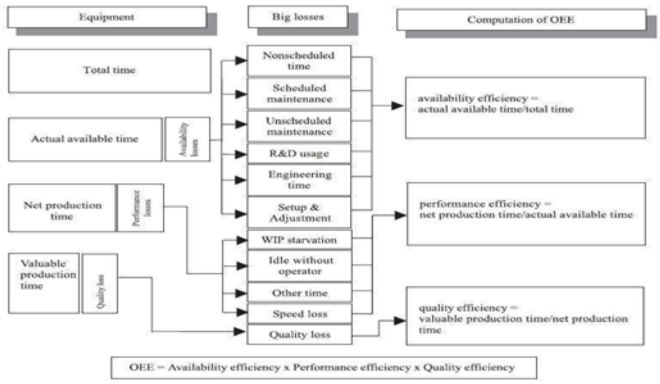
According to [6] maintenance is a process of caring for factory machinery/equipment by extending its lifespan and preventing machine failures or damage. Total productive maintenance (TPM) is a maintenance concept that involves all members of the work team with the aim of achieving effectiveness throughout the production system through active participation and maintenance activities focused on productivity, proactivity, and planning [7]. The benefits of TPM include improved quality, reduced equipment breakdowns, and decreased machine downtime through focused methods.

2.5 Six Big Losses Analysis

To enhance the productivity and efficiency of machinery or equipment, an analysis of the productivity and efficiency of the machinery or equipment in relation to the six major loss factors (six big losses) is necessary, namely, (1) equipment failure is damage to machinery (equipment and work tools) can lead to losses for the company due to decreased production volume or material losses from defective products, (2) setup and adjustment are losses caused by setup and adjustments include the time required for making adjustments and changes to the machine, as well as the time needed to switch to the next type of product to be manufactured. In other words, during this time, the machine cannot produce because it is undergoing equipment (dies) replacement for the next product type until the appropriate product can be generated for the next process, (3) idling and minor stoppages are losses caused by downtime and minor machine disruptions result in suboptimal machine performance, (4) reduced speed is losses incurred when machinery operates at a low speed, below the desired speed, (5) defects in process and (6) reduced yield is breakdowns during the production period that prevent the machine from producing quality products [8].

2.6 Overall Equipment Effectiveness (OEE)

According to [9], Overall Equipment Effectiveness (OEE) is a metric that measures the productive efficiency of machines within a production line. It serves as a benchmark and tool for evaluating progress in manufacturing processes. Achieving an OEE of 100% represents perfect production, where only good parts are produced at maximum speed without any downtime. OEE is divided into 3 main variables: availability efficiency, performance efficiency, and quality efficiency [1].



$$OEE = Availability \; x \; Performance \; Rate \; x \; Rate \; of \; Quality \; Product \quad (1)$$

$$Availability = \frac{Operation\ Time}{Loading\ Time} \times 100\% = \frac{Loading\ Time - Downtime}{Loading\ Time} \times 100\% \quad (2)$$

$$Performance\ Efficiency = \frac{Process\ Amount \times Ideal\ Cycle\ Time}{Operation\ Time} \times 100\% \quad (3)$$

$$Rate\ of\ Quality\ Product = \frac{Process\ Amount \times Defect\ Amount}{Processed\ Amount} \times 100\% \quad (4)$$

Figure 1. Operational Optimization Variables

2.7 OEE Calculations

Overall Equipment Effectiveness (OEE) aims to enable the classification of one or more production lines as best-in-class in terms of their level [10]. The basic OEE calculation involves assumptions about the theoretical maximum capacity on one hand and production output on the other. OEE not only clearly illustrates the losses between these two points, but more importantly, the concept can be fully understood by all teams involved, including operators, supervisors, technical staff, engineers, and others.

2.8 Cause Effect Diagram

Cause and effect diagrams are useful for analyzing and identifying factors that have a significant impact on the quality characteristics of work output. This diagram is a structured approach that allows for a more detailed analysis to find the causes of problems, inconsistencies, and gaps that exist.

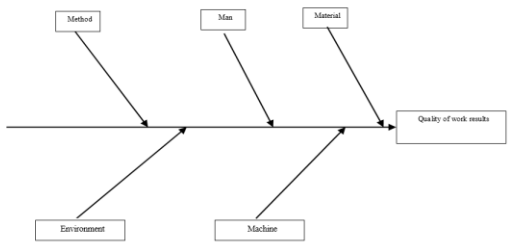


Figure 2. Cause Effect Diagram [11]

2.9 Conceptual Framework

The framework of this research involves processing three efficiency variables (availability, performance, and quality) using a quantitative approach, namely the measurement of Overall Equipment Effectiveness (OEE). This is then processed with a qualitative approach through the analysis of a cause-and-effect diagram as the main tool for determining the root cause, which results in conclusions and solutions to improve the efficiency of the three variables and the company's profit. Therefore, this research does not formulate a hypothesis because it tends to use a qualitative approach in most of the research; instead, it is expected that this research can discover hypotheses that, if further explored by other researchers, can be tested using a quantitative approach.

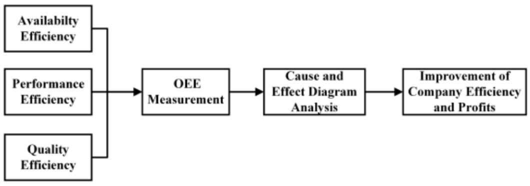


Figure 3. Conceptual Framework

3. METHODS

This type of research employs a mixed methods approach, combining two previously established research methodologies: qualitative research and quantitative research. Creswell in [12] states that the selection of a qualitative research model largely depends on the perspective used by the researcher and the research objectives. Meolong in [13] asserts that the aim of qualitative research is to understand certain phenomena experienced by the research subjects. The objective of this qualitative research is to provide an analysis of the context and process that explains the theoretical issues being studied [14].

Table 1. Operational Variables

Variable	Interview Questions
Availability	1. What are the most common causes of downtime for equipment in our production environment? 2. Are there any shortcomings in equipment maintenance planning and scheduling that could be affecting its availability? 3. How can we improve equipment repair time in the event of breakdowns or failures? 4. Are there any gaps in operator understanding and skills in maintaining and operating equipment efficiently? 5. Are there any infrastructure or supply constraints that limit equipment availability? [15]
Performance	1. What factors affect the production speed of our equipment and how can we overcome these obstacles? 2. Are there any processes or activities that cause time wastage or overburden our equipment, and what can we do to reduce this waste? 3. How can we ensure that our equipment operates at its peak efficiency and utilizes available technologies? 4. Is there any training or skill development required for our operators or production personnel to improve equipment performance? 5. Are there any product or process design changes that could be made to enhance equipment performance? [16]
Quality	1. What are the primary causes of the most frequently occurring product defects in our equipment? 2. Are there any factors affecting the quality of products generated by

	the equipment, such as measurement errors or equipment malfunctions? 3. How can equipment maintenance and calibration be enhanced to ensure consistent product quality? 4. Are there any errors or shortcomings in the inspection or quality control process that need to be addressed? 5. How can the utilization of quality technologies or software assist in enhancing product quality control and monitoring? [17]

This research was designed using 5 qualitative questions to identify availability efficiency factors through downtime analysis. Major losses in this study were explored using Pareto and fishbone (cause and effect) diagrams. The research stages are as follows, calculate the values of availability, performance rate, and rate of quality product, calculate the OEE (Overall Equipment Effectiveness) value, calculate the OEE Six Big Losses value, describe the problems and what should be done to address them using a Cause and Effect Diagram, determine risk mitigation from the Cause and Effect diagram to determine improvement recommendations [18]. The following are the stages of the research conducted:

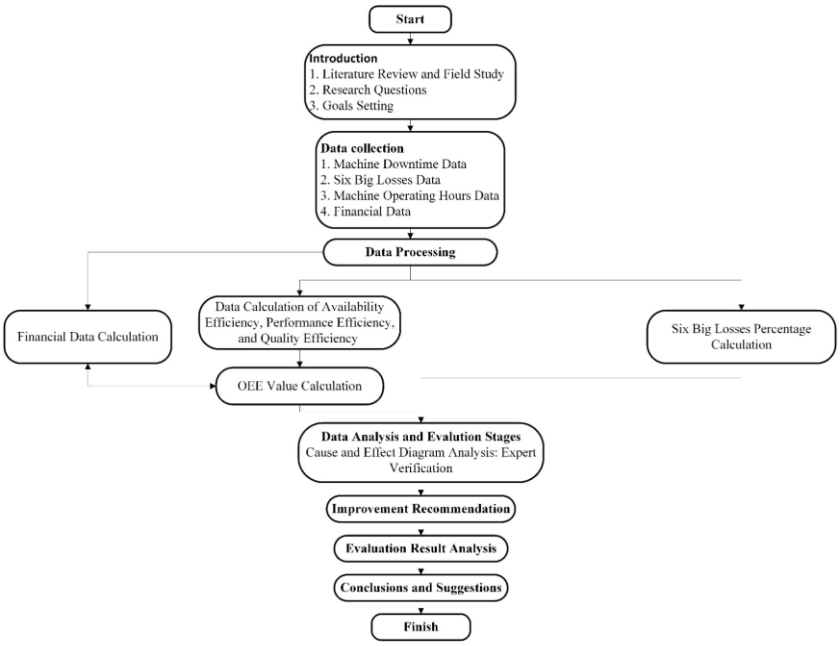
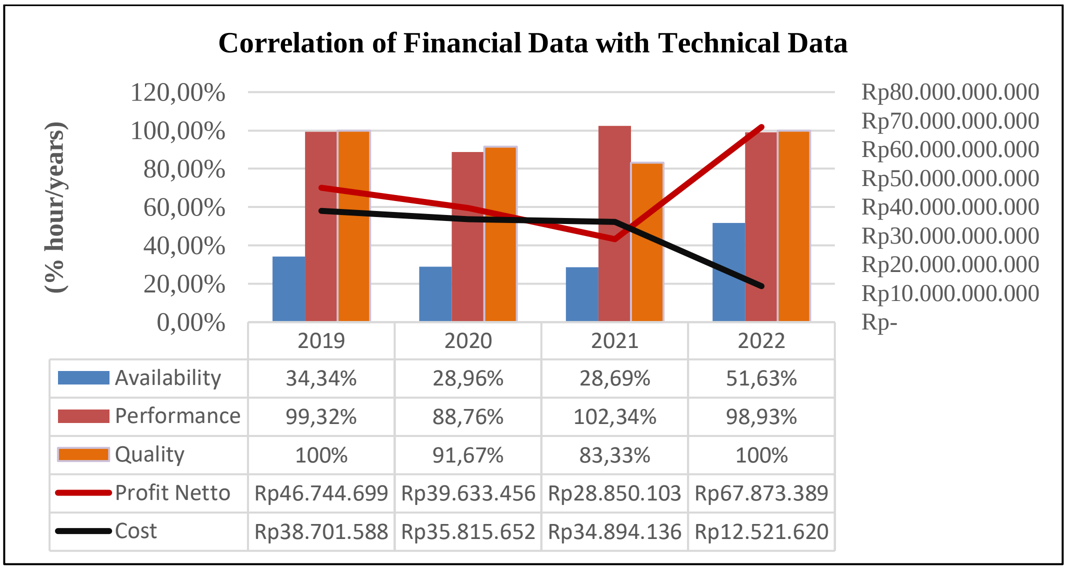


Figure 4. Research Stages

4. RESULTS AND DISCUSSION

This research aims to determine the analysis of availability efficiency, performance efficiency, and quality efficiency in the service unit of Orya HPP, where the production process runs continuously and the machines/equipment operate for 24 hours. This chapter also describes the interview data presented in the research results. The data collected spans the past four years, from January 2019 to December 2022.



	2019	2020	2021	2022
Availability	34,34%	28,96%	28,69%	51,63%
Performance	99,32%	88,76%	102,34%	98,93%
Quality	100%	91,67%	83,33%	100%
Profit Netto	Rp46.744.699	Rp39.633.456	Rp28.850.103	Rp67.873.389
Cost	Rp38.701.588	Rp35.815.652	Rp34.894.136	Rp12.521.620

Figure 5. Correlation of Financial Data with Technical Data

From the Figure 5 above, the analysis reveals a positive correlation between the availability factor and the profit of Orya Jayapura Hydroelectric Power Plant. This implies that as the availability factor increases, the company's profit also rises. However, performance and quality do not exert a significant impact on the company's profit.

$$Availability\ = \frac{Operating\ time}{Loading\ Time} \times 100\%$$
$$= \frac{194}{616} \times 100\% = \ 31{,}49\%$$

$$Performance\ efficiency$$
$$= net\ operating\ rate\ x\ operating\ speed\ rate$$
$$= = 100\%\ x\ 91{,}60\% = 91{,}60\%$$

$$Rate\ of\ quality\ product$$
$$= \frac{Product - reject\ and\ rework}{target} x\ 100\%$$
$$= \frac{1.453 - 0}{1.453} x\ 100\% = 100\%$$

The formula and calculation of the average Overall Equipment Effectiveness (OEE) value for January 2019 – December 2022 are as follows:

$$Overall\ Equipment\ Effectiveness$$
$$= availability\ x\ performance\ x\ quality =$$
$$= 35{,}90\% \ \times\ 97{,}34\% \ \times 93{,}75\% = 32{,}76\%$$

From the cause and effect diagram in Figure 6, the causes of high Equipment Failure Losses on Generator Nanning #1 can be identified.

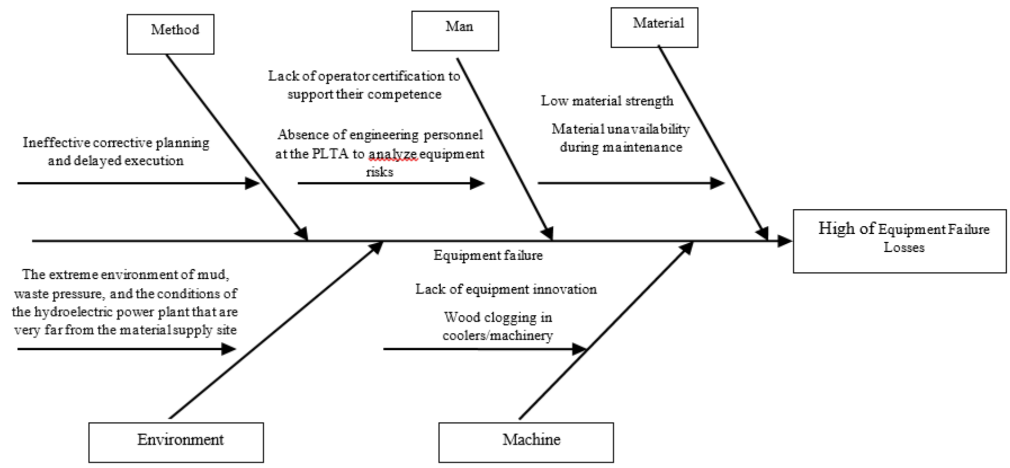


Figure 5. Cause and Effect Diagram/Fishbone

The cause and effect diagram analysis in this study focuses on identifying the factors that significantly contribute to the low effectiveness of Generator Nanning #1. This analysis is based on the Pareto Six Big Losses diagram, which highlights the cumulative percentage of time loss. The most significant factor, accounting for 72.11% of the total time loss, is Equipment Failure.

The fishbone diagram analysis of the Orya Jayapura hydroelectric power plant reveals several key issues contributing to the low OEE, namely the lack of operator certification and the absence of engineering staff. The lack of operator certification results in suboptimal operator performance, maintenance errors, and insufficient capability in handling emergency situations. On the other hand, the absence of engineering staff leads to inadequate equipment risk analysis, insufficient engineering supervision, and delays in addressing equipment issues. To address these problems, it is necessary to enhance operator training and certification, as well as recruit engineering staff to conduct risk analysis, supervision, and timely problem-solving of equipment issues. By addressing these issues, the Orya Jayapura hydroelectric power plant can improve its OEE and achieve more optimal performance.

Several causes of equipment failure at the hydroelectric power plant include equipment damage, lack of innovation, and wood blockages in coolers/machines. Damage is caused by inadequate maintenance and overuse, while the lack of innovation makes outdated equipment more prone to failure. Wood blockages can obstruct airflow or water flow, leading to overheating. With regular preventive maintenance, investment in the latest technology, and routine cleaning, the hydroelectric power plant can improve operational efficiency and reduce repair and replacement costs.

Material factors contributing to high Equipment Failure Losses at the hydroelectric power plant include low material strength and unavailability of materials during maintenance. Low-strength materials are prone to failure under high pressure or constant wear, while delays in obtaining necessary materials hinder timely maintenance, increasing failure risks. To mitigate these issues, selecting materials resistant to environmental and operational stresses and maintaining adequate stock levels are crucial. Efficient maintenance planning and material procurement can reduce repair delays, minimize downtime, and enhance electricity production, benefiting the company's shareholders.

Environmental conditions around the hydroelectric power plant contribute to high Equipment Failure Losses, including extreme mud environments, waste pressure, and the plant's remote location from material supplies. Mud can cause corrosion and erosion of equipment, while waste pressure from river flow can block inlets and outlets, damaging mechanical components and reducing operational efficiency. The remote location delays material procurement, hindering timely maintenance and increasing failure risks. To mitigate these issues, the plant can enhance equipment protection, improve maintenance planning, build storage facilities nearby, and implement innovations like dam cleaners to ensure reliable operation and reduce environmental impact risks.

From a workflow perspective on the fishbone diagram, delayed or untimely corrective plans in response to equipment failures can escalate the risk of further damage or production losses. Any delay in addressing identified issues can worsen equipment conditions, hastening subsequent failures or damages. Such delays, stemming from inadequate planning, can result in additional costs due to production losses or equipment failures. To mitigate Equipment Failure Losses, it's crucial to design operational methods considering equipment capacity and limitations, and to implement regular preventive maintenance and condition monitoring to manage and reduce equipment failure risks. Training for personnel involved in operational methods considering equipment capacity and limitations, preventive maintenance, and regular condition monitoring is also necessary. Therefore, designing operational methods that consider equipment capacity and limitations, along with regular preventive maintenance and condition monitoring, is essential. With effective operational methods, the hydroelectric power plant can enhance responsiveness, efficiency, and the quality of corrective planning, reducing the risk of Equipment Failure Losses, particularly in supporting increased availability efficiency.

5. CONCLUSION

Based on the research conducted on the Nanning #1 turbine at the Orya Jayapura hydroelectric power plant, several conclusions can be drawn:

1) The analysis of Overall Equipment Effectiveness (OEE) reveals an availability efficiency value of 35.90%, performance efficiency of 97.34%, and quality efficiency of 93.75%, resulting in an OEE value of 32.76%, below the standard value of 85% according to the Japan Institute of Plant Maintenance. This inefficiency in availability efficiency significantly impacts downtime, leading to a decrease in electricity production for sale and affecting the company's revenue. While performance efficiency and quality efficiency also affect profitability, they are not discussed further in the fishbone diagram as they have remained within a normal range since 2019-2022.
2) The primary factor contributing to high downtime is Equipment Failure Losses within the scope of Availability Efficiency, accounting for 72.11% according to the Pareto six big losses diagram. Analysis of the cause-and-effect diagram indicates that equipment damage, wood blockages in coolers/machines, and extreme environmental conditions are the main contributors to high Equipment Failure Losses, resulting in high costs for the Orya Jayapura hydroelectric power plant.
3) The company's availability efficiency shows fluctuating trends related to net profit over the period from 2019-2022. There was a decrease from 34.34% with a profit of Rp46.74 billion in 2019 to 28.96% with a profit of Rp39.63 billion in 2020. In 2021, availability efficiency further decreased to 28.69% with a profit of Rp28.85 billion. However, there was an increase in 2022 to 51.63% with a profit of Rp67.87 billion. This demonstrates a direct relationship between net profit and availability efficiency, indicating that higher equipment availability efficiency leads to higher company profits.

RECOMMENDATION

Based on the findings of this research, several recommendations can be provided:

1) PLTA Orya Jayapura needs to implement preventive maintenance management, strict quality control, employ engineering staff, and provide training and certification for employees to address downtime of the Nanning #1 turbine and streamline its production.
2) PLTA Orya Jayapura should enhance equipment maintenance, material quality, and employee skills. It is also crucial for the company to provide ready-to-use materials according to company standards and innovate equipment. The hydroelectric power plant infrastructure design also needs to be reassessed to reduce the impact of wood and extreme environmental conditions. This is expected to reduce overall PLTA costs.
3) PLTA Orya Jayapura needs to adopt a strategy focused on asset optimization, employee development, and exploring new business opportunities. Considering benchmarking and a corporate culture focused on continuous improvement, especially to increase availability efficiency directly related to company revenue, is crucial.

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