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Reliability-Based Maintenance for Operational Cost Efficiency in Geothermal Power Plants

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Abstract

Operational cost efficiency is essential for maintaining the sustainability and competitiveness of energy companies, particularly in geothermal power plants with highly complex operational systems. However, maintenance activities that still rely heavily on corrective approaches often lead to frequent failures, increased downtime, and higher operational costs. This study aims to analyze the implementation of reliability-based maintenance (RBM) and evaluate its investment feasibility in improving operational cost efficiency. The study employs a descriptive quantitative approach using a case study on the Fluid Collection and Reinjection System (FCRS) at the Lumut Balai Geothermal Power Plant. Data were analyzed through before–after comparison, cost-benefit analysis, return on investment (ROI), and payback period analysis. The results indicate that the implementation of preventive maintenance innovation through the CLEAR-FCRS system significantly reduced downtime duration from 2–3 hours to 15–30 minutes and decreased failure frequency. Financially, an investment of IDR 44,000,000 generated annual operational savings of IDR 177,600,000, with an ROI of 403.64% and a payback period of approximately three months. These findings demonstrate that integrating reliability-based maintenance with investment feasibility analysis can significantly improve operational reliability, cost efficiency, and overall operational performance in geothermal power plants.

Article Info

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cost efficiency, geothermal power plant, investment feasibility, operational performance, reliability-based maintenance

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1. Introduction

Operational cost efficiency is a critical factor in maintaining the sustainability and competitiveness of companies, particularly in the energy generation industry, which involves complex systems. In the context of geothermal power plants, system reliability is crucial because operational disruptions not only reduce production output but also increase maintenance costs and financial risks. Maintenance practices that are still dominated by corrective maintenance tend to be reactive, resulting in a high frequency of failures and significant downtime. This condition highlights the need for a more systematic and reliability-based maintenance approach to improve operational efficiency sustainably (Mobley, 2002).

With the advancement of asset management practices, reliability-based maintenance (RBM) has been increasingly adopted as a strategy to enhance system reliability while optimizing maintenance costs. This approach emphasizes maintenance decision-making based on risk levels and failure probabilities, allowing organizations to allocate resources more efficiently (da Silva et al., 2023). Furthermore, within the asset management framework, the ISO 55000 standard emphasizes the importance of integrated asset management to maximize value and cost efficiency throughout the asset lifecycle (Menéndez et al., 2022).

Several previous studies have demonstrated that reliability-oriented maintenance approaches contribute significantly to improving operational performance and reducing operational disruptions in industrial systems. Liang et al. (2024) explained that predictive and reliability-based maintenance strategies improve thermal system performance through early failure detection and operational optimization. Similarly, Ujević Andrijić and Rimac (2025) highlighted that data-driven maintenance approaches are effective in improving reliability and operational sustainability in engineering systems. These findings indicate that reliability-based maintenance has become an increasingly important strategy in modern asset management practices.

However, previous studies have generally focused more on the technical aspects of reliability without comprehensively integrating investment feasibility analysis into maintenance strategies. In practice, maintenance innovation requires careful economic consideration, including investment costs, operational savings, and return on investment. More et al. (2024) highlighted that integrating cost, risk, and performance in maintenance decision-making remains a challenge and requires a more holistic approach. Therefore, empirical studies are needed not only to assess technical impacts but also to evaluate the investment feasibility of maintenance innovations.

This research gap is particularly relevant in the Fluid Collection and Reinjection System (FCRS) at the Lumut Balai Geothermal Power Plant, where recurring failures have led to high disruption frequency and increased operational costs. Empirical data show that the implementation of preventive maintenance innovation through the CLEAR-FCRS system has improved operational reliability, as indicated by a reduction in handling time from 2–3 hours to 15–30 minutes. From a financial perspective, an investment of IDR 44,000,000 resulted in annual operational cost savings of IDR 177,600,000, with a return on investment (ROI) of 403.64% and a payback period of approximately three months. These findings indicate that relatively simple technical innovations can have a significant impact on cost efficiency and operational performance.

Unlike previous studies that primarily focus on the technical reliability aspect of maintenance systems, this study integrates reliability-based maintenance implementation with investment feasibility analysis within the operational context of geothermal power plants. This integration provides a more comprehensive evaluation framework by simultaneously examining operational reliability improvements and their financial implications. Therefore, this study contributes to bridging the gap between technical maintenance strategies and economic decision-making in energy asset management.

Based on this phenomenon and research gap, this study aims to analyze the implementation of preventive maintenance innovation within a reliability-based framework and to evaluate its investment feasibility in improving operational cost efficiency. Specifically, this study examines the relationship between improved operational reliability, reduced downtime, and the resulting financial implications.

This study is built upon a conceptual framework integrating three main constructs: reliability-based maintenance, operational performance, and investment feasibility. Reliability-based maintenance contributes to improving system reliability and reducing failure frequency, which in turn enhances cost efficiency. Meanwhile, investment feasibility is measured through financial indicators such as ROI and payback period to support managerial decision-making. The relationship among these constructs demonstrates that improvements in operational reliability not only affect technical performance but also significantly contribute to the financial performance of the company.

2. Methods

Research Design

This study employs a descriptive quantitative approach using a case study design to analyze the implementation of reliability-based maintenance and its impact on operational cost efficiency in geothermal power plant operations. The quantitative approach is selected because the study focuses on measurable operational and financial indicators, including downtime duration, failure frequency, operational cost savings, return on investment (ROI), and payback period. Quantitative analysis enables objective evaluation through numerical comparison and systematic interpretation of operational performance before and after the implementation of the maintenance innovation (Rausand & Høyland, 2004).

The case study design is considered appropriate because the research investigates a specific operational system within its actual industrial environment. According to Yin (2018), a case study approach is effective for exploring contemporary phenomena within real-life contexts, particularly when the boundaries between the phenomenon and context are not clearly evident. In this study, the case study approach allows for a comprehensive understanding of operational issues, maintenance practices, and investment decisions associated with the Fluid Collection and Reinjection System (FCRS) at the Lumut Balai Geothermal Power Plant.

In addition, this study adopts a comparative before–after evaluation approach to assess the effectiveness of the implemented innovation. The comparison focuses on operational conditions before and after the implementation of the CLEAR-FCRS preventive maintenance innovation. This approach allows the study to identify operational improvements and quantify the resulting financial benefits generated by the innovation (Southgate et al., 2024).

Study Site and Time Frame

The research was conducted at the Lumut Balai Geothermal Power Plant, specifically within the Fluid Collection and Reinjection System (FCRS). The FCRS is one of the most critical operational systems in geothermal power generation because it functions to manage geothermal fluid circulation and maintain operational continuity. Any disruption occurring within this system can directly affect electricity production stability, operational safety, and overall plant performance.

The selection of the research location was based on operational considerations indicating recurring maintenance problems and repeated failures in the FCRS. Prior to the implementation of the innovation, the system experienced relatively high downtime duration and frequent operational interruptions, leading to increased operational costs and reduced efficiency. These conditions made the system suitable for evaluating the effectiveness of reliability-based maintenance implementation.

The study compares operational conditions during two different periods:

1. Before the implementation of the CLEAR-FCRS innovation
2. After the implementation of the CLEAR-FCRS innovation

This comparison enables a systematic evaluation of the innovation's effectiveness in improving operational reliability and reducing operational costs.

Population and Sample

The population of this study includes all operational and maintenance activities associated with the Fluid Collection and Reinjection System (FCRS) at the Lumut Balai Geothermal Power Plant. The population also includes operational performance records, maintenance reports, financial records, and historical failure data related to the system.

The sampling technique used in this research is purposive sampling. Purposive sampling is applied because the study requires specific operational and financial data directly related to the implementation of preventive maintenance innovation (Sugiyono, 2017). This sampling method enables the researcher to select data considered most relevant to the objectives of the study.

The criteria for data selection include:

1. Operational data associated with recurring failures in the FCRS
2. Maintenance records before and after innovation implementation
3. Downtime and operational disruption data
4. Financial records related to maintenance costs and operational savings
5. Investment expenditure data associated with the CLEAR-FCRS innovation

The selected sample consists of quantitative operational and financial data used to evaluate the effectiveness and feasibility of the implemented maintenance innovation. This approach ensures that the collected data are valid, relevant, and representative of the operational conditions being analyzed.

Data Collection

This study utilizes secondary quantitative data obtained from internal company documentation and operational records. Secondary data are used because they provide historical and objective information regarding operational performance and maintenance activities within the power plant system (Heale & Twycross, 2015).

The data sources used in this study include:

1. FCRS operational reports
2. Maintenance activity records
3. Historical failure and downtime reports
4. Documentation of CLEAR-FCRS implementation
5. Operational cost records
6. Investment expenditure reports

Data collection was conducted using documentation and archival study methods. Operational reports and maintenance records were reviewed systematically to identify patterns of failure frequency, downtime duration, and operational disruptions occurring before and after the implementation of the innovation.

In addition, financial records were analyzed to determine investment costs, operational savings, and economic benefits generated from the implementation of the preventive maintenance strategy. The collected data were then organized and classified according to operational and financial categories to facilitate further analysis.

Operational Definition of Variables

Table 1. Operational Definitions and Measurement Indicators of Research Variables

Variable	Operational Definition	Measurement Indicators
Reliability-Based Maintenance	A maintenance strategy focused on improving system reliability through preventive and reliability-oriented maintenance innovation	Reduction in failure frequency, increased system stability
Operational Performance	The effectiveness and reliability of the operational system in maintaining production continuity	Downtime duration, operational interruption frequency
Operational Cost Efficiency	The ability of the operational system to minimize maintenance and operational costs after innovation implementation	Annual operational cost savings
Investment Feasibility	The financial viability of the maintenance innovation investment	ROI, payback period

Measurement Scale

All variables in this study are measured using ratio scales because the variables are represented in numerical form and possess absolute values, enabling mathematical calculations and objective comparison. Ratio scales are commonly used in quantitative research because they provide the highest level of measurement accuracy and flexibility for statistical interpretation (Sekaran & Bougie, 2016).

Downtime duration is measured in units of time (hours and minutes), operational costs are measured in Indonesian Rupiah (IDR), and return on investment is expressed as a percentage value. The use of ratio scales allows for precise comparison between operational conditions before and after the implementation of the innovation.

Data Analysis

Data analysis in this study was conducted using descriptive comparative analysis and investment feasibility analysis. The analytical process consists of several stages:

1. Before–After Comparative Analysis

This analysis was used to compare operational performance before and after the implementation of the CLEAR-FCRS innovation. The comparison focused on failure frequency, downtime duration, and operational cost conditions. This stage aims to identify operational improvements resulting from the implementation of preventive maintenance innovation.

2. Cost-Benefit Analysis

Cost-benefit analysis was conducted to compare the total investment cost with the operational savings generated by the innovation. This analysis helps determine whether the innovation provides positive financial benefits for the company (Southgate et al., 2024).

3. Return on Investment (ROI) Analysis

ROI analysis was used to measure the effectiveness of the investment by calculating the percentage of financial return generated from the innovation implementation. The ROI formula used in this study is as follows:

$$ROI = \frac{Annual\ Savings - Investment\ Cost}{Investment\ Cost} \times 100\%$$

4. Payback Period Analysis

The payback period analysis was conducted to determine the amount of time required for the investment cost to be recovered through operational savings generated by the innovation. The formula used is:

$$Payback\ Period = \frac{Investment\ Cost}{Annual\ Savings}$$

5. Interpretation of Results

The final stage involves interpreting operational and financial findings to evaluate the effectiveness of reliability-based maintenance implementation in improving operational cost efficiency and investment feasibility.

Strategies to Ensure Methodological Rigor

Several strategies were implemented to ensure the validity, reliability, and consistency of the research findings. First, the study utilized official operational and financial records obtained directly from internal company documentation to ensure data credibility.

Second, data triangulation was applied by comparing information from multiple sources, including operational reports, maintenance records, and financial documents. This triangulation process helps reduce potential bias and improve data consistency.

Third, cross-checking procedures were conducted to validate operational performance data and financial calculations. Data verification was performed systematically to ensure the accuracy of downtime measurements, failure records, operational cost calculations, and investment analysis.

Furthermore, analytical consistency was maintained throughout the study by applying the same comparative framework for all operational indicators before and after the implementation of the innovation. These strategies align with quantitative research principles emphasizing reliability, objectivity, and methodological rigor (Creswell, 2014).

Ethical Considerations

This study uses secondary operational and financial data obtained from internal company documentation without involving individual respondents or personal data collection. Therefore, the study does not involve direct human participation.

All data used in this research are presented in aggregated form to maintain company confidentiality and protect sensitive operational information. The use of data was conducted solely for academic and research purposes and complied with research ethics principles regarding confidentiality, transparency, and responsible data usage (Resnik, 2020).

3. Result and Discussion

Results

Descriptive Results

The results of this study are presented based on operational and financial data obtained from the Fluid Collection and Reinjection System (FCRS) at the Lumut Balai Geothermal Power Plant before and after the implementation of preventive maintenance innovation through the CLEAR-FCRS system.

Before the implementation of the innovation, the FCRS frequently experienced operational disturbances caused by recurring system failures. These failures contributed to relatively high downtime duration, operational instability, and increased maintenance activities. Operational handling time for each disruption ranged from approximately 2 to 3 hours per incident, indicating that the existing maintenance approach was still highly reactive and corrective in nature.

After the implementation of the CLEAR-FCRS preventive maintenance innovation, operational performance improved significantly. The downtime duration decreased substantially to approximately 15–30 minutes per incident. In addition, the frequency of operational disturbances declined, indicating an improvement in system reliability and operational stability.

The implementation of the innovation also contributed to better operational efficiency by reducing maintenance response time and minimizing production interruptions. These improvements indicate that reliability-based maintenance implementation can effectively support operational continuity within geothermal power plant systems.

From a financial perspective, the implementation of the innovation required an initial investment of IDR 44,000,000. Despite the relatively small investment value, the innovation generated substantial annual operational savings amounting to IDR 177,600,000. The reduction in operational disruptions and maintenance activities significantly contributed to lowering operational expenditures.

The comparison of operational and financial conditions before and after the implementation of the innovation is presented in Table 2.

Table 2. Comparison of Operational and Financial Performance Before and After Implementation

Indicator	Before Implementation	After Implementation
Downtime Duration	2–3 hours	15–30 minutes
Failure Frequency	High	Decreased
Operational Costs	High	More efficient
Investment	–	IDR 44,000,000
Cost Savings	–	IDR 177,600,000/year

Source: Processed operational data (2025)

Figure 1 presents a comparison of downtime duration before and after the implementation of the CLEAR-FCRS innovation. The figure illustrates a substantial reduction in downtime duration following the implementation of the preventive maintenance strategy.

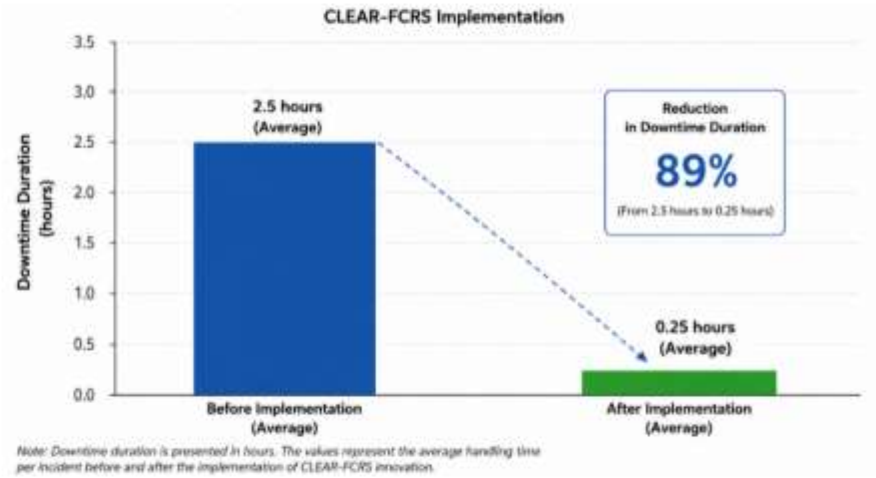

Figure 1. Comparison of Downtime Duration Before and After CLEAR-FCRS Implementation
Source: Processed by authors (2025)

Inferential Results

To evaluate the economic feasibility of the implemented innovation, investment feasibility analysis was conducted using return on investment (ROI) and payback period indicators.

The analysis results indicate that the implemented preventive maintenance innovation generated a return on investment (ROI) value of 403.64%. This result demonstrates that the innovation produced financial benefits significantly higher than the initial investment cost.

The ROI value indicates that the implementation of the CLEAR-FCRS innovation is financially advantageous and capable of generating substantial operational savings for the company. These findings suggest that maintenance innovation should not only be viewed from a technical perspective but also from an economic and managerial perspective.

The ROI calculation used in this study is presented as follows:

$$ROI = \frac{Annual\ Savings - Investment\ Cost}{Investment\ Cost} \times 100\%$$

$$ROI = \frac{177{,}600{,}000 - 44{,}000{,}000}{44{,}000{,}000} \times 100\%$$

$$ROI = 403.64\%$$

In addition to ROI analysis, payback period analysis was conducted to determine the amount of time required to recover the investment cost through operational savings generated by the innovation.

The payback period formula used is as follows:

$$Payback\ Period = \frac{Investment\ Cost}{Annual\ Savings}$$

$$Payback\ Period = \frac{44{,}000{,}000}{177{,}600{,}000}$$

$$Payback\ Period \approx 0.25\ years$$

The calculation results indicate that the investment can be recovered within approximately three months. This finding demonstrates that the innovation has a relatively rapid investment recovery period and is financially feasible for implementation.

The complete investment feasibility analysis results are presented in Table 3.

Table 3. Investment Feasibility Analysis

Parameter	Value
Total Investment	IDR 44,000,000
Annual Savings	IDR 177,600,000
ROI	403.64%
Payback Period	± 3 months

Source: Processed financial analysis results (2025)

Figure 2 illustrates the investment feasibility indicators of the implemented innovation, including ROI and payback period. The results demonstrate that the innovation is financially feasible and capable of generating rapid investment recovery.

Figure 2. Investment Feasibility Indicators of CLEAR-FCRS Innovation

Source: Processed by authors (2025)

Supplementary Analysis

As an additional analysis, operational performance trends before and after the implementation of the innovation were examined to evaluate the consistency of system improvements. The findings consistently demonstrate that the implementation of preventive maintenance innovation contributed to lower downtime duration and reduced operational disturbance frequency.

The reduction in downtime duration also indicates improved maintenance responsiveness and better operational coordination within the maintenance management system. Furthermore, recurring annual operational savings suggest that the implemented innovation provides sustainable financial benefits for long-term operational efficiency.

Overall, the findings confirm that the integration of reliability-based maintenance and investment feasibility analysis can effectively improve both operational reliability and financial performance within geothermal power plant operations.

Discussion

Interpretation of Main Findings

The findings of this study demonstrate that the implementation of preventive maintenance innovation through the reliability-based maintenance (RBM) approach significantly improves operational performance and operational cost efficiency in the Fluid Collection and Reinjection System (FCRS) at the Lumut Balai Geothermal Power Plant. The most substantial operational improvement is reflected in the reduction of downtime duration from approximately 2–3 hours to only 15–30 minutes after the implementation of the CLEAR-FCRS innovation.

This reduction indicates that preventive maintenance strategies are more effective than conventional corrective maintenance approaches in minimizing operational disruptions. The findings suggest that maintenance activities based on reliability considerations enable faster response times, improved operational coordination, and more stable system performance. These results are consistent with the concept proposed by Mobley (2002), which emphasizes that predictive and reliability-oriented maintenance can significantly reduce unexpected equipment failures and improve operational continuity.

In addition to operational improvements, the study also demonstrates substantial financial benefits resulting from the implementation of the innovation. The operational savings generated annually reached IDR 177,600,000, while the initial investment required was only IDR 44,000,000. These findings indicate that maintenance innovation not only contributes to technical performance but also provides measurable economic value for the organization.

The investment feasibility analysis further strengthens these findings. The calculated ROI value of 403.64% demonstrates that the innovation generated financial returns substantially higher than the investment cost. Moreover, the payback period of approximately three months indicates that the implemented innovation has rapid investment recovery capability and low financial risk.

These findings support previous studies emphasizing the importance of integrating reliability, operational performance, and cost efficiency within maintenance management systems. According to da Silva et al. (2023), reliability-based maintenance enables organizations to optimize maintenance planning and reduce operational risks through proactive maintenance strategies. Similarly, Menéndez et al. (2022) explained that integrated asset management systems contribute significantly to organizational value creation and operational efficiency.

Similar findings have also been reported in international studies on maintenance optimization in energy industries. Liang et al. (2024) emphasized that predictive and reliability-oriented maintenance approaches contribute significantly to operational stability and cost reduction in thermal systems. Likewise, Ujević Andrijić and Rimac (2025) demonstrated that data-driven maintenance strategies improve early fault detection and support sustainable operational performance. These studies support the argument that integrating reliability analysis with operational decision-making can enhance both technical and financial outcomes.

Furthermore, the findings indicate that relatively simple technical innovations can produce significant operational and financial impacts when implemented appropriately within the organizational context. This suggests that maintenance innovation does not always require large-scale technological transformation, but rather effective identification of operational problems and efficient preventive maintenance solutions.

However, the effectiveness of reliability-based maintenance implementation is highly dependent on operational conditions, maintenance management capability, and organizational readiness. Therefore, maintenance innovation should be implemented systematically and supported by adequate operational monitoring systems to ensure sustainable performance improvement.

Theoretical Implications

This study contributes to the development of operational management, maintenance management, and asset management literature by emphasizing the integration between reliability-based maintenance implementation and investment feasibility analysis.

From a theoretical perspective, this study reinforces the argument that maintenance management should not be viewed solely as a technical operational activity but also as a strategic managerial function that directly influences organizational financial performance. The findings support the asset management perspective proposed in ISO 55000, which emphasizes that asset-related decisions should integrate operational reliability, risk management, and economic value creation (Menéndez et al., 2022).

This study also extends previous literature by demonstrating that operational indicators and financial indicators should be analyzed simultaneously when evaluating maintenance effectiveness. Most previous studies primarily focused on technical reliability aspects such as system performance, failure frequency, and equipment availability. In contrast, this study integrates technical operational indicators with economic feasibility indicators such as ROI and payback period, thereby providing a more comprehensive framework for maintenance decision-making.

Furthermore, the findings strengthen the theoretical relationship between reliability improvement and operational cost efficiency. Improved reliability reduces downtime duration and operational disturbances, which subsequently lowers operational costs and increases organizational efficiency. Therefore, reliability-based maintenance can be considered an important strategic approach for improving both operational sustainability and financial performance.

Practical Implications

From a practical standpoint, the findings indicate that preventive maintenance innovation can serve as an effective operational strategy for geothermal power plants and other energy industries with complex operational systems. The implementation of reliability-based maintenance contributes significantly to reducing operational disruptions, improving system reliability, and enhancing maintenance responsiveness.

The substantial reduction in downtime duration indicates that proactive maintenance strategies can improve operational continuity and production stability. This improvement is highly important within energy industries because operational disruptions may directly affect electricity production, operational safety, and organizational profitability.

In addition, the financial analysis demonstrates that relatively low-cost maintenance innovation can generate substantial operational savings within a short recovery period. This finding suggests that operational managers and decision-makers should consider maintenance innovation as a strategic investment rather than merely an operational expense.

The findings also imply that organizations should strengthen maintenance planning, operational monitoring, and preventive maintenance implementation to achieve sustainable operational efficiency. Integrating operational reliability analysis with investment feasibility evaluation may support more objective and data-driven managerial decision-making.

Policy Implications

From a policy perspective, this study highlights the importance of promoting reliability-based maintenance implementation within the energy sector. Organizations and industry stakeholders should encourage preventive maintenance culture and systematic asset management practices to improve operational sustainability and reduce operational risks.

The findings also indicate that maintenance innovation policies should not only prioritize technical reliability but also consider financial feasibility and long-term economic benefits. Therefore, maintenance investment policies should integrate operational performance evaluation with economic analysis to ensure optimal resource allocation.

Furthermore, the results support the adoption of integrated asset management systems aligned with ISO 55000 principles to improve operational efficiency and organizational competitiveness within the energy industry.

Limitations and Directions for Future Research

Despite its contributions, this study has several limitations that should be acknowledged. First, the study adopts a case study approach focusing on a single operational system within one geothermal power plant. Therefore, the findings may have limited generalizability to other operational systems or industrial sectors with different operational characteristics.

Second, the study primarily utilizes operational and financial data within a limited observation period before and after the implementation of the innovation. Consequently, the study may not fully capture the long-term sustainability and performance impact of the implemented maintenance strategy.

Third, the analysis mainly focuses on operational and financial indicators without incorporating organizational, behavioral, or human resource factors that may also influence maintenance performance and operational effectiveness.

Based on these limitations, future research is recommended to expand the scope of analysis by involving multiple operational systems, comparative studies across different power plants, or longitudinal research designs. Future studies may also integrate qualitative approaches to explore organizational readiness, maintenance culture, and managerial factors influencing the successful implementation of reliability-based maintenance strategies.

In addition, future research may incorporate advanced analytical approaches such as predictive analytics, machine learning, or risk-based maintenance modeling to provide deeper insights into operational reliability and maintenance optimization within energy industries.

4. Conculsion

This study aims to analyze the implementation of preventive maintenance innovation within a reliability-based maintenance framework and evaluate its investment feasibility in improving operational cost efficiency in the Fluid Collection and Reinjection System (FCRS) at the Lumut Balai Geothermal Power Plant.

The findings indicate that the implementation of the CLEAR-FCRS innovation significantly improves operational performance, particularly through the reduction of downtime duration and failure frequency. The implementation of preventive maintenance strategies based on reliability principles enables the operational system to function more effectively and efficiently compared to conventional corrective maintenance approaches.

From an operational perspective, the reduction in downtime duration from approximately 2–3 hours to 15–30 minutes demonstrates that the implemented innovation successfully improves system reliability and operational stability. These improvements contribute directly to reducing operational disruptions and supporting sustainable production continuity within geothermal power plant operations.

From a financial perspective, the implemented innovation is proven to be highly feasible and economically beneficial. An investment of IDR 44,000,000 generated annual operational savings of IDR 177,600,000, resulting in a return on investment (ROI) value of 403.64% and a payback period of approximately three months. These findings indicate that maintenance innovation can provide significant financial returns while minimizing operational risks.

Overall, this study confirms that the integration of reliability-based maintenance and investment feasibility analysis can serve as an effective strategy for improving operational reliability, operational cost efficiency, and organizational performance within energy industries. The study also demonstrates that maintenance activities should not only be viewed as technical operational functions but also as strategic managerial investments capable of generating long-term organizational value.

The findings provide important implications for operational managers, maintenance practitioners, and decision-makers in the energy sector, particularly in supporting data-driven maintenance planning and investment decision-making processes. Furthermore, the results strengthen the importance of integrating technical reliability analysis with financial evaluation in modern asset management practices.

Limitations and Future Research Directions

This study has several limitations that should be acknowledged. First, the research adopts a case study approach focusing on a single operational system within one geothermal power plant, which may limit the generalizability of the findings to other industrial contexts or operational environments.

Second, the study utilizes operational and financial data collected within a limited observation period before and after the implementation of the innovation. Therefore, the study may not fully capture the long-term sustainability and effectiveness of the implemented maintenance strategy.

Third, this study primarily focuses on operational and financial indicators without incorporating additional factors such as organizational culture, managerial capability, employee competence, or external environmental influences that may also affect maintenance performance and operational effectiveness.

Based on these limitations, future research is recommended to expand the scope of analysis by involving multiple operational systems or conducting comparative studies across different geothermal power plants and industrial sectors. Future studies may also utilize longitudinal research designs to evaluate the long-term impacts and sustainability of reliability-based maintenance implementation.

In addition, integrating quantitative and qualitative approaches is recommended to provide a more comprehensive understanding of the organizational, managerial, and technical factors influencing the successful implementation of maintenance innovation strategies. Future research may also incorporate advanced analytical techniques such as predictive maintenance modeling, machine learning approaches, and risk-based maintenance analysis to strengthen operational reliability and maintenance optimization in energy industries.

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