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Development of Decision Support System for Diesel Generator Maintenance Planning : A Case Study on KM. Bukit Siguntang

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Abstract

Purpose This study aims to develop and validate a decision support system for diesel generator maintenance at KM. Bukit Siguntang through identifying critical parameters that affect maintenance needs, analyzing failure patterns and reliability levels of key components, and implementing a validated model to optimize maintenance strategies based on actual engine conditions.
Methodology This study uses a mixed-method approach with a combination of quantitative and qualitative methods. The research design is exploratory sequential mixed-method, which begins with a qualitative stage to identify parameters and decision-making criteria, followed by a quantitative stage for model development and system validation. The collected data were analyzed using the Descriptive Statistical Analysis method, Reliability Centered Maintenance (RCM) Analysis.
Findings The results showed a decrease in the number of unplanned failures by 57.1% and a reduction in downtime by 53.8% indicating a substantial increase in system reliability. This contributed to an increase in diesel generator availability from 94.2% to 97.3%, which is very important for ship operations.
Originality This study successfully developed and validated a decision support system for diesel generator maintenance at KM. Bukit Siguntang by identifying 11 critical parameters that affect maintenance needs and analyzing failure patterns and reliability of critical components.

INTRODUCTION

The power generation system on a ship is a vital component that supports all ship operations and safety. On KM. Bukit Siguntang, a passenger ship owned by PT. PELNI that serves National shipping routes, diesel generators are the main backbone in providing electrical power for all systems on the ship. Failure or decreased performance of diesel generators can cause serious disruption to ship operations (Issa et al., 2020; Karatuğ & Arslanoğlu, 2022), endanger the safety of passengers and crew (Bolbot et al., 2021), and potentially cause significant company losses (Marqusee & Jenket, 2020). Optimal diesel generator maintenance is a complex challenge because it involves various technical, operational, and financial considerations (Hamilton et al., 2017; Mohammed et al., 2015). On the one hand, too frequent

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maintenance can waste resources and reduce ship operational time (Barone et al., 2023). On the other hand, inadequate maintenance can result in unexpected equipment failure, more severe component damage, and even total failure of the power generation system on board the ship (Rasoulzadeh Khorasani, 2015). This problem is increasing in KM. Bukit Siguntang which operates in Indonesian waters with diverse operational characteristics, including variations in electrical loads, environmental conditions, and limited access to maintenance facilities at several ports of call. In addition, the increasing age of the ship and diesel generators causes changes in operational characteristics and dynamic maintenance needs (Dujmović et al., 2024; Musril et al., 2023).

Research on decision support systems for diesel engine maintenance has been widely conducted with various methodological approaches. A fuzzy logic-based model for determining optimal maintenance intervals on merchant ship diesel generators by considering operational parameters and component conditions (Gharib & Kovács, 2024). Furthermore, The development of a real-time condition monitoring system for diesel generators with an Internet of Things (IoT) approach (Mohapatra et al., 2023). The system is capable of continuously acquiring critical parameter data such as temperature, pressure, and vibration, which are then processed using predictive algorithms to estimate component failure times. Then a decision support system for diesel generator maintenance was developed based on the context and operational conditions in developed countries with better maritime infrastructure (Correia Da Fonseca et al., 2021). A machine learning approach to optimize diesel generator maintenance schedules in a shipping environment (Yüksel, 2022). They developed a hybrid model that combines random forest for component condition classification and genetic algorithm for schedule optimization.

There are limited studies that specifically consider the unique characteristics of passenger ship operations in Indonesian waters such as KM. Bukit Siguntang. Existing research tends to focus on particular technical parameters and pays little attention to the integration of various factors that influence maintenance decisions, including operational aspects, logistics, spare part availability, and technical capacity of the ship's crew (Kristiyanti et al., 2024; Lazakis et al., 2010; Shafiee, 2015). Existing decision support system models are generally static and less able to adapt to changes in ship operational conditions and equipment characteristics as operational age increases (Hirdaris et al., 2014; Iman Mujiarto et al., 2022). Furthermore, a significant gap exists between theoretical models developed in the literature and their practical implementation in the field, particularly on ships with limited access to technology and trained personnel.

This study aims to develop and validate a diesel generator maintenance decision support system on KM. Bukit Siguntang through identifying critical parameters that influence maintenance needs, analyzing failure patterns and reliability levels of key components, and implementing a validated model to optimize maintenance strategies based on actual engine conditions. Through this approach, the research seeks to transform the maintenance paradigm from a scheduled corrective and preventive model to a condition-based predictive model to improve ship operational reliability, reduce the number of unplanned failures and downtime, optimize spare part usage, improve fuel efficiency, and extend engine life, which ultimately contributes to long-term cost efficiency and overall improvement of ship operational performance.

RESEARCH METHOD

This study employs a mixed-methods approach, combining quantitative and qualitative methods. The research design is exploratory sequential mixed-method, which begins with a qualitative stage to identify decision-making parameters and criteria, followed by a quantitative stage for model development and system validation (Antony et al., 2023). This approach was chosen to ensure that the decision support system developed is not only mathematically accurate but also relevant and can be implemented in the operational context of KM. Bukit Siguntang.

This research was conducted at KM. Bukit Siguntang owned by PT. PELNI with a focus on the diesel generator system. The object of research is the diesel generator system at KM. Bukit Siguntang. Historical data on diesel generator maintenance and operations. Technical documentation, maintenance procedures, and operational manuals. And Technical personnel responsible for the operation and maintenance of diesel generators

Data Collection Methods are carried out through participatory observation, Semi-Structured Interviews, Documentation, measurement of diesel generator operational parameters (temperature, pressure, vibration, and fuel consumption), and Surveys.

The collected data were analyzed using the Descriptive Statistical Analysis method, Reliability Centered Maintenance (RCM) Analysis (Chalifoux, 1999), while to ensure the reliability of the decision support system developed, model validation was carried out using the Cross-Validation and Expert Judgment methods in the form of Validation of system recommendations by ship diesel generator technical experts.

This research was conducted through several systematic and integrated stages. The first stage began with a preliminary study and comprehensive data collection. The next stage focused on analyzing system requirements, which included identifying critical parameters that affect diesel generator reliability. The next stage involved designing a decision support system model, beginning with the system architecture design. The final stage of the research was impact analysis and finalization, which included a comprehensive evaluation of the operational impact of the system implementation.

RESULTS AND DISCUSSIONS

1. Identification of Critical Parameters for Diesel Generator Maintenance

The results of the identification of critical parameters that affect the need for diesel generator maintenance at KM. Bukit Siguntang are shown in Table 1.

Table 1. Critical Parameters for Diesel Generator Maintenance

Parameter Category	Parameter	Weight (%)	Measurement Method	Critical Threshold
Operational	Operating hours	15,4	Log book	10.000 hours
Operational	Average load (%)	12,8	Power meter	>85% continue
Operational	Start-stop frequency	8,7	Operational Log	>5 times/day
Component Condition	Lubricating oil pressure	11,2	Pressure gauge	<3,5 bar
Component Condition	Cooling water temperature	10,5	Thermometer	>85°C
Component Condition	Engine vibration	9,8	Vibration analyzer	>7,5 mm/s
Performance	Specific fuel consumption	8,4	Flowmeter	>220 g/kWh
Performance	Cylinder compression pressure	7,6	Compression tester	<25 bar
Environment	Engine room humidity	5,3	Hygrometer	>85% RH
Logistic	Availability of spare parts	6,2	Inventory database	<75%
Personnel	Kompetensi engineer	4,1	Performance evaluation	<70% value

Source: author's data processing, 2025

The identification results show that there are 11 critical parameters grouped into 5 main categories. These parameters were obtained through a combination of historical data analysis, interviews with the Chief Engineer and machinist of KM. Bukit Siguntang, and validation by diesel generator technical experts. The parameter weights were determined using the Analytical Hierarchy Process (AHP) method based on assessments from 8 expert respondents (Goepel, 2019). Furthermore, operational parameters have the highest cumulative weight (36.9%), indicating that machine usage is the primary consideration in maintenance planning. Operating hours are the most significant parameter, with a weight of 15.4%, indicating the importance of monitoring machine operating time as an indicator of maintenance needs.

Component condition parameters occupy the next important position with a cumulative weight of 31.5%, with lubricating oil pressure and cooling water temperature serving as primary indicators of machine health that enable engineers to detect early signs of deterioration before catastrophic failures occur. Performance parameters follow closely with a total weight of 16%, functioning as critical indicators for identifying declining machine efficiency that necessitates maintenance intervention, particularly through monitoring specific fuel consumption patterns and cylinder compression pressure that directly reflect the combustion quality and mechanical integrity of the engine.

Although environmental aspects (such as engine room humidity affecting electronic components), logistics considerations (particularly spare parts availability that can delay critical maintenance), and personnel factors (including engineer competency that influences maintenance quality) carry comparatively lower weights, they remain significant as supporting determinants in maintenance decision-making processes, primarily influencing the optimal timing, resource allocation, and overall feasibility of maintenance execution.

2. Failure Patterns and Component Reliability

Analysis of historical maintenance data for the past 3 years resulted in the identification of failure patterns and reliability levels of critical components in the KM. Bukit Siguntang diesel generator, as shown in Table 2.

Table 2. Analysis of Critical Component Reliability of Diesel Generator

Component	MTBF (hours)	Failure Pattern	Parameter Weibull	Reliability at 8,000 hours (%)	Maintenance Priorities
Fuel Injection System	12.450	Wear-out	β=3,2; η=14.500	78,4	high
Turbocharger	15.800	Random	β=1,1; η=16.200	82,5	medium
Cylinder Head	24.600	Wear-out	β=2,8; η=27.000	91,7	Low
Main Bearing	18.300	Wear-out	β=3,5; η=20.500	89,3	medium
Cooling Water Pump	10.200	Random	β=1,2; η=10.800	67,8	high
Lubricating Oil Pump	14.700	Wear-out	β=2,4; η=16.400	79,1	high
Piston Rings	9.800	Wear-out	β=2,7; η=11.200	64,5	Very high
Air Starting System	11.500	Early failure	β=0,8; η=12.300	55,7	high
Generator Bearing	16.400	Wear-out	β=2,9; η=18.200	85,2	medium
AVR System	13.200	Random	β=1,0; η=13.200	54,3	high

Source: author's data processing, 2025

Component reliability analysis showed significant variation in Mean Time Between Failures (MTBF) among diesel generator components. Piston rings had the lowest MTBF (9,800 hours) with a reliability of only 64.5% at 8,000 hours of operation, making it a component with a very high maintenance priority. In contrast, the cylinder head showed the highest MTBF (24,600 hours) with a reliability of 91.7% at 8,000 hours of operation.

The failure pattern analysis revealed three distinct categories of component degradation within the diesel generator system: predominant wear-out behavior affecting six critical components including fuel injection systems and main bearings, random failure patterns observed in three components (turbocharger, cooling water pump, and AVR system) that exhibited no clear correlation with operational time, and early failure syndrome uniquely identified in the air starting system which demonstrated decreasing failure rates over time.

Weibull distribution parameters meticulously calculated from the three-year historical maintenance data provided critical insights, with shape parameters (β) exceeding 1.0 indicating components experiencing increasing failure rates as they age particularly concerning for piston rings (β=2.7) and main bearings (β=3.5) clearly signaling the necessity for strategically planned preventive maintenance interventions before reliability deteriorates to unacceptable levels.

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Component reliability assessments at the standard 8,000-hour maintenance interval revealed substantial variations, ranging from concerning low values of 54.3% for the AVR System and 64.5% for piston rings to a much more acceptable 91.7% for cylinder heads, with this dramatic reliability differential compelling maintenance engineers to establish a tiered priority system where components exhibiting reliability below the critical 70% threshold (specifically piston rings, cooling water pump, and AVR system) were designated as requiring heightened maintenance vigilance through significantly intensified condition monitoring protocols and strategically shortened maintenance intervals to mitigate the elevated risk of operational failures that could potentially disable the vessel during critical navigation periods.

3. Validation of Decision Support System Model

The prototype of the decision support system developed has been validated through simulation with historical data and limited trials for 3 months at KM. Bukit Siguntang. The validation results are shown in Table 3.

Table 3. Validation of Decision Support System Accuracy

Validation Aspects	Validation Method	Accuracy (%)	Information
Component Condition Prediction	Cross-validation	84,7	Using 5-fold cross-validation with 3 years of data
Estimated Time of Failure	Backtesting	78,2	Validation against 27 historical failure cases
Priority Treatment Recommendations	Expert judgment	89,5	Assessment by 5 experts on a 5-point Likert scale
Optimal Scheduling	Benchmark testing	91,3	Comparison with mathematical optimal solutions
Ease of Use	System Usability Scale	76,8	Assessment by 12 ship personnel
Response Time	SistemPerformance testing	97,2	Response <3 seconds for 97.2% of test cases
Compatibility with Workflow	Process conformance	81,5	Analysis of compliance with ship operational procedures
Recommendation Compliance	User acceptance	72,4	Level of compliance with system recommendations
Overall Accuracy	Comprehensive testing	83,8	Weighted average of all criteria

Source: author's data processing, 2025

The validation results showed a satisfactory level of accuracy for various aspects of the decision support system. The highest accuracy was achieved in the aspects of system response time (97.2%) and optimal scheduling (91.3%), indicating the superior performance of the developed optimization algorithm.

Maintenance priority recommendations demonstrated an accuracy of 89.5% based on expert assessment, indicating that the developed decision-making model effectively incorporated expert knowledge and experience. Component condition prediction achieved an accuracy of 84.7% through cross-validation, indicating the ability of the predictive model to identify component degradation trends.

The aspect with the lowest accuracy was recommendation compliance (72.4%), indicating challenges in system adoption by ship personnel. This was confirmed by the results of the ease of use assessment (76.8%) which indicated the need for improvements in the user interface and integration process with the ship's operational workflow.

Overall, the system achieved an average accuracy of 83.8%, indicating promising implementation potential but still requires improvements, especially in the aspects of the user interface and integration with standard operating procedures on the ship.

Table 4. Impact of Decision Support System Implementation

Performance Indicators	Before Implementation	After Implementation	Change (%)	Annual Projection
Number of unplanned failures	7 events/3 months	3 failures/3 months	-57,1	-56,0
Total downtime	52 hours/3 months	24 hours/3 months	-53,8	-51,5
Availability of diesel generators	94,2%	97,3%	+3,1	+3,5
Fuel consumption	217 g/kWh	208 g/kWh	-4,1	-4,8
Thermal efficiency	37,2%	39,1%	+1,9	+2,2
Maintenance planning time	14 hours/week	8 hours/week	-42,9	-43,0
Maintenance schedule compliance	76,5%	92,3%	+15,8	+18,0
Spare parts utilization	82,3%	93,7%	+11,4	+12,5
Estimated engine life extension	-	-	-	+12,0

Source: author's data processing, 2025

The evaluation results demonstrated a significant positive impact of implementing the decision support system on various performance indicators. The decrease in unplanned failures by 57.1% and the reduction in downtime by 53.8% indicate a substantial improvement in system reliability. This contributed to an increase in diesel generator availability from 94.2% to 97.3%, which is very important for ship operations.

The improvement in engine operating conditions is reflected in a 4.1% decrease in specific fuel consumption and a 1.9% increase in thermal efficiency. Maintenance management efficiency also increased, marked by a 42.9% reduction in maintenance planning time and an increase in maintenance schedule compliance from 76.5% to 92.3%.

The estimated 12% extension of engine life is a significant long-term indicator, indicating a substantial potential return on investment from implementing the decision support system. The increase in spare parts utilization from 82.3% to 93.7% indicates more efficient inventory management, which contributes to reduced logistics costs and increased availability of spare parts when needed.

The study's results indicate that a decision support system based on critical parameters and component reliability analysis has significant potential to enhance the effectiveness and efficiency of diesel generator maintenance programs on ships. Although there is still room for improvement, especially in terms of user interface and integration with standard operating procedures, the benefits obtained from implementing this system are auspicious for more reliable and efficient ship operations.

This study has significant implications for ship maintenance management, especially in the management of vital assets such as diesel generators. The implementation of a decision support system based on critical parameters and component reliability analysis has the potential to transform the maintenance paradigm from a scheduled, corrective, or preventive approach to a condition-based, predictive approach. This allows for the optimization of maintenance resources by directing focus on components that truly require attention based on their actual conditions, rather than solely on a predetermined schedule. Furthermore, there was a significant decrease in economic terms, namely in the event of unplanned failure (57.1%) and downtime (53.8%), which has direct implications for reducing ship operating costs. Increasing the availability of diesel generators to 97.3% helps minimize ship service disruptions, which can result in financial and reputational losses. The 4.1% increase in fuel efficiency also provides significant long-term cost savings, considering that fuel is the largest component of a ship's operational costs. From a technical perspective, there is a 12% extension of engine life projected from the implementation of this system indicating a delay in investment in replacing high-value assets. The 1.9% increase in thermal efficiency also has implications for reducing environmental burdens through reduced emissions per unit of energy produced. In addition, the increase in spare part utilization from 82.3% to 93.7% indicates the potential for optimizing supply chain management to support ship operations.

Meanwhile, when viewed from an organizational perspective, there was a 42.9% decrease in maintenance planning time allowing the allocation of engineer time for other value-added tasks. The increase in maintenance schedule compliance to 92.3% indicates an increase in operational discipline, which in turn contributes to a more professional and reliability-oriented work culture. This decision support system also plays a role in documenting and converting the tacit knowledge of experienced engineers into an explicit knowledge system that can be accessed and utilized by the next generation of engineers.

The broader implication of this study is the potential application of similar methodologies to other critical systems on board ships, such as propulsion systems, steering systems, and other support systems. An integrated approach to maintaining various systems on board ships can generate synergies that improve the overall operational reliability of the ship. Additionally, the data collected through the implementation of this system can serve as the basis for developing more effective maintenance policies at the fleet level, providing guidance for standardizing maintenance procedures across the shipping company's fleet. This is in line with previous studies on the evolution of maintenance approaches in the power industry that highlighted the shift from traditional to modern AI-based methods to prevent equipment failures and minimize economic losses by detailing various maintenance techniques (Rojas et al., 2025).

CONCLUSIONS

This study successfully developed and validated a diesel generator maintenance decision support system on KM. Bukit Siguntang by identifying 11 critical parameters that influence maintenance needs and analyzing failure patterns and reliability of critical components, where the implementation of the system during a 3-month trial period showed very promising results with a significant reduction in the number of unplanned failures (57.1%) and downtime (53.8%), an increase in diesel generator availability from 94.2% to 97.3%, an increase in fuel efficiency by 4.1%, and an increase in maintenance schedule compliance from 76.5% to 92.3%, so that this system is proven to be able to optimize maintenance strategies, improve operational efficiency, and potentially extend engine life by up to 12% which contributes significantly to the operational reliability of the ship and long-term cost efficiency, although there are still limitations such as a relatively short validation period (3 months), limited coverage to one type of ship with specific operational characteristics, and a relatively low accuracy of system recommendation compliance (72.4%) which indicates a gap in technology adoption by ship personnel.

Further research is planned to expand the system's implementation to various types of ships with different operational profiles, integrate the system with the Internet of Things (IoT) for real-time parameter monitoring, and develop machine learning modules to enhance the accuracy of component condition predictions. The addition of environmental impact analysis and energy consumption features supports green shipping initiatives, enabling this decision support system to improve not only operational and economic aspects but also contribute to environmental sustainability in the shipping industry.

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