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Optimization of Safety and Reliability of Electrical Systems of Tourist Ships in Labuan Bajo through FMEA

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Abstract

This study aims to optimize the safety and reliability of the electrical systems on tourist ships in Labuan Bajo through Failure Mode and Effects Analysis (FMEA). The analysis identified key electrical components, including the battery and energy storage system, electric generator, charging system, and cables and connectors, as having high Risk Priority Numbers (RPNs). These components, if they fail, could significantly impact ship operations and passenger safety. The study emphasizes the importance of regular maintenance and early detection to prevent system failures and highlights critical areas, such as backup energy storage and power distribution, that require more attention. Despite having lower RPNs, components like the ship's lighting system and ventilation system still require maintenance to ensure smooth operation and passenger comfort. Additionally, the research revealed that proper load management of the electric generator is essential for extending its lifespan. It is recommended to limit the generator load to 60-86% of its maximum capacity to reduce the risk of overheating and enhance operational efficiency. By implementing these preventive measures, ship operators can enhance the reliability and safety of the electrical systems, leading to a safer and more comfortable experience for tourists while minimizing disruptions to operations. Overall, the findings show that FMEA is a valuable tool for optimizing the electrical systems of tourist ships, ensuring they operate with maximum efficiency and minimum risk.

1. Introduction

Labuan Bajo, as one of the leading tourist destinations in Indonesia, has experienced rapid development in the tourism sector, especially with the presence of tourist ships as the main means to explore the natural beauty of the sea and the surrounding small islands [1-5]. Tourist ships play a vital role in supporting tourism activities, from transportation, marine exploration, to the provision of floating accommodation facilities. However, the sustainability of tourist ship operations in this area is highly dependent on the safety and reliability of its systems, including the electrical system which is a crucial component in supporting the overall function of the ship. The electrical system plays a role in operating various important equipment, such as navigation, communication, lighting, and comfort facilities for tourists [6-12].

Nevertheless, the risk of failure in the electrical system of tourist ships remains a major challenge [13], [14], [15]. This failure can be caused by various factors, such as suboptimal design, inadequate maintenance, exposure to corrosive marine environments, and non-compliance with safety standards. The impact can lead to operational disruptions, accidents, or even threats to the safety of passengers and crew. Therefore, a systematic approach is needed to identify and address potential failures in the electrical system so that tourist ship operations can run safely and reliably [16], [17], [18].

Failure Mode and Effects Analysis (FMEA) is one of the effective risk analysis methods to identify potential failures, analyze their impacts, and determine appropriate mitigation steps [19], [20], [21], [22]. By using FMEA, each component in the electrical system can be evaluated in detail to identify possible failure modes, analyze their causes, and prioritize risks that require immediate action [23], [24], [25]. The application of this method to tourist ships in Labuan Bajo is expected to provide a significant contribution to improving the reliability and safety of the electrical system. In addition, optimizing the electrical system not only has an impact on operational safety, but also supports the image of Labuan Bajo tourism as a world-class tourist destination that prioritizes safety and comfort aspects [26], [27], [28].

Labuan Bajo, as one of the main maritime tourism destinations in Indonesia, faces unique challenges that affect the safety and reliability of the electrical systems of tourist vessels. The harsh marine environment with high humidity and significant salinity levels can accelerate corrosion of the vessel's electrical components, increasing the risk of system failure, short circuits, or even fires. In addition, the high volume of tourists causes tourist vessels to operate at high intensity almost all year round, increasing the electrical load due to the use of equipment such as air conditioning, navigation systems, communications, and lighting. Many tourist vessels in Labuan Bajo are also traditional wooden vessels that have been modified with modern electrical systems, often without regard to optimal safety standards, thus increasing the variation of operational risks. Coupled with limited time for maintenance and the lack of electrical experts in the area, the potential for electrical failure is even greater and can endanger the safety of passengers and crew. Therefore, this study is very significant in optimizing the safety and reliability of the electrical system of tourist vessels in Labuan Bajo through the FMEA approach, which can identify critical points in the system and provide more effective risk mitigation recommendations.

This study aims to apply the FMEA method in optimizing the safety and reliability of the electrical system on tourist ships in Labuan Bajo. With this approach, it is hoped that measurable solutions can be found to minimize the risk of failure, increase operational efficiency, and support more sustainable management of tourist ships. In the long term, the results of this study are also expected to be a reference for ship owners, tour operators, and related authorities in efforts to develop safety and reliability standards in the marine tourism transportation sector. This research is not only important in the context of operational safety but also has a long-term impact on the sustainability of the tourism industry in Labuan Bajo. By improving the reliability of the electrical system of tourist vessels, the risk of incidents such as fire or power failure in the middle of the voyage can be reduced, which ultimately increases tourist confidence and the reputation of the destination. Furthermore, the results of this study can be the basis for the development of stricter maritime safety standards, encouraging ship operators to adopt more efficient predictive maintenance systems [29]. By implementing FMEA-based mitigation strategies, ship operators can also reduce long-term maintenance costs, as early detection of potential failures allows prevention before greater damage occurs. Thus, this research contributes not only to operational safety, but also to the economic sustainability and efficiency of the maritime industry in Labuan Bajo.

2. Methods

This study uses a descriptive method with the Failure Mode and Effects Analysis (FMEA) approach to identify and optimize the safety and reliability of the electrical system on tourist ships in Labuan Bajo. The research begins with a literature study aimed at understanding relevant concepts and theories, including maritime safety standards, characteristics of ship electrical systems, and technical guidelines related to FMEA analysis. Furthermore, data collection is carried out through direct observation in the field, interviews with ship technicians, crew, and tour operators, and review of technical documents such as electrical diagrams, component specifications, and maintenance records. This data is used to identify potential failure modes in each component of the electrical system, such as control panels, batteries, inverters, or generators, which have the potential to cause operational disruptions or safety hazards. The activity was carried out on the Dara Rinca, which is one of the tourist ships in the Labuan Bajo area (Figure 1). The activity was carried out from January 2024-December 2024.

Figure 1. Tourist boat in Labuan Bajo

The selection of this vessel as the object of research was based on its characteristics that can represent most of the tourist vessels in Labuan Bajo. This vessel has a medium size, an electrical system that has been modified to meet intensive operational needs, and an age and technical condition like many other vessels operating in the region. Thus, the findings of this study are expected to be generalized and applied to a wider fleet of tourist vessels, helping vessel operators improve the safety and reliability of their electrical systems.

In terms of methodology, direct observation in this study was conducted with a focus on routine operations, monitoring failure incidents, and evaluating the performance of electrical equipment under various operational conditions. The interviews conducted were semi-structured, combining specific questions to identify common failure modes and their causes, as well as open-ended questions to gather broader insights from the ship's crew and technicians. The document review included analysis of maintenance records, incident reports, and technical specifications of the ship's electrical system.

In the context of this study, the safety and reliability of the electrical system are defined through several clear benchmarks. Operational reliability is assessed based on the system's ability to function without interruption within a certain operational period, as well as its ability to minimize downtime due to electrical failures. In addition, this study also considers safety standards that refer to international maritime safety codes, including regulations related to ship electrical systems. With this clearer definition, research can be more focused in optimizing risk mitigation strategies and providing more effective recommendations for the tourist boat industry in Labuan Bajo.

After identifying the failure mode, the study continues with an analysis of the causes and impacts of each failure found. This analysis is carried out by assessing the severity, frequency of occurrence, and detection capability of failure. These parameters are used to calculate the Risk Priority Number (RPN), which is the basis for determining which risk priorities require immediate action. Components with the highest RPN values are analyzed in more depth to design specific mitigation strategies. These strategies may include design improvements, material replacement, adjustments to operational procedures, or increased maintenance schedules.

As a next step, recommendations generated from the FMEA analysis are tested through simulation or limited implementation to evaluate their effectiveness in improving the reliability of the electrical system. The test data is then analyzed to validate that the proposed measures have significantly reduced the risk. This study concludes with the preparation of a report that summarizes the analysis results, key findings, and optimization recommendations that can be implemented by tour boat operators in Labuan Bajo. This comprehensive approach is expected to not only improve the safety and reliability of the electrical system but also support passenger safety and sustainable ship operations.

2.1. Risk Priority Number (RPN)

FMEA is used in this study to identify failure modes in the electrical system of tourist boats in Labuan Bajo and calculate the Risk Priority Number (RPN). RPN is obtained by multiplying three main factors: Severity (S) or the severity of the impact of the failure, Occurrence (O) or the frequency of failure, and Detection (D) or the possibility of failure being detected before causing serious problems. After the RPN value is calculated for each failure mode, this result is used to prioritize risks based on their severity. Failure modes with the highest RPN are considered the most critical threats to the safety and reliability of the system, so they are the focus of the mitigation strategy. Based on this RPN value, remedial measures can be designed, such as improving electrical insulation materials to reduce the impact of corrosion, implementing an automatic monitoring system to detect anomalies earlier, or improving periodic inspection procedures to reduce the frequency of failures. By using an RPN-based approach, ship operators can allocate resources more efficiently, address the most significant risks first, and implement more targeted mitigation measures. This not only improves the safety and reliability of the ship's electrical system but also helps reduce long-term maintenance costs and improves the sustainability of tourist boat operations in Labuan Bajo.

To determine the parameters of severity (S), occurrence (O), and detection (D) in calculating the Risk Priority Number (RPN), this study uses a combination of expert judgment, historical data, and industry standards. Historical failure data is obtained from ship maintenance records, incident reports, and interviews with ship technicians and operators. Meanwhile, industry standards such as the International Maritime Organization (IMO) and IEC 60092-507 (ship electrical standards) are used as references in assessing risk. To ensure consistency in subjective assessments by experts, the Delphi Method approach is applied, where several experts provide independent assessments, then alignment is carried out through discussion until consensus is reached.

The RPN calculation helps determine the priority in handling potential failures based on the risks generated. If the RPN value indicates a high risk, then improvements are needed such as installing additional sensors for early detection or replacing components that are more corrosion resistant as a mitigation priority. Thus, RPN functions as a systematic and quantitative tool to ensure that optimization steps are carried out in a focused and effective manner. The RPN calculation formula can be seen in Eq. 1 [19], [20], [21], [25], [28].

$$RPN = Severity\ (S) \times Occurrence\ (O) \times Detection\ (D) \tag{1}$$

In optimizing the safety and reliability of the electrical system of tourist boats in Labuan Bajo, the RPN calculation is used to:

1. Determining Risk Priority. By calculating the RPN value for each potential failure in the electrical system, researchers can identify components or failure modes that have the highest risk level. Components with high RPN are the main focus for optimization first.
2. Identifying Root Causes. Analysis of RPN results allows researchers to understand the root causes that cause high risks. For example, a high RPN value may be due to a high frequency of occurrences or low detection capabilities. This information helps in designing targeted solutions.
3. Designing Mitigation Strategies. Based on the RPN value, specific mitigation measures can be designed to reduce the risk parameters. For example: reducing severity by improving the system design to minimize the impact of failures, reducing the frequency of occurrences by improving component quality or implementing preventive maintenance, and increasing detection capabilities by introducing additional sensors or stricter inspection procedures.
4. Improving Efficiency and Safety. By reducing the RPN value for potential critical failures, the reliability and safety of the electrical system can be improved. This is crucial to ensure the safe and hassle-free operation of tourist boats, especially in destinations like Labuan Bajo that are renowned for their premium tourism ecosystem.
5. System Performance Evaluation. After the mitigation measures are implemented, a recalculation of the RPN is used to evaluate the effectiveness of the measures. A decrease in the RPN value indicates the success of optimization efforts.

2.2. Electrical System Optimization Recommendations

The research method for formulating optimization recommendations in this study is based on the results of the Failure Mode and Effects Analysis (FMEA) analysis that has been carried out on the electrical system of tourist ships in Labuan Bajo. The first step is the collection and analysis of data from the calculation of the Risk Priority Number (RPN), where the component with the highest RPN value is identified as an area that requires priority in optimization actions. Based on this data, an in-depth study was carried out on the main causes of failure, both in terms of system design, component quality, maintenance procedures, and the operational environment. This method involves a combination of qualitative and quantitative approaches to ensure that the solutions formulated are holistic and applicable.

Furthermore, to formulate appropriate recommendations, the benchmarking method is used by comparing best practices in managing electrical systems on similar tourist ships or other maritime industries. Researchers also conducted technical simulations to evaluate the effectiveness of potential solutions, such as the application of corrosion-resistant materials, strengthening the electrical protection system, or the use of sensor-based early detection technology. More structured preventive maintenance procedures are designed to reduce the frequency of failures, while routine inspection systems are updated to improve detection capabilities.

In addition, interviews with ship operators, technicians, and experts in the field of maritime electricity were conducted to obtain practical input that could enrich the recommendations. Training for ship crews was also integrated as part of the solution to improve competence in operating and maintaining the system. Validation of recommendations was carried out through simulations or limited trials on ships selected as case studies, with a focus on reducing RPN values and increasing system reliability. This method aims to produce optimization recommendations that are not only applicable, but also have a direct impact on the safety, reliability, and efficiency of the tourist ship's electrical system in Labuan Bajo. Interviews were conducted with those who actually work in this field, such as captains and technicians, to gain in-depth insights into system failures and the most effective solutions. Their feedback played a role in determining mitigation priorities. The success of the solution was measured not only by the reduction in RPN values, but also by other performance indicators. Reduction in the number of electrical system failures in a certain period, reduction in maintenance costs due to more effective and scheduled repairs, increase in ship operational time without electrical disruptions, and increase in compliance with international maritime safety standards were the highlights of this activity. With this approach, the study ensured that the proposed solution was not only technically feasible, but also effective in improving the safety and reliability of tourist ship operations in Labuan Bajo.

3. Results and Discussion

The application of Failure Mode and Effects Analysis (FMEA) on a tourist boat in Labuan Bajo provides in-depth insight into the potential risks in the ship's electrical system, which is a crucial element to support operations and safety. The results of the analysis show that FMEA activities are very important in identifying failure modes in electrical system components, such as generators, inverters, batteries, and distribution panels, which are susceptible to damage due to exposure to corrosive marine environments, continuous use, and lack of preventive maintenance. Through this analysis process, it was found that the Risk Priority Number (RPN) values for several main components were quite high, indicating the need for immediate mitigation actions to prevent operational disruptions and potential hazards to the safety of passengers and crew.

The application of FMEA to the electrical system of a tourist boat in Labuan Bajo also shows the importance of a systematic approach in managing risk. By evaluating the severity, frequency of occurrence, and detection capability, ship operators can identify risk priorities and design appropriate mitigation strategies, such as improving the design of the electrical system, selecting corrosion-resistant materials, and increasing routine maintenance schedules. In addition, this activity provides added value by increasing awareness of the importance of early detection through the installation of modern sensor systems or monitoring tools that can detect anomalies in electrical operations.

Tour ships in Labuan Bajo operate in areas with high safety standards, considering the high flow of domestic and international tourists who use this service. By implementing FMEA, ship operators can not only improve the reliability of the electrical system but also strengthen Labuan Bajo's image as a world-class tourist destination that is safe and of high quality. In addition, FMEA also provides technical guidance for ship crews in understanding potential failures and how to handle them, so as to reduce the risk of accidents due to electrical disturbances. The results of this discussion confirm that FMEA is not only an analytical tool, but also a strategic approach to improving the safety, reliability, and operational efficiency of tour ships in a sustainable manner.

Tourist ships in Labuan Bajo require an average of 5002 W of electrical energy, with an electrical energy requirement of 87.5 kWh/day. The use of this energy is used to meet the electrical load needs on the ship, such as lighting, air conditioning, engine equipment in the engine room, equipment in the cooking room, and navigation equipment. Complete data on the electrical load of this ship can be seen in Table 1. This electrical load is supplied from 2 generators with a size of 5000 VA which are used alternately.

Table 1. Electrical load requirements for tourist boats

Electrical Equipment	Power (W)	Number of Units	Duration of Uses (h)	Position	Energy (Wh)
Lighting					
- Outdoor lighting	23	16	12	Outdoor	4416
- Spotlight	30	2	12	Mast	720
- Spotlight	10	2	12	Deck	240
- Indoor Lighting	23	10	12	Room, cabin, bridge	3312

Pump	125	2	24	Machine room	6000
AC	750	3	24	Cabin	54000
Speaker	45	1	4	Bridge	180
Rice Cooker	1450	1	4	Kitchen	5800
Mixer	200	1	5	Kitchen	1000
refrigerator	94	1	24	Kitchen	2256
Radio	25	1	4	Bridge	100
AIS	10	1	4	Bridge	40

3.1. Failure Mode and Effects Analysis on Ship Electrical Systems

Failure Mode and Effects Analysis (FMEA) is a systematic method for identifying, analyzing, and evaluating potential failures in a system, including a ship's electrical system. On a ship, the electrical system plays a vital role in supporting key operations, such as navigation, communication, and passenger comfort. Therefore, FMEA analysis is a very important tool to ensure the reliability of the electrical system and prevent failures that can disrupt operations or even endanger the safety of passengers and crew.

The FMEA process on a ship's electrical system begins with the identification of each major component, such as generators, inverters, batteries, distribution panels, electric motors, and other supporting devices. Each component is analyzed to identify potential failure modes, for example, short circuits, overheating, decreased battery capacity, or damage to the control system. Once the failure mode is identified, an evaluation is carried out on the root cause of each failure, such as material damage, installation errors, lack of maintenance, or the influence of corrosive marine environments.

In FMEA, three main parameters are analyzed for each failure: severity, frequency of occurrence, and detection. Based on these parameters, the Risk Priority Number (RPN) value is calculated to determine which risk priorities require more attention. Components with high RPN values, for example, the main generator experiencing a short circuit due to lack of insulation, will be the main focus in mitigation recommendations.

Table 2. Failure Mode and Effects Analysis on Tourist Ships

Component	**Subcomponent**	**Failure Mode**	**Effect**
Electric Generator	Alternator, voltage regulator, cooling system	Turbine or generator component failure, overheating, automatic control system failure.	Loss of main power, disruption of ship operations, potential fire.
Battery and Energy Storage System	Main battery, backup battery, battery charger, charging regulator.	Battery capacity reduction, short circuit, overcharging, electrolyte leakage.	Inability to provide backup power, disruption of critical electrical systems during emergencies.
Electrical Distribution Panel	Main panel, distribution switch, busbar, fuse.	Short circuit, switch or fuse failure, loose cable connection.	Disruption of power supply to critical systems, fire, damage to electrical equipment.
Inverter and Current Converter System	Inverter, converter, electronic components of current controller.	Overheating, component failure, current regulation error, software failure.	Disturbance of DC to AC current conversion or vice versa, inability to power systems that require special current.
Ship Lighting System	Navigation lights, interior and exterior lights, automatic lighting systems.	Damage to light bulbs, interference with automatic lighting systems, problems with cables and switches.	Disturbance of lighting during nighttime or emergency situations, reduced visibility of the ship.
Electrical Protection System	Circuit breakers, ground fault protection, Residual Current Device (RCD).	Circuit breakers fail, failure to detect leakage current or more.	Potential fire or electric shock, further damage to electrical components, accidents to crew or passengers.
Steering and Electronic Control System	Steering motor, electronic control system, actuators.	Damage to steering motor, interference with automatic control systems, sensor failure.	Inability to control ship direction, difficulty in maneuvering, risk to safety.

Electrical Alarm and Monitoring System	Temperature sensors, current sensors, alarm devices.	Sensor failure or alarm that does not provide early warning.	Failure to detect potential electrical hazards, slowing response to problems that could endanger the ship.
Charging System	Battery charger, charging regulator, charging cable connections.	Uneven charging, charger failure, or failure in charging regulator.	Battery not charging properly, reducing power reserve, potential electrical disruption if main power is lost.
Cables and Connectors	Main cables, connecting cables between components, connectors.	Cable disconnection, short circuit, corrosion on connectors.	Power supply disruption, fire, damage to devices dependent on the electrical system.
Electrical Power Supply System for Ship Equipment	Power supply system for entertainment equipment, communication systems, navigation equipment.	Power supply disruption to critical equipment, damage to equipment.	Power supply disruption to critical equipment, damage to equipment.
Ventilation and Cooling System	Engine cooling system, fans, air conditioning.	Failure of cooling fan or pump, failure of HVAC (heating, ventilation, air conditioning) system.	Overheating of electrical or engine components, passenger discomfort, damage to electrical equipment.

The main benefit of FMEA on a ship's electrical system is to provide structured insights to improve reliability and safety. For example, through FMEA, ship operators can implement mitigation measures such as installing additional protection (such as overcurrent relays), upgrading cable materials to more corrosion-resistant ones, or implementing tighter maintenance schedules. In addition, this analysis also encourages the use of modern technologies such as IoT-based sensors to detect potential failures in real-time, so that preventive measures can be taken before failure occurs.

With the implementation of FMEA, the ship's electrical system becomes more reliable and safer, reducing the risk of operational disruptions, and ensuring the safety and comfort of passengers. This approach also supports compliance with international maritime safety standards and strengthens confidence in ship operations, especially in premium tourist destinations such as Labuan Bajo.

In the context of the electrical system of a pleasure boat, Failure Mode and Effects Analysis (FMEA) can be applied to identify potential failures in various electrical components and sub-systems on the boat. Several failure modes that can be analyzed in the electrical system of a pleasure boat can be clearly seen in Table 2. Based on Table 2 about FMEA found on the tourist ship, the RPN value of several electrical components on the ship can be calculated. Each parameter is rated on a scale of 1 to 10, where severity (S) indicates the impact of the failure on the safety and operation of the ship (1 = minimal impact, 10 = total failure or serious harm), occurrence (O) describes the frequency of failure based on historical data and expert judgment (1 = rare, 10 = very frequent), and detectability (D) reflects the likelihood that the failure can be detected before it has a negative impact (1 = very easy to detect, 10 = difficult or undetectable). The results of this calculation can be seen in Table 3.

Based on the results of the RPN calculation, the Battery and Energy Storage System component has the highest RPN value (315). This shows the importance of maintaining the ship's backup energy storage system in prime condition, because failure of this component can cause power loss in an emergency. Other components with high RPN values, such as the Electric Generator, Charging System, and Cables and Connectors, also require extra attention in maintenance and supervision.

Table 3. Matrix for filling in risk index and RPN parameters

Component	**S**	**O**	**D**	**RPN**
Electric Generator	10	4	6	240
Battery and Energy Storage System	9	5	7	315
Electrical Distribution Panel	8	4.	6	192
Inverter and Current Converter System	8	4	6	192
Ship Lighting System	7	3	5	105
Electrical Protection System	10	3	7	210
Steering and Electronic Control System	9	4	6	216
Electrical Alarm and Monitoring System	9	4.	6	216
Charging System	8	5	6	240
Cables and Connectors	8	5	6	240
Electrical Power Supply System for Ship Equipment	8	4	6	192
Ventilation and Cooling System	7	4	5	140

3.2. Optimization of Electrical System Improvements on Tourist Boats in Labuan Bajo

Optimizing the repair of the electrical system on tourist ships in Labuan Bajo is very important to improve reliability, safety, and comfort during the tour. Based on the FMEA analysis, one of the components with the highest RPN value is the battery and energy storage system, which reached 315. This value indicates that the ship's backup energy storage system has a high potential risk that can threaten the continuity of ship operations, especially if there is a loss of power in an emergency. In addition, other components with high RPN values, such as the Electric Generator, Charging System, and Cables and Connectors, also need more serious attention, because failure of these components can cause major disruption to ship operations.

1. Battery and Energy Storage System
   It is important to carry out regular maintenance on the Battery and Energy Storage System to ensure that the backup battery remains in good condition and ready to use in an emergency. This system must be monitored carefully to avoid a decrease in energy storage capacity that can reduce the backup power time. Some improvement steps that can be taken are by improving battery quality and maintenance, real-time battery power monitoring, and battery reassembly. In improving the quality and maintenance of the battery, it can be done by choosing a battery with a larger capacity and longer life, as well as conducting routine testing and maintenance to prevent performance degradation. In battery power monitoring, it can be implemented with a technology-based monitoring system to monitor battery power levels and charging status. Meanwhile, battery redundancy can be done by providing more battery backup systems, so that if one battery fails, the other system can take over.
2. Electric Generator
   The electric generator is a vital component in the ship's electrical system. Failure of the main generator can stop the entire flow of electricity to the ship, which has the potential to endanger the safety of passengers and crew. With an RPN value of 240, the generator must receive extra attention by means of routine maintenance and testing, implementation of a redundancy system, and monitoring of the generator load. For routine maintenance and testing of the generator, periodic maintenance and testing of the generator can be carried out to ensure that the generator is working optimally, including checking key components such as spark plugs, filters, and fuel systems. In the implementation of the Redundancy System, it can provide a backup generator that can be used immediately when the main generator experiences a disruption. Meanwhile, generator load monitoring can be done to ensure that the generator load does not exceed the specified capacity, to prevent long-term damage.
3. Charging System
   The charging system also plays an important role in ensuring the continuity of power on the ship. With an RPN value of 240, optimizing the charging system is crucial, especially to keep the battery and electrical system functioning properly. Things that can be done include repairing the charging system, supervision and monitoring, and redundancy of the charging system. For repairing the charging system, it can be done by ensuring that the charging system is functioning properly and can charge quickly and efficiently, including replacing worn components. In the supervision and monitoring of the charging system, the implementation of an alarm system or reminder to notify if there is a disruption in the charging system or if the battery is not optimally charged can be done. Meanwhile, redundancy in the charging system can be done by adding backup power sources to ensure that the battery is always fully charged, especially on long voyages.
4. Cables and Connectors
   Problems with cables and connectors can cause power outages to various ship systems. With an RPN value of 240, cables and connectors need special attention. Visual Inspection and Cable Testing need to be done. Regular inspection of cables and connectors to detect damage, corrosion, or wear that can cause electrical disturbances can be one solution. The use of high-quality cables can also provide resistance to extreme conditions at sea. Good connector installation will also ensure that the connectors are tightly and securely installed to prevent short circuits.
5. Generator Loading Exceeding Maximum Limits
   In addition to maintaining individual components, attention must also be paid to the percentage of generator loading that exceeds the maximum limit. Excessive loading of the generator can cause overheating and damage to internal components. Some steps to optimize generator loading are monitoring generator loads, applying distributed loads, and improving the generator cooling system. Generator Load Monitoring can be done using a load measuring device to monitor and ensure that generator loading remains within safe limits. Try to keep the generator loading at 60-86%, and not less than 30%. This is to maintain the generator's service life and optimize generator performance. For distributed load application activities, if possible, distribute the electrical load evenly among several generators to avoid overloading one unit. As for improving the generator cooling system, make sure that the generator cooling system is working properly to prevent overheating due to excessive load.

4. Conclusion

Optimizing the safety and reliability of the electrical system on a tourist ship in Labuan Bajo through Failure Mode and Effects Analysis provides a deep understanding of the potential risks associated with the ship's electrical system. Based on the FMEA results, key components such as the battery and energy storage system, electric generator, charging system, and cables and connectors show high Risk Priority Number (RPN) values, indicating that failure of these components can have a major impact on ship operations and passenger safety. This emphasizes the importance of routine maintenance and early detection to prevent damage to the electrical system, as well as identifying critical areas that require more attention, especially related to backup energy storage and power distribution. In addition, although components such as the ship lighting system and ventilation and cooling system have lower RPNs, they still require maintenance to ensure passenger comfort and the smooth operation of the ship. In terms of electric generator loading, the FMEA results also show that more appropriate load management is essential to increase the life of the generator. It is recommended that the generator load does not exceed 60-86% of its maximum capacity. This will reduce the risk of overheating, extend the life of the generator, and maintain operational efficiency. With preventive measures taken based on FMEA analysis, ship managers can ensure the reliability and safety of the electrical system of tourist ships in Labuan Bajo, providing a safer and more comfortable experience for tourists, and reducing the possibility of disruptions that can hinder ship operations. Overall, the implementation of FMEA contributes significantly to optimizing the reliability and safety of the electrical system of tourist ships, ensuring that ships operate with maximum efficiency and minimal risk.

The findings of this study can have a significant impact on tourism operations in Labuan Bajo in the long term, especially in terms of safety, operational efficiency, and sustainability of the maritime industry. By improving the reliability of the electrical system of tourist vessels, the risk of operational disruption due to electrical failure can be reduced, which directly improves the safety and comfort of tourists. This not only contributes to a more positive tourist experience but also strengthens Labuan Bajo's reputation as a premium tourism destination, which in turn can attract more tourists and investment in the maritime tourism sector. In addition, reducing the risk of electrical failure can also reduce the maintenance and operational costs of vessels in the long term, which benefits vessel operators and increases the profitability of their businesses.

From a broader perspective, the approach used in this study has great potential to be applied in other maritime tourism destinations in Indonesia and globally. The FMEA methodology applied in this study can be used to improve the reliability of the electrical system of various types of vessels, including cruise ships, ferries, and expedition vessels. Tourism destinations with similar environmental challenges, such as Raja Ampat, Derawan Islands, or Maldives, can benefit from the results of this study to improve their vessel safety standards. In addition, the concept of risk-based maintenance proposed in this study can serve as a model for the wider maritime sector, including the commercial shipping industry and passenger ships in international waters. By adopting a more proactive strategy in early detection and mitigation of electrical system risks, the maritime industry can achieve more reliable, efficient and sustainable operations globally.

The conclusion of this study has highlighted the importance of early detection and preventive measures, but it can still be expanded by discussing the role of modern technology in improving the effectiveness of maintenance of pleasure boat electrical systems. The integration of IoT (Internet of Things) sensors and real-time data-based monitoring systems can be an innovative solution to improve the reliability of failure detection and optimize maintenance strategies. By using smart sensors, the ship's electrical system can automatically monitor critical parameters such as voltage, current, cable temperature, and insulation resistance continuously. This data is then sent in real time to a monitoring center or cloud-based application, allowing ship operators to identify potential problems before total failure occurs.

In addition, AI (Artificial Intelligence) and machine learning-based analytics can be applied to analyze failure patterns and provide early warnings if there are anomalies in the system. With this approach, maintenance strategies can shift from reactive methods (repairing after damage occurs) to predictive methods (preventing failures before they occur). This will reduce ship downtime, improve operational efficiency, and reduce maintenance costs in the long run. The implementation of this technology not only improves passenger safety but also provides a competitive advantage for tour boat operators in Labuan Bajo, making them better prepared to face future operational challenges.

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