Journal of Education and Technology Development
https://myjournal.or.id/index.php/JETD
E-ISSN: 3031-8637
Vol. 2, No. 1, July – December (2024), pp. 60-74

Risk Mitigation For Ship Cargo And Electric Vehicle Cargo In Ferry Transportation

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Submited : 20-07-2024, Accepted : 20-08-2024, Published : 20-09-2024

Abstract

This study aims to identify the main risks and evaluate the effectiveness of risk mitigation for ship cargo and electric vehicles in sea crossing transportation. With the increasing use of electric vehicles, risks associated with electrical systems, overheating, and lithium-ion battery fires have become major concerns in sea crossing operations. This study used a survey method with a questionnaire distributed to 100 respondents consisting of ship crew, ferry operators, and maritime safety experts. The results showed that the risks of overheating and battery fire are the most significant risks, with a higher frequency of occurrence compared to other risks. Inadequate cooling systems and cargo placement that does not comply with safety standards contribute to the increased potential risk. While existing mitigation procedures, such as battery monitoring and cooling system upgrades, are in place, improvements are needed in specific regulations and crew training related to electric vehicle handling.
Keywords: Risk mitigation, electric vehicles, sea crossing, lithium-ion batteries

Introduction

The maritime transport industry is critical to facilitating trade and distribution across the vast Indonesian archipelago, connecting many islands through an effective transit system for passengers, vehicles and a variety of cargo loads (Regina Asariotis, 2016). The development of maritime transport infrastructure, including ports and terminals, enhances island connectivity, which is critical for economic integration and social cohesion (Regina Asariotis, 2013). As the industry evolves, the adoption of electric marine vehicles presents a sustainable alternative to traditional fuel-powered vessels, potentially reducing emissions and operating costs (Dong-Wook Song, 2012). However, this shift introduces new challenges, particularly in cost management and ensuring safety during crossings, which are critical to protecting passengers and cargo (Regina Asariotis, 2015). In addition, the implementation of advanced cargo management systems is critical to optimising logistics and improving the efficiency of cargo handling across Indonesia's maritime routes (Dong-Wook Song, 2012). This system, in addition to stringent safety regulations, must adapt to the integration of electric vehicles to address emerging safety challenges and improve overall maritime safety (Regina Asariotis,2015). Thus, while the maritime transport sector is critical to Indonesian trade, it must navigate the complexities introduced by technological advances and safety requirements.(Sukandi A.2024)

Electric vehicles (EVs) use high-power battery technology, primarily lithium-ion batteries, which present unique safety risks compared to conventional vehicles. These batteries are known for their high energy density but are also associated with significant hazards, including overheating, fire, and potential explosions, especially under extreme conditions during transport (Andrzej Erd,2020) Reliance on lithium-ion technology requires a robust monitoring system due to its narrower safety window compared to other battery types (Fabio Freschi,2017).

In addition, EVs eliminate the risks associated with flammable fuels such as gasoline or diesel, the potential for fire hazards remains a critical concern, especially in the event of damage or misuse of the energy storage system (Hafiz Fadillah, 2018). Comprehensive safety assessments, including dynamic impact tests, have been conducted to evaluate the performance of high-voltage batteries in severe collision scenarios, revealing that even under significant stress, the risk of thermal or electrical reactions is minimized (Wang Haiwen, 2018). Nevertheless, the safety of passengers and crew remains paramount, highlighting the need for continued vigilance and improved safety standards in EV transportation. The dynamic and unpredictable marine environment poses significant risks to EV transportation, primarily due to factors such as large waves, strong winds, and high humidity. These conditions can cause physical damage, which is a major concern for maintaining cargo integrity during transit (Bilal M. Ayyub, 2002). Effective cargo integrity management is critical, as it directly impacts economic outcomes and safety, especially in challenging sea conditions (Jason R. W. Merrick, 2001). To reduce these risks, implementing strong safety protocols for maritime transport is essential. These protocols are designed to minimize hazards and ensure the safety of cargo and personnel, thereby preventing accidents during transit (Przemysław Krata,2012).

In addition, conducting a thorough risk assessment in maritime logistics allows for the identification and mitigation of potential hazards, ensuring safer transport of goods (Braemig Falk-Hagen,2018). Understanding the risks of maritime transport is essential, as these hazards can cause significant economic losses and safety issues, especially for electric vehicles (Hans Rømer,2015). In short, addressing the challenges posed by the dynamic marine environment through comprehensive safety measures and risk management strategies is essential to maintain cargo integrity and prevent adverse outcomes during EV transport.

The transport of electric vehicles (EVs) by sea is fraught with unique risks that are not adequately addressed by current safety procedures, which largely rely on conventional vehicle standards. These risks include battery fire hazards and weight distribution issues, necessitating the development of tailored safety protocols specifically for EVs (Baolong Peng,2024). Furthermore, existing maritime transport regulations often ignore the specific characteristics and risks associated with electric vehicles, highlighting the critical need for updated guidelines that reflect advances in EV technology (Y.-Z. Li,2024). Regulatory gaps in current laws hinder the establishment of comprehensive regulations that ensure the safe transportation of EVs across the marine environment (Ahmed Hamdy El-Kady ,2024).

To effectively mitigate these risks, risk management systems must evolve to address the distinct challenges posed by electric vehicles, ensuring that robust safety measures are implemented (Mirza Zeeshan Baig .2024). In-depth studies are essential to identify these gaps and develop better risk mitigation strategies that prioritize the unique needs of electric vehicle transportation. Overall, improving safety procedures and regulations is essential to optimize the transportation of electric vehicles by sea.

Literature Review

Risks in Maritime Transportation

Maritime transportation is very important for an archipelagic country like Indonesia, especially for crossings. However, the ever-changing and unpredictable sea conditions increase the risk of cargo safety. According to Anic (2007), some of the main risks of maritime transportation are weather, wave conditions, ship stability, and navigability. According to Bendall (2010), the main cause of maritime accidents is a combination of extreme sea conditions and ship technical errors. Therefore, maritime transport risk management must include the implementation of strict operational safety standards as well as control of unpredictable variables, such as weather and sea conditions. When electric vehicles are transported, conditions such as high waves or ship stability issues can increase the risk of battery damage or more serious incidents. Ulstein's 2019 study showed that ship stability and proper cargo management are essential to prevent accidents caused by cargo movement during the crossing.

Electric Vehicle Risks and Safety

The main power source of electric vehicles, lithium-ion battery technology, is experiencing increasing risks as its technology advances. According to Nassar et al. (2013), although lithium-ion batteries have high energy density, they are still susceptible to thermal runaway, which is when the battery heats up too much and can explode or explode. Ren et al. (2019) showed that electric vehicles have a higher risk of fire than conventional vehicles, especially in cases of mechanical damage or exposure to high temperatures.

According to Schimpe et al. (2018), there are safety risks to electric vehicles during use and storage. The danger can increase if there is mishandling during transport, especially at sea. Therefore, to reduce the risks when transporting electric vehicles, it is important to pay special attention to adequate temperature control, ventilation and battery handling during the journey.

Battery Technology and Potential Risks

Given their role as a critical part of electric vehicles, battery technology, particularly lithium-ion batteries, will be the main focus of this study. According to Wang et al. (2012), lithium-ion batteries are highly sensitive to temperature and pressure. If they are damaged or broken, they can leak or even catch fire. Manthiram (2017) emphasized that safer battery materials and more sophisticated battery management systems are essential to reduce safety threats.

In addition, Hansen et al. (2020) emphasized the importance of specific safety regulations for battery transportation, which include requirements for packaging, storage, and ventilation during transit. These standards also include emergency response protocols in the event of a fire or explosion due to battery failure.

Risk Management in Transportation

A systematic method known as risk management is used to identify, analyze, and mitigate potential hazards in various situations, such as maritime transportation. Risk management includes preventive measures to reduce the impact of hazards (Hillson, 2002). Berg (2011) stated that in maritime transport, identifying the risks of the marine environment and the technology used (such as electric vehicles) is very important to maintain the safety of the cargo. According to Gwilliam (2018), establishing operational safety procedures that cover all stages of the transportation process, from loading to unloading, is very important. To ensure the safety of the cargo, the International Maritime Organization (IMO) sets international standards, such as the International Convention for the Safety of Life at Sea (SOLAS), which regulates cargo securing procedures and emergency procedures on board ships. However, these standards need to be changed to consider new risks arising from the transportation of electric vehicles.

Safety Regulations and Policies

Risk mitigation is highly dependent on the regulations governing the transportation of risky goods, including electric vehicles. Levinson (2015) stated that maritime transport regulations must be continuously updated to keep up with technological developments and the types of cargo being transported. The International Maritime Dangerous Goods Code (IMDG) regulates how to transport and transport dangerous goods on ships, such as lithium-ion batteries. However, Jones (2020) stated that the IMDG Code needs to be further adjusted to cover the specific hazards that electric vehicles may face during crossings.

Bainbridge (2021) emphasized that in creating more comprehensive regulations, there needs to be cross-sector collaboration between regulators, the transportation industry, and electric vehicle manufacturers. This collaboration will ensure that all parties understand the risks involved and are involved in developing effective mitigation solutions.

Methods

Data were collected through survey methods and field studies designed for this study on risk factors in ferry transportation, especially those related to electric vehicles. In addition, to gain a broader understanding of mitigation strategies that can be applied, this study involved a literature review and in-depth interviews with related parties such as ship crews, ferry operators, and maritime experts. All ferry vessels operating in Indonesia were included in the study population, especially vessels carrying motorized vehicles, including electric vehicles. The purposive sampling method selected samples based on certain criteria. These factors include busy ferry routes and vessels that have transported large numbers of electric vehicles. This study targeted ten to fifteen ferry vessels on several main routes between Java and Bali.

Results and Discussion

Descriptive Analysis

Table 1.

Frequency Distribution of Risk Incidents

Electric Vehicles at Crossings

No	*Types of Risk*	*Incident Frequency*	*Percentage (%)*
1	*Lithium-ion battery fire*	*15*	*50.0%*
2	*Overheating of electric vehicles*	*8*	*26.7%*
3	*Damage to the ship's electrical system*	*5*	*16.7%*
4	*Improper load placement*	*2*	*6.6%*
Total		*30*	*100%*

Interpretation:

Table 1 shows the Incident Frequency distribution of risks that occur during ship crossings carrying electric vehicles. Of the total 30 incidents recorded:

a) Lithium-ion battery fire is the most significant risk, with 15 incidents or 50% of the total incidents. This shows that lithium-ion batteries in electric vehicles are the main source of risk.

b) Overheating of electric vehicles occurred in 8 incidents or 26.7%, which is also an important risk that requires attention in crossing management.

c) Damage to the ship's electrical system occurred in 5 incidents or 16.7% of the total incidents, indicating a problem in the interaction between the ship's electrical system and electric vehicles.

d) Improper load placement occurred only 2 times or 6.6% of the total incidents, indicating that improper load placement is less common than other risks.

This interpretation highlights that battery fire and overheating are two major risks that should be prioritized in mitigation strategies.

Table 2.

Average Risk Incident Frequency per Month

No	Types of Risk	Incident Frequency per Month
1	Lithium-ion battery fire	1,25
2	Overheating of electric vehicles	0,67
3	Damage to the ship's electrical system	0,42
4	Improper load placement	0,17
Total		2,25

Interpretation:

Table 2 shows the average frequency of incidents per month:

a) Lithium-ion battery fire is the most frequent incident with an average of 1.25 incidents per month, meaning that almost every month there is at least one case of battery fire in electric vehicles during crossings.

b) Overheating of electric vehicles occurs with an average of 0.67 incidents per month, indicating that the risk of overheating occurs quite often even though the frequency is lower than fires.
c) Damage to the ship's electrical system occurs with an average of 0.42 incidents per month, meaning that this risk is not as frequent as battery fires or overheating, but is still significant.
d) Improper load placement is the risk with the lowest frequency, with an average of 0.17 incidents per month, meaning that this incident is relatively rare but still needs to be considered in crossing management.

From this analysis, it can be concluded that battery fire and overheating incidents occur more frequently, thus requiring more proactive risk management.

Table 3.
Percentage of Main Risk Factors

No	Types of Risk	Percentage (%)
1	Lithium-ion battery fire	50.0%
2	Overheating of electric vehicles	26.7%
3	Damage to the ship’s electrical system	16.7%
4	Improper load placement	6.6%

Interpretation:

Table 3 illustrates the Percentage of the main risk factors:

a) Lithium-ion battery fire reached 50% of the total incidents, indicating that half of all risks that occur on ferry vessels involve battery fires. This confirms that electric vehicle batteries are the most significant source of risk.

b) Overheating of electric vehicles contributed 26.7% of the total incidents. Although smaller than fire, overheating is still the main cause of incidents that require mitigation measures.

 E-ISSN: 3031-8637
Vol. 2, No. 1, July – December (2024), pp. 60-74

c) Damage to the ship's electrical system at 16.7% indicates that this problem occurs in almost 1 in 6 risk events, and can worsen the condition of the ship during the crossing.

d) Improper load placement contributed the lowest, only 6.6%, but is still a risk factor that must be monitored to prevent disruption to ship stability.

Overall, this table makes it clear that the main risks that need to be addressed are those related to batteries and overheating, while damage to the ship's electrical system should also not be ignored in the overall mitigation efforts.

1. Validity & Reliability Test

Validity test

Tabel 4.
Validity Content untuk Instrumen Penelitian Mitigasi Risiko

No	Questionnaire	Questions Average	Score Validity Description (Valid/Not)
1	Is the risk of Lithium-ion battery fire common during crossings?	4,33	Valid
2	What is the level of overheating in electric vehicles transported during the crossing?	0,21	Valid
3	How often does damage occur to the electrical system on ships during electric vehicle crossings?	4,33	Valid
4	Does the placement of electric vehicle cargo comply with safety standards during the crossing?	3,33	Need Revision
5	Are there effective procedures for mitigating the risk of battery fires in electric vehicles during the crossing?	4,67	Valid
6	How is the cooling system on the ship to prevent Overheating of electric vehicles during the crossing?	4,67	Valid

7	How great is the potential risk of damage to the electric vehicle battery charging system during the crossing?	4,00	Valid

Interpretation

From the table above, it can be concluded that the majority of question items are considered valid, except for questions related to the placement of content which need to be revised to be more representative and relevant.

Reliability Test

Table 5.

Reliability Test

Reliability Statistics	
Cronbach's Alpha	N of Items
,81	7

Interpretation:

The results of the Reliability Test show that the value of the cronbacs`h Alpha is 0.810, >0.70, thus it can be stated that this study is reliable and can be continued to the next stage

3. Qualitative Analysis

1. Identification of Risks in Electric Vehicle Loads on Crossings

From the results of surveys and interviews with ship crews and crossing operators, several main risks related to electric vehicle loads on crossings have been identified:

a) Overheating of Lithium-Ion Batteries: Most respondents reported concerns about the risk of overheating of lithium-ion batteries in electric vehicles during the trip, especially during hot weather or if there is inadequate ventilation.
b) Battery Fires: As many as 65% of the interviewed ship crews stated that fires due to electric vehicle batteries are one of the most dangerous risks. This is in line with several cases of fire reported in the document study.

c) Improper Placement of Loads: Field observations show that the placement of electric vehicles often does not take into account the separation from other potentially hazardous loads, such as fuel or chemicals.

d) Failure of Fire Extinguishing System: In some cases, the fire extinguishing equipment on board the ship is not yet compatible with the specific risks posed by Lithium-ion battery fires, which require specific extinguishing agents.

2. Level of Awareness and Knowledge of Ship Crews

A survey conducted on ship crews showed that the level of awareness and knowledge related to the risks posed by electric vehicles is still relatively low:

a) Only 40% of the crew are aware of the special handling related to Lithium-ion battery fires.

b) The level of understanding of the crew regarding adequate ventilation and cooling systems for electric vehicles is also low, with only 30% of respondents understanding the importance of ventilation arrangements in vehicle storage areas.

c) Most of the crew are not familiar with extinguishing equipment specific to electric vehicles, and there is no formal training related to this.

3. Mitigation Methods That Have Been Implemented

Based on interviews and observations, several risk mitigation methods have been implemented by ship operators, although not yet fully optimal:

a) More Orderly Cargo Placement: Several ferry ships have begun to implement procedures to separate electric vehicles from other hazardous cargo. However, this implementation has not been carried out consistently across all ships studied.

b) Use of Enhanced Ventilation Systems: More modern ferry vessels have been equipped with additional ventilation systems in vehicle stacking areas, although not all vessels have this system.

c) Special Fire Extinguishers: Only 25% of the vessels observed had fire extinguishers specifically designed to handle Lithium-ion battery fires. Most other vessels still use conventional extinguishers, which are less effective for incidents related to electric vehicles..

4. Applicable Policies and Regulations

a) Lack of Specific Policies: The results of the document study show that regulations related to the transportation of electric vehicles in ferry transportation have not been specifically regulated by the relevant authorities. Most maritime safety regulations still refer to general cargo, without considering the specific characteristics of electric vehicles.

b) Insurance Policies: Most ship operators do not have insurance that specifically covers risks related to electric vehicles, especially in the case of battery fires. Only a few operators have implemented more comprehensive insurance policies against this new risk.
c) Improvement of Ship Infrastructure: Ferry vessels, especially those that frequently transport electric vehicles, must be equipped with better ventilation systems and fire extinguishing devices that are compatible with the characteristics of electric vehicles.
d) Special Insurance for Electric Vehicles: Ship operators should provide an insurance package that covers specific risks related to electric vehicles, in.

Discussion

In this study, proactive risk assessment is used to minimize damage. This risk assessment includes improving safety infrastructure, crew training, safe cargo placement protocols, and creating special regulations and insurance.

1. Proactive Approach with Risk Assessment (Risk Assessment): This comprehensive approach will help reduce the risks associated with electric vehicles in ferry transportation from a technical, human, and policy perspective. Before the ferry trip is carried out, risk identification, analysis, and evaluation are carried out. In addition, evaluation of potential hazards such as battery fire, overheating, and Improper load placement. The goal is to find potential risks early on and take preventive measures before they arise. Ship operators can prioritize appropriate preventive measures, such as the most appropriate cargo placement and providing special safety equipment for EVs.
2. Infrastructure and Technology Preparation There are a number of actions that must be taken to reduce risks, including. Improving ventilation in areas where electric vehicles gather. As well as installing hazardous gas detectors and real-time temperature monitoring systems. and handling Lithium-ion battery fires with special fire extinguishers. The goal is to prevent fires and overheating by using proper ventilation systems and monitoring technology. This is done because advanced technology can detect and quickly address potential hazards before they develop into serious accidents.
3. Crew Training for Specific Safety of Electric Vehicles: This training teaches crew members about the specific safety aspects of electric vehicles, especially how to deal

with battery fires and how to safely place cargo. In addition, it trains employees in the use of fire extinguishing equipment specifically designed for electric vehicles. The goal is to improve the crew's ability to handle risks that may arise during the crossing. Proper training will make the crew more prepared to deal with emergency situations and better able to handle electric vehicle incidents.

4. Safe Load Placement Protocol

   Ensure that electric vehicles are placed in an area with sufficient air and are easily accessible for emergency handling and keep them away from other hazardous goods, such as fuel. This is done to reduce the risk of dangerous interactions between electric vehicles and other cargo and to maintain the stability of the cargo during the journey. This method will reduce the risk of fire or explosion due to unregulated interactions between cargo.
5. Regulating the Battery Charge Level of Electric Vehicles: Ensure that electric vehicles are transported with a safe battery charge level (e.g., below 80%) during the journey and conduct battery checks before being loaded onto the ship. This aims to reduce the risk of overheating or fire caused by overcharged batteries. Overheating is one of the main risks for electric vehicles, and changing the battery charge level can help reduce this risk.
6. Developing Specific Regulations for EVs Work with maritime authorities to create specific regulations for EV safety on ferry vessels. In addition, regulate cargo placement, firefighting, and emergency evacuation procedures. The goal is to create clear standards for ship operators to reduce risks and ensure safety during the transportation of electric vehicles. Clear regulations will provide easy-to-follow guidelines for ship operators and crew to reduce the risk of accidents.
7. Special Insurance for Electric Vehicles: Purchase insurance that protects electric vehicles from hazards such as battery damage or fire. The purpose of insurance is to provide financial protection to ship operators and electric vehicle owners in the event of an incident. Insurance can also reduce the financial burden on electric vehicle owners and provide security for them.

Recommendations for Risk Mitigation

The results of the study suggest that there are several steps that can be taken to help mitigate the risks associated with EV cargo on ferry crossings:

a) Specific Training for Ship Crew: There needs to be more specific training for ship crew on how to deal with the risks associated with EVs, especially those related to Lithium-ion battery fires. It is strongly recommended that this training include monitoring the battery status during the voyage and instruction on the use of special firefighting equipment.

b) Strengthening Regulation and Policy: Maritime authorities should create more specific regulations regarding the safety of EVs on ferry crossings. These regulations should include cargo placement, fire extinguishing systems, and ventilation standards.

c) Use of Real-Time Monitoring Technology: Ships should be equipped with gas and temperature sensors that can monitor the condition of EV batteries in real-time during the voyage. This will allow for quick action to be taken if there is a problem

Conclusion

1. Key Risk Identification: Battery overheating and possible Lithium-ion battery fire are the most important risks when transporting electric vehicles on ferry ships. This is due to the technical features of electric vehicles that have high potential hazards, such as poor electrical systems and thermal management during the ferry. In addition, there is a risk of Damage to the ship's electrical system that can occur due to excessive electric current from electric vehicles and Improper load placement, both of which can increase the risk of accidents during the ferry process.
2. Frequency of Risk Occurrence: Descriptive data show that, compared to other risk factors, such as damage to the battery charging system and failure of the ship's cooling system, battery fire and overheating are the risk factors with the highest frequency of occurrence. It is often reported that increased safety risks are caused by improper cargo placement, especially for electric vehicle cargo that requires special handling.
3. Effectiveness of Risk Mitigation: Current risk mitigation strategies have been shown to reduce the risk of overheating and fire by conducting stricter supervision of battery conditions and improving ship cooling systems. However, the findings of this study indicate that better safety procedures are needed for placing electric vehicles during ferry crossings. Technology-based mitigation procedures, such as the use of temperature sensors and early fire detection systems, can reduce risks and improve the safety of passengers and goods.
4. The Role of Training and Regulation: The study also shows that crews need training on how to deal with the risks posed by electric vehicles. In addition, the study shows that there is a need for specific regulations governing the safety standards for transporting electric vehicles on ferry ships. To reduce future risks, more specific regulations for managing electric vehicles on ships should be created and implemented immediately.

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