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Risk Analysis and Handling of Packaged Flammable Cargo Aboard the Ro-Ro Vessel DLN Nusantara

Kresna Satria Perdana*, Kuncowati, and Elva Febriana Anggraeny
Hang Tuah University, Surabaya, Indonesia
*kresnasatriap@gmail.com

Abstract

The handling of packaged flammable cargo aboard Roll-on/Roll-off (Ro-Ro) vessels presents significant operational safety risks, including cargo leakage, fire, explosion, obstruction of evacuation routes, and exposure to hazardous vapors. These risks may be exacerbated by inadequate packaging inspections, improper vehicle positioning, insufficient ventilation, and inconsistent control of ignition sources. This study aims to identify potential hazards, evaluate risk mitigation strategies, and develop systematic procedures for handling packaged flammable cargo aboard the Ro-Ro vessel DLN Nusantara. A mixed-methods approach was employed, integrating descriptive qualitative analysis with Failure Mode and Effects Analysis (FMEA). Data were collected through direct observations of loading operations and onboard activities, supplemented by interviews with the Master and Chief Officer. Identified failure modes were assessed using Severity (S), Occurrence (O), and Detection (D) ratings to determine their respective Risk Priority Numbers (RPNs). The findings reveal three major categories of hazards: the physical condition of cargo packaging and vehicles, improper cargo positioning and technical deficiencies in cargo spaces, and human factors associated with operational supervision and emergency preparedness. The highest-priority risk was noncompliance with the stowage plan, potentially obstructing emergency evacuation routes, with an RPN of 168. Other critical failure modes included undetected packaging or vehicle damage, proximity to ignition sources, inadequate ventilation, and improper cargo segregation. The findings indicate that effective risk mitigation requires an integrated sequence of preventive and operational controls, encompassing cargo information verification, packaging and vehicle inspections, stowage planning, loading supervision, cargo securing through lashing and wheel chocks, onboard monitoring, and emergency response procedures. Recommended measures include verification of actual cargo positioning before departure, enhanced inspection and patrol routines, stringent ignition-source control, maintenance of ventilation and closure arrangements, readiness of portable fire extinguishers, hydrants, and spill response equipment, and regular crew training and coordination. These findings provide a practical risk-based framework for improving the safety of packaged flammable cargo handling during Ro-Ro vessel operations.

Keywords: Failure Mode and Effects Analysis (FMEA); Flammable Cargo; Maritime Safety; Risk Assessment; Risk Mitigation; Ro-Ro Vessel.

1. INTRODUCTION

As an archipelagic country, Indonesia relies heavily on maritime transportation to facilitate international and domestic trade, cargo distribution, and inter-island mobility. Maritime transportation plays a fundamental role in maintaining the continuity of national logistics networks, making effective cargo management, port facilities, and supporting infrastructure essential for improving connectivity and logistics efficiency. The reliability of maritime transportation systems is therefore closely associated with operational efficiency, appropriate cargo handling practices, and the implementation of comprehensive safety management measures [1].

One of the critical safety concerns in maritime transportation is the handling of flammable cargo, which may present significant fire and explosion hazards when exposed to ignition sources, excessive heat, friction, or incompatible chemical substances. Managing these hazards requires systematic hazard identification, assessment

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of incident likelihood and potential consequences, and the implementation of appropriate preventive and protective measures. The International Maritime Dangerous Goods (IMDG) Code provides an internationally recognized regulatory framework for the classification, packaging, marking, labeling, documentation, stowage, and segregation of dangerous goods transported by sea [2], [11]. Effective risk management should also incorporate fire detection and suppression systems, crew training, appropriate firefighting equipment, and safe separation between hazardous cargo, ignition sources, and incompatible substances [3].

Roll-on/Roll-off (Ro-Ro) vessels are widely used to transport vehicles and wheeled cargo, including commercial trucks, passenger vehicles, and specialized transport units. Depending on their configuration and declared contents, these vehicles may carry diesel fuel, liquefied gases, chemical solvents, and other potentially hazardous substances. The concentration of numerous vehicles within enclosed or partially enclosed cargo spaces introduces specific fire safety challenges, particularly when inadequate cargo inspection, improper stowage, insufficient ventilation, or ineffective cargo securing practices are present. These conditions may increase the likelihood of fuel leakage, accumulation of flammable vapors, ignition, and fire propagation within vehicle decks [4], [12].

The Ro-Ro vessel DLN Nusantara operates on the Surabaya–Balikpapan route and its return service, utilizing ramp-based loading and unloading operations to facilitate the movement of vehicles and cargo. Although this system offers advantages in cargo handling efficiency and operational turnaround, it also requires systematic risk management throughout cargo acceptance, inspection, loading, stowage, transportation, and unloading activities. Failure to identify and control potential hazards during these stages may result in fuel leakage, hazardous vapor accumulation, fire, explosion, and rapid fire spread within cargo spaces [5]. Consequently, the safe transportation of vehicles carrying flammable substances requires coordinated operational procedures, equipment readiness, and continuous supervision.

Preliminary field observations aboard DLN Nusantara revealed several operational concerns related to cargo inspection, placement, and safety supervision. One documented incident involved diesel fuel spillage from a vehicle on the car deck, evidenced by a noticeable diesel odor, a wet deck surface, and visible liquid accumulation on the deck plating. Following detection, the affected area was secured, and absorbent materials were used to contain and remove the spilled fuel. Although the incident was managed without a reported escalation, it demonstrated the potential consequences of inadequate cargo inspection and monitoring. Fuel spillage within a vehicle deck may create fire hazards, increase slip risks, generate combustible vapor under certain conditions, and obstruct safe personnel movement. This observation highlights the need for a structured risk assessment to identify critical hazards, evaluate their potential consequences, and establish appropriate risk control priorities.

In addition to hazard identification, the safe transportation of flammable cargo depends on the consistent implementation of established standard operating procedures (SOPs). Before cargo acceptance and loading, inspections should address the physical condition of packages or transport units, the accuracy of dangerous goods documentation, appropriate marking and labeling, and compliance with applicable stowage requirements. Previous evaluations of dangerous goods handling procedures have highlighted that inadequate inspection and supervision may contribute to cargo leakage, improper stowage, and delayed emergency response [6]. Therefore, preventive measures should extend beyond cargo acceptance to include continuous monitoring and effective coordination among vessel personnel responsible for cargo operations.

Vehicle cargo spaces on Ro-Ro vessels present additional safety considerations because ventilation arrangements, cargo density, and connections to adjacent ship compartments may influence the movement and accumulation of hazardous vapors. Openings leading to machinery spaces, accommodation areas, and other compartments require appropriate protection to limit the spread of smoke, flammable vapors, and fire. Depending on vessel design and the applicable safety requirements, ventilation systems, fire-resisting boundaries, and closing arrangements must be maintained in their prescribed operational conditions [7]. These protective measures should be supported by controlled access, systematic cargo deck inspections, and layered safety arrangements intended to limit the escalation of hazardous incidents. Numerical modelling of Ro-Ro vehicle-deck fires also indicates that ventilation conditions can influence fire development and the time available for safe intervention [13].

Cargo stowage planning also plays an essential role in minimizing fire and explosion risks. The placement of dangerous goods must consider potential ignition sources, electrical installations, machinery space access points, emergency escape routes, and the compatibility of adjacent cargoes. Appropriate separation and segregation arrangements help reduce interactions between incompatible substances while maintaining access for inspection and emergency intervention [8]. Furthermore, the distribution of vehicles and dangerous goods within the cargo space should account for individual hazard characteristics, available clearance, and the accessibility of firefighting

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equipment. Compliance with relevant IMDG Code provisions is particularly important for packaged dangerous goods, including those transported in cargo transport units, to ensure that hazardous substances are identified, segregated, and stowed according to their classification.

The transportation of dangerous goods by sea must be supported by systematic procedures covering cargo identification, documentation, inspection, stowage, securing, and loading and unloading operations. The implementation of these procedures is essential for protecting personnel, vessels, cargo, property, and the marine environment [9]. In Ro-Ro operations, effective cargo management should also consider the potential contribution of individual vehicles and transport units to the overall fire risk within vehicle decks. Factors such as fuel condition, cargo characteristics, ignition sources, separation between vehicles, and access for detection and firefighting may influence the development and consequences of an onboard fire. Integrating these factors into cargo placement and operational safety assessments can support more effective emergency preparedness and risk mitigation [10].

Although existing maritime safety regulations and operational guidance address dangerous goods classification, cargo handling, fire prevention, and vessel safety, practical implementation remains challenging in Ro-Ro operations involving mixed vehicle and cargo configurations. In particular, the interaction between cargo inspection practices, vehicle placement, fuel leakage hazards, and emergency accessibility requires closer examination under actual shipboard operating conditions. The diesel spill observed aboard DLN Nusantara provides a practical basis for evaluating these interconnected risks and identifying weaknesses in existing preventive measures. Accordingly, a vessel-specific risk assessment is needed to determine how flammable cargo hazards arise during cargo handling operations and how appropriate control measures can be prioritized. Related quantitative research on Ro-Ro fires also emphasizes the roles of crew response and onboard protection systems in determining the consequences of fire incidents [14].

To address these concerns, this study aims to (1) identify potential hazards associated with the handling and transportation of packaged flammable cargo aboard the Ro-Ro vessel DLN Nusantara, (2) analyze risk reduction strategies based on identified hazards and their potential consequences, and (3) formulate practical recommendations for improving flammable cargo handling procedures. By integrating field observations with a structured assessment of cargo handling practices, the study seeks to provide operational insights that may support improved fire prevention, cargo safety management, and risk control during Ro-Ro transportation on the Surabaya–Balikpapan route.

2. METHODS

2.1. Research Object and Study Location

This study employed a mixed-methods design integrating a descriptive qualitative approach with Failure Mode and Effects Analysis (FMEA) to investigate the risks associated with handling packaged flammable cargo aboard a Roll-on/Roll-off (Ro-Ro) vessel. The qualitative component was used to examine actual cargo handling conditions, assess the relationship between documented safety procedures and shipboard practices, and interpret operational decisions made by responsible deck officers. FMEA was applied as a semi-quantitative risk assessment technique to systematically identify potential failure modes and establish measurable priorities for corrective and preventive actions [15].

The field investigation was conducted aboard the Ro-Ro vessel DLN Nusantara, operating on the Surabaya–Balikpapan and Balikpapan–Surabaya routes in Indonesia. The vessel transports passengers, vehicles, and vehicle-carried cargo, with an approximate effective voyage duration of 38 hours. The study period extended from August 16, 2024, to February 27, 2026, encompassing cargo loading, sea passage, and unloading operations. The Master and Chief Officer served as the principal informants because of their respective responsibilities for overall vessel command, cargo stowage planning, and supervision of cargo handling operations.

The primary unit of analysis comprised operational hazards and potential failure modes associated with the inspection, placement, securing, monitoring, and handling of packaged flammable cargo and relevant vehicle-related hazards. The investigation focused on identifying discrepancies between prescribed safety requirements and actual operational practices, evaluating their potential consequences, and determining appropriate risk control priorities.

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2.2. Data Collection

Primary data were collected through direct shipboard observations and interviews with the Master and Chief Officer. These methods were used to obtain complementary information concerning cargo handling practices, operational safety arrangements, potential hazards, and decision-making processes during loading, navigation, and unloading.

The observation instrument consisted of 26 indicators covering major aspects of cargo and vessel safety. These included emergency escape access, safety warning signs, closing arrangements, ventilation, ignition source control, compliance with engine shutdown requirements, portable electrical equipment, deck markings, wheel chocks, firefighting equipment, spill response materials, drainage arrangements, gas or vapor detection, safety patrols, inspection records, emergency procedures, personal protective equipment (PPE), assignment of crew responsibilities, internal communication, electrical isolation, safety briefings, supervision of external personnel, and post-operation evaluations.

These indicators were used to examine both the availability of safety arrangements and their implementation under actual operating conditions. Particular attention was directed toward potential ignition sources, hazardous cargo placement, obstruction of emergency access, leakage or spillage, and the adequacy of preventive and emergency response measures within vehicle cargo spaces.

The interview instrument comprised 15 questions structured around three research objectives: hazard identification, risk reduction, and cargo handling procedures. The questions addressed flash point information and vapor characteristics, damaged packaging, suspicious vehicle conditions, cargo stowage decisions, segregation arrangements, ventilation, ignition sources, emergency response equipment, safety patrols, and operational decisions when unsafe cargo conditions were identified.

Information obtained from the interviews was used to clarify operational practices observed aboard the vessel and to examine the considerations underlying cargo acceptance, stowage adjustments, safety inspections, and corrective actions. The integration of observational and interview data provided a basis for comparing documented safety expectations with actual shipboard practices and identifying potential failure modes for subsequent FMEA assessment.

2.3. Qualitative Analysis and Failure Mode and Effects Analysis

The collected data were analyzed through an integrated descriptive qualitative and semi-quantitative FMEA approach. Qualitative analysis involved three stages: data reduction, data presentation, and conclusion drawing. During data reduction, relevant information was selected, classified, and organized according to the research objectives. The findings were subsequently presented in descriptive and structured forms to facilitate interpretation and support the identification of operational failure modes.

The qualitative analysis followed a procedure–event–time framework, linking applicable safety requirements or operating procedures with observed events and the operational stages during which those events occurred. The analysis distinguished between the existence of documented procedures and their actual implementation during pre-loading preparation, cargo loading, sea passage, and post-unloading activities. This framework allowed the investigation to identify discrepancies between prescribed safety practices and actual shipboard conditions while considering their operational context.

Following the qualitative assessment, ten potential failure modes were identified based on recurring findings and their significance for operational safety. Each failure mode was assessed using three FMEA parameters: Severity (S), Occurrence (O), and Detection (D), each evaluated on an eight-point ordinal scale ranging from 1 to 8.

Severity represented the potential magnitude of consequences affecting personnel safety, vessel operations, property, and the marine environment. Occurrence represented the estimated likelihood or frequency of a failure mode, informed by field observations, interview findings, and relevant safety requirements. Detection represented the difficulty of identifying a failure mode before it developed into an operational incident. Higher Severity and Occurrence scores indicated more serious consequences and greater likelihood, respectively, whereas a higher Detection score indicated lower detectability.

The Risk Priority Number (RPN) for each failure mode was calculated using Equation (1):

$$RPN = S \times O \times D \quad (1)$$

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where (S) represents the severity of the potential consequences, (O) denotes the likelihood of occurrence, and (D) indicates the difficulty of detecting the failure mode before it develops into an incident.

The assessment scores were assigned based on field observations, interview findings, and predefined FMEA rating criteria. The scoring process was further supported by information obtained from the Master and Chief Officer to ensure consistency with actual shipboard operating conditions. Higher RPN values indicate failure modes requiring greater attention in risk control planning. However, the final risk prioritization was determined by considering not only the numerical ranking but also the potential consequences for personnel safety, fire development, emergency evacuation, and operational continuity.

3. RESULTS AND DISCUSSION

3.1. Hazard Indicators Identified During Shipboard Observations

The shipboard observations identified several safety concerns associated with the handling and stowage of flammable cargo aboard the Ro-Ro vessel DLN Nusantara. The identified hazards were associated with cargo and vehicle conditions, cargo positioning within vehicle decks, and the implementation of operational safety precautions. Particular attention was directed toward the accessibility of emergency escape routes, the physical condition of cargo and vehicles, potential fuel leakage, and the availability of appropriate spill response measures.

The findings indicated that discrepancies between actual cargo placement and designated emergency access arrangements required systematic corrective action. Vehicles or cargo positioned near escape routes, firefighting equipment, access doors, and inspection corridors could restrict personnel movement and delay emergency intervention. Therefore, corrective measures should extend beyond the immediate rearrangement of vehicles to address the operational procedures and organizational factors contributing to improper positioning. One practical measure is to verify and, where necessary, adjust vehicle positions before closure of the ramp door. The effectiveness of these corrective actions should subsequently be evaluated through repeated inspections and risk assessments during following voyages.



Figure 1. Liquefied petroleum gas (LPG) cylinder observed on the car deck of DLN Nusantara.
Source: Field documentation.

Another significant observation involved diesel fuel spillage from heavy equipment positioned on the vehicle deck. The spilled diesel was observed around the tracked running gear of the equipment, resulting in visible liquid accumulation and wetting of the deck surface. In response, the crew applied sawdust as an absorbent material to

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contain the spill, reduce its spread, and minimize slipping hazards. The contaminated absorbent was subsequently collected and placed in an appropriate container, and the affected deck area was cleaned.



Figure 2. Diesel fuel spillage from heavy equipment on the car deck of DLN Nusantara.
Source: Field documentation.

Although the spill was addressed through immediate containment and cleanup, the incident demonstrated the importance of maintaining readily accessible spill response materials and implementing appropriate procedures for collecting, storing, and disposing of contaminated waste. Diesel contamination on a vehicle deck may increase slipping hazards, create combustible residues, and introduce additional fire risks when exposed to sufficiently energetic ignition sources or elevated temperatures. The observation therefore highlights the need for systematic vehicle inspection before loading, early detection of fluid leakage, and effective spill response arrangements.

These findings also demonstrate that cargo-related hazards should not be evaluated independently. Damaged packaging or unsafe vehicle conditions may become more consequential when combined with improper cargo positioning, restricted ventilation, inadequate separation from ignition sources, or obstructed emergency access. Such interactions can increase the potential for incident escalation and reduce the effectiveness of existing safety barriers. Accordingly, safety compliance should be assessed through verification of actual operational conditions rather than solely through the presence of warning signs, firefighting equipment, or documented procedures. The physical characteristics and declared contents of the cargo must also be considered when determining the applicable handling requirements.

3.2. Risk Prioritization Using Failure Mode and Effects Analysis

Failure Mode and Effects Analysis (FMEA) was applied to prioritize ten potential failure modes identified through shipboard observations and interviews. Each failure mode was assessed using Severity (S), Occurrence (O), and Detection (D) scores on an eight-point scale. The Risk Priority Number (RPN) was calculated by multiplying the three parameters. The assessment results are presented in Table 1.

Table 1. FMEA risk prioritization results for cargo handling operations aboard DLN Nusantara.

No.	Potential failure mode	S	O	D	RPN	Rank
1	Cargo placement deviates from the stowage plan and obstructs evacuation or emergency access	8	7	3	168	1
2	Damaged packaging or unsafe vehicle conditions remain unidentified before loading	7	5	4	140	2
3	Cargo is positioned too close to heat or ignition sources	8	4	4	128	3
4	Vehicle deck ventilation is ineffective or obstructed by vehicles or cargo	8	3	5	120	4
5	Cargo compatibility and segregation requirements are incorrectly assessed	8	3	4	96	5
6	Closing arrangements connecting vehicle decks with machinery or accommodation spaces are ineffective	8	3	3	72	6
7	Restrictions on ignition sources are inadequately enforced	8	3	3	72	7

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No.	Potential failure mode	S	O	D	RPN	Rank
8	Leakage or vapor detection and safety patrols are inadequately implemented	7	2	5	70	8
9	Firefighting equipment or personnel are inadequately prepared for initial emergency response	8	2	4	64	9
10	Spill response equipment and procedures are not readily available or operationally prepared	7	3	3	63	10

The highest RPN of 168 was associated with cargo placement that deviated from the approved stowage plan and potentially obstructed evacuation routes or emergency facilities. This failure mode received the maximum Severity score of 8 because improper vehicle positioning could simultaneously compromise personnel evacuation, emergency equipment accessibility, cargo inspection, and firefighting operations. The relatively high Occurrence score of 7 reflected operational difficulties associated with changes in vehicle arrival sequences during loading, which could require adjustments to the planned stowage arrangement.

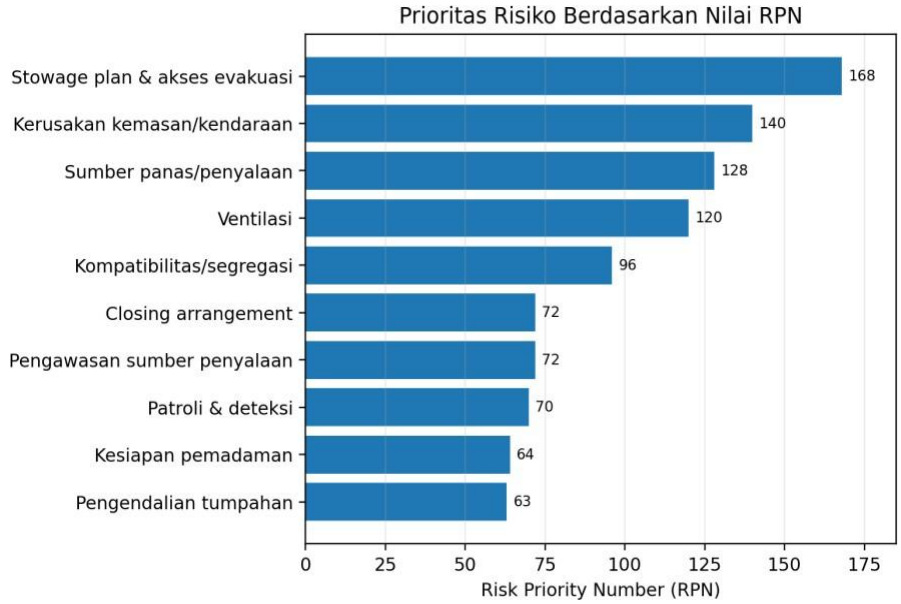


Figure 3. Risk Priority Number (RPN) distribution for the ten identified failure modes.

As illustrated in Figure 3, the four highest-priority failure modes were deviations from the stowage plan (RPN 168), unidentified packaging or vehicle defects (RPN 140), proximity to ignition sources (RPN 128), and ineffective ventilation (RPN 120). These results suggest that initial risk reduction efforts should prioritize cargo placement verification, pre-loading inspections, ignition source control, and ventilation management.

The second-ranked failure mode involved damaged packaging or unsafe vehicle conditions that were not identified before loading. With an RPN of 140, this finding emphasizes the importance of detecting visible defects such as corrosion, loose closures, damaged seals, wet surfaces, fluid leakage, and unusual odors. These indicators should trigger additional inspection, corrective action, or rejection of unsafe cargo, as appropriate. Failure to recognize such conditions before loading may allow hazardous materials or defective vehicles to enter cargo spaces where subsequent inspection and intervention become more difficult.

The third- and fourth-ranked failure modes concerned cargo proximity to heat or ignition sources (RPN 128) and ineffective vehicle deck ventilation (RPN 120). These hazards may interact because elevated temperatures can increase the evaporation of volatile substances, while inadequate ventilation may allow flammable vapors to accumulate. Under certain conditions, a combustible atmosphere may develop if sufficient vapor concentration is combined with an effective ignition source. Therefore, ignition source control and ventilation management should be treated as complementary preventive measures rather than independent safety arrangements.

Incorrect cargo compatibility and segregation assessment produced an RPN of 96. Although its Occurrence score was lower than those of the highest-ranked failure modes, its Severity score remained at 8 because inappropriate segregation may allow incompatible materials to interact, potentially intensifying fire development or causing hazardous chemical reactions. This finding reinforces the importance of verifying cargo classifications and applicable segregation requirements before determining final stowage positions.

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Two failure modes produced identical RPN values of 72: ineffective closing arrangements and inadequate enforcement of ignition source restrictions. These findings illustrate the complementary roles of structural protection and procedural discipline. Fire-resistant boundaries, doors, dampers, and other protective arrangements must remain functional and be operated according to their prescribed requirements. Similarly, restrictions on smoking, open flames, hot work, and unsuitable electrical equipment require consistent enforcement. Neither structural protection nor personnel discipline should be considered an adequate substitute for the other.

Inadequate leakage detection and safety patrols (RPN 70), insufficient firefighting readiness (RPN 64), and inadequate spill response preparedness (RPN 63) occupied the lower positions in the numerical ranking. However, their lower RPN values should not be interpreted as indicating negligible safety significance. These failure modes retained relatively high Severity scores because delayed hazard detection, ineffective firefighting intervention, and inadequate spill containment may contribute to incident escalation.

The results therefore demonstrate the usefulness of FMEA as a structured method for identifying risk control priorities while also highlighting an important limitation of RPN-based ranking. Failure modes with similar or lower RPN values may still involve severe consequences, particularly when they affect evacuation, fire protection, or emergency response capabilities. Consequently, operational decisions should consider individual Severity scores and the potential interaction among failure modes rather than relying exclusively on the numerical ranking [16].

3.3. Risk Reduction Strategies

Risk reduction strategies were developed by linking the identified failure modes with preventive and corrective measures appropriate to shipboard cargo handling operations. The proposed controls focused on cargo inspection, stowage verification, ignition prevention, ventilation management, equipment readiness, and emergency response preparedness. The recommended measures for all ten failure modes are summarized in Table 2.

Table 2. Recommended risk control measures based on FMEA prioritization.

No.	RPN	Recommended control measures
1	168	Verify actual vehicle positions against the approved stowage plan and maintain unobstructed escape routes, doors, stairways, fire extinguishers, and hydrants.
2	140	Conduct pre-loading inspections of packaging, closures, seals, leakage, odors, vehicle fuel systems, engines, brakes, and electrical conditions; isolate or reject unsafe cargo.
3	128	Establish and enforce appropriate separation from machinery, exhaust systems, electrical installations, hot surfaces, and other potential ignition sources.
4	120	Verify ventilation system readiness, operate ventilation according to cargo and vessel safety requirements, and prevent obstruction of air inlets and outlets.
5	96	Verify dangerous goods classification, compatibility, and segregation requirements before approving final cargo placement.
6	72	Inspect closing arrangements, including gaskets, hinges, securing devices, and relevant fire or watertight integrity features; rectify identified defects.
7	72	Enforce restrictions on smoking, open flames, hot work, and unsuitable electrical equipment; shut down vehicle engines after parking and conduct safety patrols.
8	70	Conduct scheduled safety patrols using documented checklists; use appropriate gas or vapor detection equipment where available and suitable for the hazard.
9	64	Ensure fire extinguishers, fire mains, hydrants, hoses, and designated response personnel are prepared for initial firefighting operations.
10	63	Provide suitable spill response kits, absorbents, PPE, collection tools, and labeled waste containers; implement appropriate containment, cleanup, and waste management procedures.

The highest-priority corrective measure concerns final verification of the actual cargo arrangement against the approved stowage plan before vessel departure. The Chief Officer should confirm that emergency escape routes,

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access to muster stations, firefighting equipment, doors, stairways, ventilation openings, and inspection corridors remain unobstructed. Any changes resulting from the actual vehicle loading sequence should be evaluated before final acceptance of the stowage arrangement. Where deviations are identified, corrective actions should be assigned to responsible personnel and documented before departure.

Pre-loading cargo and vehicle inspections constitute another essential preventive measure. Inspections should verify cargo declarations, identification markings, package integrity, leakage indicators, and the mechanical and electrical condition of vehicles. Suspected leaks, damaged containers, defective fuel systems, or other unsafe conditions should be referred for further assessment before loading is authorized. These measures are intended to prevent hazardous conditions from entering vehicle decks and reduce the likelihood of subsequent operational disruptions.

Ignition source control and ventilation management should be implemented throughout cargo operations and the voyage. Smoking, open flames, unauthorized hot work, and unsuitable electrical equipment should be prohibited or controlled in accordance with the applicable safety requirements. Vehicle engines should be shut down after parking unless an authorized operation requires otherwise. Ventilation arrangements should be inspected and operated according to the vessel's approved procedures and the characteristics of the cargo being transported. Ventilation openings should remain unobstructed to preserve the intended airflow and reduce the likelihood of hazardous vapor accumulation.

Cargo compatibility and segregation should be verified before finalizing the stowage plan. For dangerous goods subject to the IMDG Code, applicable requirements concerning classification, packaging, documentation, stowage, and segregation should be considered according to the declared substances and transport units. These requirements should be distinguished from the controls applicable to fuel contained in vehicle operating systems, as the regulatory treatment may differ.

During sea passage, scheduled safety patrols should be conducted using standardized checklists and documented inspection records. The patrols should focus on unusual odors, evidence of leakage, abnormal heat, ventilation conditions, vehicle securing arrangements, deck contamination, and continued access to emergency equipment. Where appropriate detection equipment is installed and available, the crew should use it according to the relevant operating and safety requirements. Abnormal findings should be reported promptly through established onboard communication and emergency procedures.

Emergency preparedness also requires continuous attention. Fire extinguishers, hydrants, fire mains, hoses, and other firefighting equipment should remain serviceable and accessible. Crew responsibilities should be clearly defined, and periodic briefings and drills should address flammable cargo hazards, initial firefighting measures, spill containment, evacuation, and emergency communication. Such preparations are particularly important because rapid fire development in densely occupied vehicle decks may restrict access and complicate emergency intervention.

Spill response procedures should include the availability of suitable absorbents, collection equipment, PPE, and designated containers for contaminated materials. The diesel spill observed during the investigation illustrates the practical importance of prompt isolation, containment, cleanup, and waste management. Although sawdust was used during the documented response, suitable absorbent materials should be selected according to the spilled substance, fire safety considerations, and applicable shipboard procedures. Contaminated materials should subsequently be collected, stored, and disposed of through appropriate waste management arrangements.

From an operational management perspective, the FMEA results should be incorporated into a continuing risk control process rather than treated as a one-time assessment. Corrective measures should have clearly assigned responsibilities, implementation deadlines, and documented verification of completion. The effectiveness of these measures should be reassessed during subsequent loading operations and voyages.

Overall, the proposed strategy integrates pre-loading verification, controlled cargo placement, operational supervision, voyage monitoring, and emergency preparedness. By connecting identified failure modes with specific corrective actions, the approach provides a practical framework for improving safety management aboard DLN Nusantara and supporting the implementation of applicable dangerous goods regulations and vessel operating procedures.

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4. CONCLUSION

This study investigated the risks associated with handling packaged flammable cargo aboard the Ro-Ro vessel DLN Nusantara by integrating shipboard observations, operational interviews, and Failure Mode and Effects Analysis (FMEA). The findings identified three principal categories of hazards: the physical condition of cargo packaging and vehicles; cargo positioning and technical conditions within vehicle decks; and human factors, operational supervision, and emergency preparedness.

The FMEA results identified deviations from the approved stowage plan that obstruct evacuation or emergency access as the highest-priority failure mode, with an RPN of 168. Other major risks included unidentified packaging defects or unsafe vehicle conditions (RPN 140), proximity to heat or ignition sources (RPN 128), ineffective or obstructed ventilation (RPN 120), and incorrect compatibility or segregation assessment (RPN 96). These findings indicate that cargo positioning, pre-loading inspections, ignition prevention, and ventilation management require particular attention. Nevertheless, lower-ranked failure modes involving detection, firefighting readiness, and spill response remain safety-critical because their potential consequences may be severe.

Effective risk reduction requires an integrated sequence of preventive and corrective measures encompassing cargo information verification, package and vehicle inspections, compatibility assessment, stowage planning, controlled loading, vehicle securing, final cargo position verification, scheduled safety patrols, and emergency response preparedness. The proposed measures emphasize the importance of assigning operational responsibilities, documenting corrective actions, and verifying their effectiveness through subsequent inspections.

The principal contribution of this study is the application of an integrated qualitative–FMEA framework to identify and prioritize cargo handling risks under actual Ro-Ro operating conditions. The resulting assessment provides a practical basis for improving hazard recognition, cargo placement decisions, and shipboard risk control procedures. However, because the assessment was conducted on a single vessel and relied on semi-quantitative scoring, the findings should be interpreted within the operational context of the study.

Future research should validate the assessment framework across multiple Ro-Ro vessels, routes, and vehicle deck configurations to examine the consistency and transferability of the identified risks. Further investigations could also evaluate the effects of digital inspection records, gas detection systems, and crew training frequency on failure occurrence and detectability, thereby supporting more evidence-based improvements in maritime cargo safety management.

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REFERENCES

[1] R. A. Alim, “Re-Design Layout Ruang Akomodasi Penumpang Kapal Ro-Ro Dengan Systematic Layout Planning (Slp) Dalam Upaya Pencegahan Penyebaran Skripsi,” Universitas Brawijaya, Malang, 2021.
[2] B. L. H. Widodo, E. T. Wahyuni, and M. A. Luhur, “Dangerous Goods Loading Management for Cargo Ship Safety and Crew B.,” *J. Marit. Polimarin*, vol. 9, no. 1, pp. 36–44, 2023.
[3] S. R. Alfitra, M. Z. Arifin, and R. H. Sari, “Fire Incident During Coal Cargo Operation: A Casu Study in MV Manalagi Tisya,” *Din. Bahari*, vol. I, no. October, pp. 37–46, 2024.
[4] Y. Tira *et al.*, “Tata Kelola Pelayanan Kapal Ro-Ro Dumai-Tanjung Kapal Provinsi Riau,” *J. Law Educ. Bus.*, vol. 2, no. 2, pp. 880–893, 2024.
[5] I. W. ALIF, “Evaluasi Penanganan Kebakaran Pada Muatan Di Mv. Armada Serasi Menurut Relasi Imdg Code,” 2024, [Online]. Available: https://repository.pip-semarang.ac.id/5754/
[6] W. Rizaldy, L. Lesmini, and A. A. Suryobuwono, “Evaluasi Sop Penanganan Barang Berbahaya Pada Green Terminal Container Teluk Lamong Surabaya Tahun 2023,” *Pros. Semin. Nas. Manaj. Ind. dan Rantai Pasok*, vol. 4, no. 1, pp. 16–26, 2023, [Online]. Available:

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https://jurnal.poltekapp.ac.id/index.php/SNMIP/article/view/1371%0Ahttps://jurnal.poltekapp.ac.id/index.php/SNMIP/article/viewFile/1371/259
[7] J. O. W. Hitalessy, M. Andiansyah, I. Hidayat, M. I. Arief, and N. I. Kadang, "Penanganan Muatan Berbahaya di Tempat Penumpukan atau Penyimpanan Barang Berbahaya pada Terminal Petikemas Semarang," *J. Penelit. Transp. Laut*, vol. 25, no. 1, pp. 11–22, 2024, doi: 10.25104/transla.v25i1.2290.
[8] R. Hariyanti, F. Kristini, O. Wahyuni, D. K. Sari, and D. Meliana, "Upaya Mengurangi Risiko dalam Pengiriman Muatan Berbahaya," *Semin. Nas. Transp. dan Keselam.*, vol. 1, no. 1, pp. 334–347, 2024.
[9] D. Darmawan and A. Widayanti, "Analisis Penanganan Bongkar Muat Barang Berbahaya (B3) di Pelabuhan Tanjung Perak Surabaya Analysis of Handling Loading and Unloading of Dangerous," vol. 2, no. 1, 2024.
[10] F. Rodero and Á. Marrero, "Fire hazard reduction in ro-ro spaces by means of using a cargo distribution algorithm including fire risk management during the stowage process," *Transp. Res. Procedia*, vol. 71, pp. 331–338, 2023, doi: 10.1016/j.trpro.2023.11.092.
[11] International Maritime Organization (IMO), "International Maritime Dangerous Goods (IMDG) Code: 2024 Edition (Amendment 42-24)," IMO, London, U.K., 2024. [Online]. Available: https://www.imo.org/en/publications/pages/imdg%20code.aspx
[12] J. Bao, Z. Bian, B. Li, Y. Li, and Y. Gong, "A hybrid approach for quantitative analysis of fire hazards in enclosed vehicle spaces on Ro-ro passenger ships," Sustainability, vol. 15, no. 17, art. no. 13059, 2023, doi: 10.3390/su151713059.
[13] I. A. Koromila and K. J. Spyrou, "Design fire methodology for vehicle spaces onboard ships," Fire Technol., vol. 59, pp. 1725–1759, 2023, doi: 10.1007/s10694-023-01403-w.
[14] S. Dahlbom, S. Andersson, E. De Carvalho, L. Lewandowski, and F. Evegren, "Fire risk model for fires in Ro-Ro ship Ro-Ro spaces," J. Risk Anal. Crisis Response, vol. 14, no. 3, pp. 333–355, 2024, doi: 10.54560/jracr.v14i3.503.
[15] International Electrotechnical Commission (IEC), "Failure modes and effects analysis (FMEA and FMECA)," IEC 60812:2018, Geneva, Switzerland, 2018. [Online]. Available: https://webstore.iec.ch/en/publication/26359
[16] J. Fabis-Domagala, M. Domagala, and H. Momeni, "A concept of risk prioritization in FMEA analysis for fluid power systems," Energies, vol. 14, no. 20, art. no. 6482, 2021, doi: 10.3390/en14206482.

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