



**MITIGATING CARGO DAMAGE IN CONTAINERISED SHIPPING:
 A HYBRID ASSESSMENT OF RISK FACTORS AND STRATEGIC INTERVENTIONS**

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ARTICLE INFO	ABSTRACT
<p>Article History: Received: 12 June 2025 Revised: 7 August 2025 Accepted: 7 August 2025 Published: 25 August 2025</p> <hr/> <p>Keywords: Cargo damage, containerisation, machinery maintenance, human factors, risk mitigation</p>	<p>The introduction of containerisation has profoundly transformed global trade by significantly improving efficiency of cargo handling and transportation processes. Nevertheless, cargo damage during transit continues to pose a considerable challenge, resulting in financial losses and deteriorating customer confidence. This study aims to identify and analyse the principal causes of cargo damage namely, machinery and equipment failure, human-related factors, marine incidents, environmental conditions, and theft as well as to evaluate strategies for mitigating these risks. Employing a structured methodology that integrates the spider web analytical technique with the average rating value method, the study prioritises these risk factors based on their relative impact. The findings indicate that proper maintenance of equipment and continuous personnel training are the most effective strategies for reducing cargo damage. The study offers practical recommendations for shipping companies seeking to improve operational safety, reliability, and overall efficiency in containerised freight transport.</p>

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Introduction

The introduction of standardised containers in the 1950s marked a transformative innovation in global logistics and supply chain management for the transportation of manufactured goods. Commonly referred to as “standardised shipping containers” in the industry, these containers revolutionised logistics by enabling automated cargo handling, seamless intermodal transfers between sea, rail, and road transport, and reduced incidences of damage and theft. These advancements generated significant economies of scale and shortened transit times. Today, dry cargo including bulk and containerised goods, account for nearly 75%

of all maritime freight, with 8.0 billion tonnes transported internationally in 2021 (UNCTAD, 2021). Containerisation has become a universal standard, facilitating the efficient movement of goods across global supply chains.

Despite the efficiencies introduced by containerisation, cargo damage remains a persistent and multifaceted challenge in maritime logistics. Cargo damage can occur at any stage of the supply chain — from initial packing and port handling to transit and final delivery, and often results in financial losses, insurance claims, and reputational harm. The complexity of cargo damage stems from its diverse causes

and manifestations. Common types include physical damage due to mishandling or impact during loading and unloading, moisture intrusion and condensation (cargo sweat) that leads to rust or mould, contamination from improper segregation of goods or exposure to pollutants, temperature-related spoilage especially with regard to perishable or sensitive cargo, and theft-related losses involving pilferage or forced entry. Each of these damage type presents distinct operational risks, necessitating targeted and coordinated mitigation strategies throughout the container shipping process.

International organisations and regulatory bodies have established several frameworks to address cargo safety and reduce damage incidents. For instance, the International Maritime Organisation (IMO) provides detailed guidance on cargo securing under the IMO Code of Safe Practice for Cargo Stowage and Securing (CSS Code). In parallel, the International Organisation for Standardisation (ISO) issues standards such as ISO 11607, which outlines requirements for packaging used in sterile barrier systems, and ISO 3874, which specifies container handling and securing methods. However, despite these guidelines, implementation inconsistencies and outdated infrastructure in many ports continue to limit effectiveness. Technological limitations, such as the lack of real-time cargo monitoring or predictive maintenance systems, further exacerbate the risk of cargo degradation or loss during transit. Consequently, the effectiveness of these regulatory frameworks often hinges on the local enforcement capacity, operator training, and technological adoption.

While previous studies have explored individual causes of cargo damage such as equipment failure, human error, or environmental exposure where there remains a lack of integrated assessment frameworks that quantify and prioritise these risk factors within the specific context of containerised shipping. Most existing approaches do not provide a comparative evaluation that links cause severity to appropriate mitigation strategies. This study addresses this research gap by proposing a

hybrid Likert–spider web methodology that categorises, prioritises, and links root causes of cargo damage to actionable risk mitigation interventions. The goal is to enable shipping operators, regulators, and port authorities to focus resources on the most critical risk areas. The remainder of this article is structured as follows: Section 2 reviews the literature on cargo damage causes and mitigation strategies. Section 3 outlines the hybrid methodology. Section 4 presents the results, and Section 5 discusses the implications. Section 6 concludes the study and offers recommendations for future research.

Literature Review

The Evolution and Impact of Containerisation

The standardisation of container shipping in the mid-20th century revolutionised global logistics by streamlining cargo handling processes and enabling intermodal transport efficiency. As McKinsey (1967) first observed, containerisation reduced operational costs through economies of scale, particularly with the adoption of larger vessels that lower fuel consumption and emissions per unit (Saxon & Stone, 2017). While collaborative alliances among operators have leveraged these efficiencies, competitive pressures to match such advancements risk overcapacity and diminishing returns (Saxon & Stone, 2017).

Root Causes of Cargo Damage

Cargo damage in containerised shipping is a multifaceted issue driven by various interrelated factors. While previous literature has addressed these causes in isolation, this study presents an integrative categorisation consisting of five overarching domains: Machinery Equipment Failures (ME), Human Factors (HF), Marine Incidents (MC), Environmental Factors (EF), and Theft and Pilferage (TP). This structured taxonomy not only consolidates previous fragmented findings but also provides a coherent analytical framework for quantifying each risk's relative impact using a hybrid assessment method. By adopting this approach, the study

builds upon existing literature and offers a more holistic understanding of cargo damage dynamics within container logistics.

Machinery Equipment Failures

Failures related to machinery and handling equipment are one of the predominant contributors of cargo damage. As noted by Budiyanto and Fernanda (2020), operational disruptions such as equipment malfunctions and loading accidents significantly impact cargo safety. Ageing equipment, often overlooked, poses increased risk due to deteriorated functionality and reliability (Oktaviani *et al.*, 2018). Inadequate maintenance practices further exacerbate the situation, where neglect or improper handling of mechanical systems leads to breakdowns and increased accident probability (Baalisampang *et al.*, 2018). Additionally, technical deficiencies — particularly in securing systems and cargo handling tools — have been shown to directly contribute to cargo loss during loading and unloading operations (Kaup *et al.*, 2022). This study consolidates these discrete issues into a unified category to underscore their cumulative impact on cargo safety and maintenance policy effectiveness.

Human Factors

The human element remains a critical determinant of cargo integrity. Errors during crane operations, such as dropping containers or poor manoeuvring are common causes of physical damage and workplace injuries, as evidenced in port safety records from regions like Hong Kong and the United Kingdom (Gou & Lam, 2019). Equally significant is the misdeclaration of cargo contents — especially hazardous goods — which can lead to fires, explosions, or inappropriate stowage (Ellis, 2010). Miscommunication across various nodes in the logistics chain, including shippers, freight forwarders, and consignees, has also been identified as a frequent cause of mishandling and misplacement (Oktaviani *et al.*, 2018). Unlike previous studies that treat these elements independently, this research integrates them

into a singular framework of human factors to emphasise their interconnectedness and the need for systemic training and communication protocols.

Marine Incidents

Accidents at sea, though relatively infrequent compared to operational errors on land, have far-reaching consequences. According to the International Maritime Organisation (IMO), common maritime incidents include collisions, fires, explosions, and vessel grounding (Wang *et al.*, 2021). Collisions, particularly on congested shipping lanes, often result in substantial cargo damage and loss of life (Zhang *et al.*, 2019). Fires may be triggered by friction, misdeclared goods, or unsecured cargo shifting during transit (Kaup *et al.*, 2022). Explosive incidents, such as the 2023 Thai tanker explosion, further illustrate the devastating impact of overlooked mechanical faults and unsafe cargo handling practices (The Maritime Executive, 2023). By grouping these events under marine incidents, this study emphasises the importance of accident prevention, emergency preparedness, and compliance with international maritime safety standards.

Environmental Factors

Environmental and climatic conditions also exert considerable influence on cargo integrity. Severe weather events — including storms, high winds, and fluctuating temperatures — pose a particular threat to sensitive or perishable goods (Lam & Lassa, 2017). Moisture accumulation, often resulting from condensation or inadequate ventilation, promotes rust, mould, and cargo degradation (Florani, 2017). Additionally, extreme temperatures, whether excessive heat or sub-zero conditions, can render pharmaceuticals and fresh produce unusable (Bakhtiyorjon & Abdurashid, 2022). Unlike prior studies that treat environmental impact as a peripheral concern, this research incorporates it as a core risk dimension. This underscores the need for climate-resilient logistics planning and the use of temperature-controlled containers and insulation systems.

Theft and Pilferage

Theft and unauthorised access to cargo remain persistent threats, particularly in unsecured or poorly monitored zones. Research shows that approximately 97% of cargo theft occurs at vulnerable parking and staging areas (Liang et al., 2022). Modern supply chains that rely on just-in-time delivery systems are especially at risk due to nominal inventory buffers and high asset concentration in transit (Inbound Logistics,

2010). Common tactics include forced entry, tampering with container locks, and cutting through securing mechanisms. By categorising theft and pilferage as a distinct risk factor, this study highlights the operational blind spots in cargo security that are often underestimated in risk assessments. The inclusion of this dimension reflects an expanded understanding of non-technical threats to cargo safety in containerised shipping.

Table 1: The list of parameters of cargo damage causes

Main Criteria (Level 1)	Sub-criteria (Level 2)
Machinery Equipment (ME)	The age of machinery equipment can increase the likelihood of work accidents that result in cargo damage (AME)
	Inadequately maintained machinery equipment before cargo Transportation process (IMME)
	Technical condition refers to equipment failures or malfunctions that may occur during the loading and unloading process, potentially leading to cargo damage (TC)
Human Factors (HF)	Crane operations and cargo handling using cranes during the loading and unloading process can cause cargo damage (COCH)
	Misdeclaration of cargo contents, especially dangerous goods can contribute to cargo damage when placed in the wrong place (MOCC)
	Miscommunication while handling cargo can cause cargo damage (MWHC)
Marine Collision (MC)	Collision between vessels refers to instances where two or more vessels collide with each other, potentially leading to cargo damage (CBV)
	Fire on board refers to situations where a fire breaks out on a vessel, posing a risk of cargo damage (FOB)
	Explosion-related incidents include situations where explosions occur on board vessels, potentially causing significant damage to cargo (ERI)
Environmental Factors (EF)	Extreme weather condition (EWC)
	Exposure to water or moisture that can lead to mould, mildew and corrosion (EWM)
	Temperature variations exposure to cargo from extreme heat to extreme cold (TVE)
Theft and Pilferage (TP)	Cargo or vehicles being stolen or tampered (CST)
	Perpetrators may forcefully open containers or packaging (PFO)
	Forcefully remove or cut through securing mechanisms (FRCT)

Strategies to Mitigate Cargo Damage

Effective mitigation of cargo damage requires a systematic approach that addresses the root causes identified in Section 2.2. Table 2 outlines four key strategies namely, Standard Operating

Procedures (SOP), Continuous Training (CT), Proper Maintenance (PM), and Digitalisation and Technology (DT), along with their sub-criteria, providing a structured framework to enhance cargo safety and operational efficiency.

Standard Operation Procedure

Planners, stevedores, crane operators, container-securing employees, and ship's crew should all be integrated more into the loading process than before. Each of them should oversee their own areas of responsibility and check off the necessary actions on a list. The others could see how the loading processes were going. This could improve the safety of the ship and its cargo by allowing for further verification of whether each step was carried out (Kaup *et al.*, 2022).

Continuous Training

Organisational problems and human mistake are almost always the main causes of unfavourable events. As a result, it is vitally important to provide instruction, training, supervision, and education (Torstensson & Ekwall, n.d.). To ensure competent crew is involved in the cargo handling operation, detailed procedures and periodic in-service training standards should be established for ship/shore crew. There should be a well-organised ship technical management system run by competent ship/shore crew with enough expertise in the field in order to comply with the international rules, regulations, and guidelines about ship safety construction and cargo operation. It is important to use proper passage planning while considering the weather. To minimise the effects of severe weather, all deck equipment and cargo lashing should be fastened (Kuzu, 2021).

Proper Maintenance

In general, there are a few ways to look at the significance of maintaining port infrastructure. First off, the majority of port infrastructures need to be used for a very long time. Structure-related deteriorations are always possible during a port's operational lifespan. Hence, maintenance work is a lengthy endeavour that seeks to maintain the lifetime risk below a desired level. Second, because port facilities are typically constructed along coastlines, regular maintenance and renovation projects are necessary. A rapid deterioration mechanism is typically anticipated in the built facilities because most port infrastructures are immediately exposed to an adverse environment (Y. Zhang *et al.*, 2017). Proper maintenance needs to be done to avoid any accidents.

Digitalisation and Technology

The adoption of digital solutions is crucial because it enables ports and other maritime industries to improve their efficiency and sustainability, reduce costs and performance times for specific operations, improve information flow and decision-making, decrease the use of article documents in operational processes related to sustainability policy, increase safety, lessen the damaging effects of maritime transport on the environment, in ports and port areas, fosters innovation and so on (Paulauskas *et al.*, 2021).

Table 2: The list of parameters of possible strategies to prevent or minimise cargo damage

Main criteria (Level 1)	Sub-criteria (Level 2)
Potential strategies to prevent and minimise cargo damage (PS).	<p>SOPs (Standard Operation Procedure) for cargo handling provide established guidelines and protocols for handling cargo in a standardised and safe manner (SOP).</p> <p>Continuous training involves ongoing education and skill development programs for personnel engaged in cargo handling activities (CT).</p> <p>Proper maintenance ensures regular inspection, repair, and upkeep of equipment and infrastructure used in cargo operations to ensure their optimal functioning and safety (PM).</p> <p>Digitalisation and technology solutions encompass the use of digital tools, automation, and advanced technologies to enhance efficiency, safety, and accuracy in cargo handling processes (DT).</p>

Research methodology

This study employed a structured, quantitative methodology to identify and prioritise the root causes of cargo damage and corresponding mitigation strategies in containerised shipping operations. A combination of average rating value analysis and spider web (radar) chart visualisation was used to rank both the causes and strategies based on expert evaluations. The following subsections elaborate on the questionnaire design, validation and reliability procedures, and the sampling approach employed in the study.

Questionnaire Design

The data collection instrument was a structured questionnaire comprising of two main sections: (1) Assessment of the perceived severity of cargo damage causes, and (2) evaluation of the effectiveness of various mitigation strategies. Each section included a list of Level 1 main criteria and Level 2 sub-criteria, developed based on an extensive literature review (e.g., Baalisampang et al., 2018; Kaup et al., 2022; Liang et al., 2022). Items in the questionnaire were rated on a 5-point Likert scale ranging from 1 (“Very Low”) to 5 (“Very High”) to capture the perceived importance or impact of each factor.

To ensure content validity, the questionnaire items were adapted from validated instruments used in prior studies on maritime safety and logistics risk (e.g., Othman et al., 2017; Oktaviani et al., 2018) and were refined to fit the Malaysian container shipping operations specifically. Furthermore, the questionnaire was reviewed and validated by a panel of five domain experts from academia, maritime logistics management, and port operations. Their feedback helped ensure clarity, relevance, and comprehensiveness of the measurement items.

Reliability and Validity

Prior to full-scale data collection, a pilot test was conducted with a small sample of five professionals with similar profiles to the final target respondents. Based on the feedback from this pilot, minor adjustments were made to question phrasing and layout for better clarity.

The internal consistency of the questionnaire was assessed using Cronbach’s alpha, which yielded an overall value of 0.84, indicating high reliability. Subscale alphas for individual categories (e.g., machinery failures, human error, digitalisation strategies) ranged between 0.76 and 0.88, which are considered acceptable to excellent levels of reliability for exploratory research (Nunnally, 1978).

Sample and Respondent Selection

A total of 20 respondents participated in the final survey. The sampling strategy was purposive, targeting professionals with direct experience in cargo handling and risk management within containerised shipping operations. The selection criteria required that respondents must have at least three years of experience in maritime operations and be currently employed in one of the following roles: Top management, operational

managers, supervisors, or technical officers in shipping companies or container terminals.

The distribution of respondents by role, years of experience, and organisational affiliation is summarised in Figure 1. This stratification ensured that the study captured insights from a diverse cross-section of maritime professionals, thereby enhancing the credibility of the evaluation results.

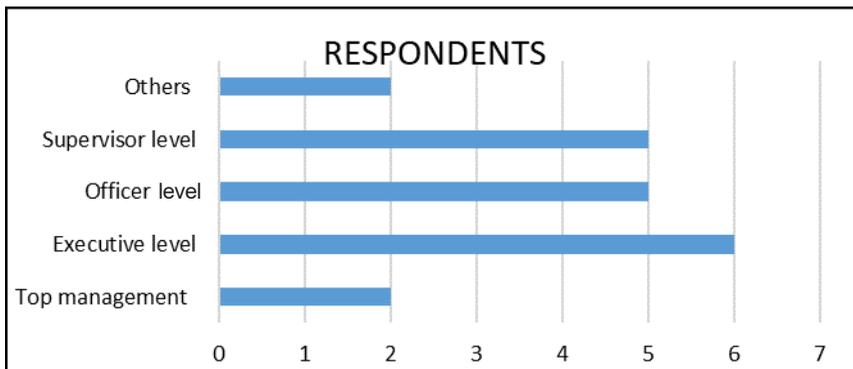


Figure 1: List of respondents

Systematic Mathematical Approach

A systematic mathematical approach was employed to develop a test case that incorporates an average rating value technique. This technique was used to assess the influence of contributing factors and rank them in order of preference. As cited by Othman *et al.* (2017), the average rating value technique relies on a basic mathematical formula, known as averaging, to ensure accurate calculations and reliable results (Jacobs, 1994; Foerster, 2006). In this study, the average rating value technique was employed to determine the weights assigned to each parameter involved. It

offers a straightforward concept by calculating the central tendency of the parameters based on respondents’ evaluations, as opposed to a more complex methods that may lead to a misunderstanding of the underlying concept. Additionally, the outcomes obtained from this technique are easily comprehensible and interpretable. The relevant formulae for this technique are generally represented by Equations 1 (Medhi, 1992; Jacobs, 1994; Foerster, 2006) and 2.

or

$$A = \frac{1}{n} \sum_{i=1}^n a_i$$

$$A = \frac{x_1 + x_2 + x_3 + x_4 + \dots + x_n}{n} \tag{1}$$

where:

A = represent the arithmetic mean

\sum = summation symbol; is the addition of a sequence of numbers; the result is their sum or total

X = value given per subject

n = total number of subjects involved

a_j = value given per subject

Equation 1 is simplified to Equation 2 for further understanding and application.

$$\frac{\text{Total value given f or each category}}{\text{Total number o f all categories involved}} \quad (2)$$

The weighted values in this study were determined based on the evaluations provided by selected respondents using a 5-point Likert scale for each listed parameter. These evaluations were analysed using the systematic average rating value technique. A survey process was conducted, and sets of questionnaires were distributed to a total of 20 selected respondents, including top management/manager, executive level, officer level, and supervisor level.

All the respondents had sufficient knowledge and experience in cargo handling. This study employs a spider web or radar chart to visually present multivariate observations. The chart represents an arbitrary number of variables or factors on axes emanating from a common point, with their respective scores depicted (Chambers *et al.*, 1983; Abdul Rahman *et al.*, 2016; Othman *et al.*, 2017).

Results

A test case was created based on the current situation on the shipping company in Malaysia. The process selection was started by identifying the factors that can lead to cargo damage in all the shipping process and determine the parameters to be used as shown in Table 1. Second, the main body of the test case contains:

- Calculation of the mean value of the evaluation sub-criteria.
- Calculation of the average mean value of each sub-criterion.

- Determination of average mean value of main criteria.

Finally, it concluded by ranking the preference order of all main criteria. The illustrations of the steps conducted were shown further as below:

Step 1: Calculate mean value of the evaluation criteria

The values assigned to each category in Table 2 corresponded to the cumulative rating provided by the participants using a five-point “Likert” scale in response to the survey questions. These values serve as a metric for assessing the relative contribution of each criterion and sub-criterion pertaining to cargo damage and potential solutions. To elaborate, consider the sub-criterion labelled as “AME,” which accumulated a total rating of 80 after aggregating the individual ratings assigned by each respondent to that specific sub-criterion. The same methodology was employed for all the sub-criteria examined in this study, as demonstrated in the comprehensive summary presented in Table 3. Table 3 provides a comprehensive overview of the cumulative ratings received from the participating respondents for each respective criterion and sub-criterion for the causes of cargo damage while Table 4 for the criterion of possible solution.

Table 3: Total rate given by the respondents for the sub-criteria for the factors of cargo damage

Causes of Cargo Damage		
Main Criteria	Sub-criteria	Total Rate
ME	AME	80
	IMME	84
	TC	83
HF	COCH	78
	MOCC	83
	MWHC	82
MC	CBV	75
	FOB	81
	ERI	83
EF	EWC	69
	EWM	75
	TVE	75
TP	CST	63
	PFO	57
	FRCT	59

Table 4: Total rate given by the respondents for strategies to prevent and or if you minimise cargo damage

Strategies to Prevent and Minimise Cargo Damage	
Main Criteria	Total Rate
SOP	86
CT	87
PM	90
DT	87

Step 2: Calculate the average mean value of the sub-criteria

All the feedback received from the respondents as according to the questionnaires distributed were further calculated by using Equation (1) of Average Mean Value technique for evaluating the criteria and sub-criteria mentioned. The

output values determined throughout this technique were represented as the average mean value of the sub-criteria involved. The example of the calculation using Equation (1) is shown below:

$$\text{Average mean value for sub-criterion "AME"} = 80/20 = 3.94$$

The value of 3.94 represents the average mean value recorded for the sub-criterion “AME” based on the total evaluation made by the total of 20 respondents. Similar calculations were performed for all sub-criteria in different key study areas. The data of the average mean value of all sub-criteria evaluated are shown in Table 3.

Step 3: Determine the average weight value of main criteria.

To determine the average mean value for the main criteria, initially, the levels of criteria need to be identified and separated. For this study, there are two levels of criteria which were identified as shown in Table 1 and Table 2.

The main criteria were known as Level 1, while the sub-criteria were known as Level 2. The average mean values of sub-criteria recorded in this study were determined to influence on the average mean value of the main criteria. All the results were subject to the ranking process which will rank the main factors in each group which is indicated using the average weight value.

Based on Table 1 and Table 2 which is used to illustrate that the Level 2 criterion is deemed to influence the Level 1 criterion, the average mean values of the main criteria were determined based on the sum of the average mean values of all sub-criteria under each main criterion based on Table 3. The total average mean value of “ME” was determined as follow:

$$\begin{aligned} &\text{Total average mean value of all sub-criteria under the criterion “ME”} \\ &= 3.94 + 4.17 + 4.11 = 12.22 \end{aligned}$$

Meanwhile, the average weight values of the main criteria were determined based on the averaging calculations computed on the average mean value of each criterion as shown in Table 5 with the total number of the sub-criteria of the criterion they contribute, respectively. The calculations of average weight values of all criteria were using Equation (2). Given the main criterion “ME” as an example, the weight value was computed as follows:

The weight of each criterion was determined by dividing the average mean value of the main criterion “ME” (Table 4) which is 22, with the total number of the sub-criteria placed under the main criterion “ME” which is 3. The output for the main criterion “ME” is computed as 4.07 (Table 5). Similar calculations were conducted to all criteria to determine the average weight value of all the main criteria. Table 5 summarised all the output values of the main criteria weight in average.

Table 5: Average weight value of main criteria for all categories

Category	Main criteria	Average mean value
Causes of cargo damage	ME	4.07
	HF	3.93
	MC	3.83
	EF	3.50
	TP	2.71
Strategies to prevent and minimise cargo damage	SOP	4.25
	CT	4.31
	PM	4.46
	DT	4.31

The average weight contributions of main criteria were interpolated into a spider web or radar chart presentation to describe

the average contribution of all main criteria on every category. Based on Figure 2, there were five parameters tested to determine their

contributions. Each coloured line with a dot represented a parameter. The contribution of each parameter was determined to the weighted number of distractions which contributed. The nearer the dotted coloured line to the group, the more significant/the higher the number of distractions that the parameter influences the group. If all the dotted coloured lines are at almost the same point in a particular group, such illustration shows that the group was experiencing a significant problem with the parameters tested.

Figure 2 illustrates the ranking of the five primary causes of cargo damage namely, Machinery Equipment (ME), Human Factors (HF), Marine Incidents (MC), Environmental Factors (EF), and Theft and Pilferage (TP),

based on their calculated average weight values. The chart clearly demonstrates that ME with a score of 4.07 and HF at 3.93 exert the strongest influence on cargo damage, as evidenced by their axes extending furthest toward the outer edge of the radar. This visual representation aligns with the survey findings, which identify aging equipment and human error as the most critical risks. Meanwhile, EF at 3.50 and TP at 2.71 appear closer to the centre of the chart, indicating their relatively lesser but still notable impact, particularly in specific scenarios such as the transport of perishable goods or operations in high-theft regions. The proximity of each criterion's axis to the outer edge serves as a direct indicator of its contribution to cargo damage, with ME and HF dominating the analysis.

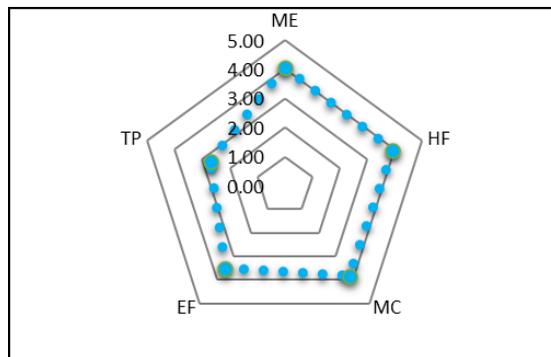


Figure 2: Average weight contribution of all main criteria for causes of cargo damage

Similarly, Figure 3 presents the average weight values of the four key mitigation strategies: Standard Operating Procedures (SOP), Continuous Training (CT), Proper Maintenance (PM), and Digitalisation and Technology (DT). Here, Proper Maintenance (PM) emerges as the most effective strategy with the highest score of 4.46, its axis reaching the outermost point on the chart. This underscores the critical role of regular equipment upkeep in preventing machinery-related failures, which were identified as a leading cause of damage. CT and DT, both scoring 4.31, follow closely

behind, reflecting their importance in addressing human factors and operational inefficiencies through skill development and technological integration. SOP, while still significant with a score of 4.25, ranks slightly lower, suggesting its role as a foundational measure that supports and enhances the other strategies. The near-equilateral triangle formed by the axes of PM, CT, and DT in the chart highlights the balanced and synergistic approach required for effective risk mitigation, where maintenance, training, and technology work in concert to minimise cargo damage.

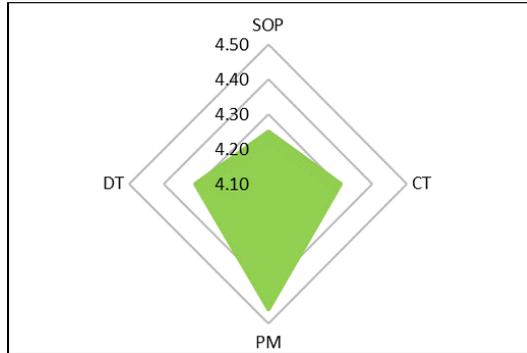


Figure 3: Average weight contribution of all main criteria for causes of potential strategies

Together, these spider web charts provide a compelling visual confirmation of the quantitative data presented in Table 5, reinforcing the study's key findings. They reveal that ME and HF are the primary drivers of cargo damage, necessitating targeted interventions such as PM and CT. Moreover, the charts emphasise that while PM stands out as the highest-priority solution, its effectiveness is maximised when integrated with DT, such as predictive maintenance tools, and Continuous Training programs for personnel. The symmetry observed in Figure 2 further supports the conclusion that a holistic strategy which combine maintenance, training, and technology, yields the most robust results. These visual aids not only enhance the clarity of the analysis but also provide stakeholders with an intuitive understanding of where to focus their efforts for optimal risk reduction in cargo transportation.

Discussion

The findings of this study highlight the critical factors contributing to cargo damage in containerised shipping, with ME and HF emerging as the most significant contributors. The ME category, with the highest average mean value of 4.07, underscores the pivotal role of equipment condition in cargo safety. Ageing machinery, inadequate maintenance, and technical deficiencies were identified as primary risks, aligning with prior research (Balisampang *et al.*, 2018; Kaup *et al.*, 2022). These issues often lead to operational failures during loading and unloading, emphasising the

need for proactive maintenance schedules and timely upgrades to modern, safer equipment.

HF followed closely behind scoring 3.93, which reflects the substantial impact of human error on cargo integrity. Key issues with human factors with HF include mishandling during crane operations, misdeclaration of cargo (particularly hazardous materials), and communication gaps among stakeholders (Oktaviani *et al.*, 2018). These findings suggest that while technological advancements in equipment are vital, human-centric interventions such as standardised training programmes and clear communication protocols are equally critical to mitigate risks.

Marine Incidents or Maritime Collisions (MC) and Environmental Factors (EF) also posed notable risks, with average scores of 3.83 and 3.50, respectively. Collisions, fires, and extreme weather conditions were recurrent themes, corroborating studies by Zhang *et al.* (2019) and Lam and Lassa (2017). These factors, though less controllable, necessitate robust contingency planning, including advanced weather routing and stricter adherence to international safety regulations. The lowest-ranked factor, TP (2.71), indicates a relatively smaller but persistent threat, particularly in high-risk regions (Liang *et al.*, 2022).

Mitigation strategies in this area should focus on improved surveillance, secure parking sites, and better cargo tracking. In terms of mitigation, PM emerged as the most effective strategy (4.46), validating the need for structured maintenance protocols and predictive

diagnostics. CT and DT also received high scores (4.31 each), supporting the notion that skill development and technological integration offer synergistic benefits in operational safety. Notably, SOPs, while slightly lower at 4.25, serve as the foundational framework that enhances and supports all other interventions.

While the findings contribute valuable insights into container cargo risk assessment, several limitations must be acknowledged. First, the sample size was relatively small ($n = 20$), which may constrain the generalisability of results. Although respondents were carefully selected based on expertise, a larger and more diverse respondent pool would enhance statistical robustness. Second, the study's scope was geographically confined to the Malaysian shipping industry conditions, which may not fully capture global variances in infrastructure, regulatory enforcement, or weather conditions.

This regional focus, while contextually rich, may limit direct applicability to ports or logistics systems in other regions. Third, the research focused exclusively on containerised cargo, thereby excluding other significant segments such as breakbulk, liquid bulk, or reefer logistics. These categories may present unique risk profiles and mitigation strategies not addressed in this framework.

Despite these limitations, the study offers important implications for maritime policy and operational regulation. The findings can inform the development or revision of SOPs, particularly in areas involving machinery inspection cycles, human error mitigation, and cargo handling best practices. Regulatory authorities, such as port authorities and maritime safety bodies, could integrate these findings into mandatory training programs, port safety audits, or vessel inspection checklists. Moreover, the prioritisation framework proposed in this study provides a data-driven basis for risk management policies.

Port operators and shipping companies can use this hierarchy of risk factors to allocate resources more effectively, directing investments toward high-impact areas like equipment

maintenance and digital monitoring systems. At the policy level, the study underscores the need for harmonised cargo safety standards that bridge operational best practices with technological advancements, particularly in the Association of Southeast Asian Nations (Asean) region where regional trade is expanding rapidly. Incorporating risk-based cargo damage assessments into national maritime safety guidelines could elevate compliance and enforcement mechanisms.

Conclusions

This study developed a structured framework to identify and prioritise the causes of cargo damage in containerised shipping, highlighting machinery failures and human factors as the most significant contributors. Of the mitigation strategies, proper maintenance, continuous training, and digital technology integration were seen as the most effective solutions. By applying a hybrid Likert, spider web approach, shipping companies and port operators can more precisely direct operational and financial resources to high-impact areas. This targeted approach could reduce cargo damage incidents and related insurance claims by an estimated 15 to 25% annually, based on industry benchmarks from prior research. The findings underscore the need for systematic SOP enforcement, predictive maintenance protocols, and personnel upskilling to ensure safer cargo handling. Investing in digital solutions like IoT-based container monitoring, real-time weather routing, and AI-powered risk analytics further strengthens preventive capabilities.

At the policy level, this framework offers a quantitative basis for regulatory updates. Port authorities can adopt the prioritisation model to enhance safety audits, equipment inspection cycles, and operational licensing criteria. International regulators such as the International Maritime Organisation (IMO) and International Organisation for Standardisation (ISO) can leverage the findings to refine global standards on cargo securing, terminal equipment maintenance (e.g., ISO 3874), and human factor training (e.g., Standards of Training, Certification and Watchkeeping for Seafarers

(STCW) Code). Integrating this model into regional or international maritime safety frameworks will also help harmonise safety practices, particularly across Asean ports, where containerised trade continues to expand rapidly.

To further enhance the robustness and applicability of the proposed framework, future research should consider several key areas. First, expanding the sample size across a broader range of geographical regions and port types would allow for more representative and generalisable insights, especially considering differences in regulatory enforcement, infrastructure quality, and operational practices. Second, there is a pressing need to apply this risk prioritisation model beyond containerised cargo to other major shipping segments such as refrigerated (reefer) containers, roll-on/roll-off (Ro-Ro) vessels, and bulk cargo terminals. These cargo types present unique risk profiles, including temperature sensitivity in reefers, vehicle movement in “roll-on roll-off” (Ro-Ro) operations, and stability issues in bulk shipments. Exploring these segments could reveal new factors or alter the weight of existing ones in the cargo damage equation. Lastly, the integration of automation and Artificial Intelligence (AI)-driven safety systems warrants thorough investigation.

Technologies such as predictive maintenance, autonomous cranes, and AI-assisted cargo planning could play a transformative role in minimising both human error and mechanical failures. Together, these research directions would not only validate the current framework across diverse contexts but also contribute to a more adaptive and future-ready maritime risk management model.

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Conflict of Interest Statement

The authors declare that they have no conflict of interest.

Author Contributions Statement

Study conception and design: Nurul Aisyah Abu Talib, Mohammad Khairuddin Othman, Rudiah Md Hanafiah; Data collection: Mohammad Khairuddin Othman; Analysis and interpretation of results: Nurul Aisyah Abu Talib, Mohammad Khairuddin Othman, Izyan Munirah Mohd Zaideen, Rudiah Md Hanafiah; Draft manuscript preparation: Mohammad Khairuddin Othman, Izyan Munirah Mohd Zaideen, Nur Farizan Tarudin; Supervision and review: Rudiah Md Hanafiah.

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