OVERHEAT
INNOVATIVE STRATEGIES FOR CONTAINERSHIP FIRES PREVENTION AND MANAGEMENT

Deliverable title:	Findings Report regarding knowledge about fire causes in cargo spaces and loss of container
Deliverable ID:	D 2.1
Document version:	V1.0
Partner responsible:	ISaSS
Due date:	30.09.2024

Funded by the European Union

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement Project No: 101076633. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them.

Document Control Sheet

Deliverable number	**D 2.1**
Deliverable name	**Findings Report about the state-of-the-art of fire causes in cargo spaces and loss of container**
Dissemination Level	**PU - Public**
Call	**HORIZON-CL5-2022-D6-01**
Topic	**HORIZON-CL5-2022-D6-01-08-Safer navigation and tackling containership fires**
Consortium Coordinator	**IMAT**
Partner responsible for the deliverable	**ISaSS**
Edition	**1.0**

Authors of the document

Authors of the document - Representatives of beneficiaries involved in the project		
Name/Beneficiary	Position/Title within the project	Date
Josephine Gerlach	Researcher at ISaSS	16/09/2024
Lennard John	Researcher at ISaSS	24/09/2024
Prof. Dr. Dominic Kudlacek	Leader of the WP/Head of the Institute	24/09/2024
Valentina Lasco	IMAT	30/09/2024
Gianna Giovanditti	IMAT	30/09/2024

Reviewers of the document

Appointed reviewers of the document - Representatives of beneficiaries involved in the project		
Name/Beneficiary	Position/Title within the project	Date
Vittorio Sangermano	ISSNOVA	24/09/2024
Daniele Palma Esposito	ISSNOVA	24/09/2024
Pedro Merino Laso	Researcher at ENSM	25/09/2024
Hasan Ahmad	Researcher at ENSM	25/09/2024
Marcus Engler	Researcher at ISL	25/09/2024
Gunnar Tietze	WP6 Leader / SeaTopic	25/09/2024
Valentina Lasco	IMAT	30/09/2024
Gianna Giovanditti	IMAT	30/09/2024
Diego Esposito	IMAT	30/09/2024
Modestino Manfredi	IMAT	30/09/2024

Responsible for the document approval

List of people approving the document - Appointed beneficiaries involved in the project		
Name/Beneficiary	Position/Title within the project	Date
Marco Pasciuto	Project Manager / IMAT	09/10/2024
Gunnar Tietze	WP6 Leader / SeaTopic	09/10/2024
Simone Panfiglio	Researcher / C&T	09/10/2024
Bartosz Dziugieł	Researcher / ILOT	09/10/2024
Vittorio Sangermano	Researcher / ISSNOVA	09/10/2024
Daniele Palma Esposito	Researcher / ISSNOVA	09/10/2024

ABSTRACT

Fires in cargo spaces on container ships represent a significant threat to the maritime industry from both economic and safety perspectives. The loss of containers, along with potential damage to vessels, cargo, and the environment, underscores the need for in-depth research into the causes of these fires and their consequences. This report presents an analysis of the causes of fires in cargo spaces and the associated loss of containers over the past 15 years.

This analysis follows three key steps: (1) identification of fire accidents (including container loss) in the last 15 years, (2) collection of detailed information about the identified incidents, and (3) identification of knowledge gaps in this field. By conducting this review, the aim is to better understand the underlying causes and effects of such incidents and thereby contribute to the improvement of fire prevention and safety measures on container ships.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

ADN	European Agreement Concerning the International Carriage of Dangerous Goods by Inland Waterways
ADR	European Agreement Concerning the International Carriage of Dangerous Goods by Road
AGCS	Allianz Global Corporate & Specialty
AI	Artificial intelligence
BIMCO	Baltic and International Maritime Council
BSU	Bundesstelle für Seeunfalluntersuchung
CCTV	Closed-Circuit Television
CSC	Container Safety Convention
CSIMA	Container Shipping Interchange Management Association
CTU	Code of Practice for Packing of Cargo Transport Units
EMSA	European Maritime Safety Agency
EU	European Union
ICS	International Chamber of Shipping
IMDG	International Maritime Dangerous Goods Code
ILO	International Labour Organization
IMO	International Maritime Organization
ISO	International Organization for Standardization
IUMI	The International Union of Marine Insurance
MAIB	Marine Accident Investigation Branch
MLC	Maritime Labour Convention
SoA	State-of-the-Art
SOLAS	International Convention for the Safety of Life at Sea
STCW	International Convention on Standards of Training, Certification, and

	Watchkeeping for Seafarers
UNECE	United Nations Economic Commission for Europe
WSC	World Shipping Council

INTRODUCTION

In recent years, fires on container ships have caused increasing concerns worldwide. These incidents not only pose a serious threat to the safety of human life and ships, but also result in significant economic losses and environmental damage. The complex and often dangerous cargoes that container ships carry significantly increase the risk of fires. In particular, incorrectly declared or inadequately secured dangerous goods have led to several serious incidents [1].

Over the last decade and a half, the shipping industry has made significant advances in technology and operating practices. From 2008 to the present day (2024), there have been numerous documented cases of fires in the holds of container ships, often resulting in significant losses of cargo containers. These fires resulted from a variety of causes, including misdeclared dangerous goods, electrical faults, human error and inadequate safety measures. A particularly worrying example is the fire on the "Maersk Honam" in 2018, which led to significant losses, five dead crew members and an intensive investigation into the underlying causes. Such events underline the need to review and improve existing safety measures. [2]

The OVERHEAT ("Innovative Strategies for Containership Fires Prevention and Management") research project was launched to systematically tackle these challenges. The aim of the project is to develop innovative strategies and technologies for the prevention and management of fires on container ships. The aim is not only to improve the protection of the crew and the ships, but also to minimize the loss of containers and reduce the environmental impact.

OVERHEAT WP2 aims to analyze the causes of fires, evaluating current safety guidelines and formulate concrete recommendations on container vessel safety. The Project will help to significantly raise safety standards in the shipping industry, which is crucial to maintaining confidence in global container transportation and promoting the sustainability of maritime transport.

This findings report aims to analyze the current State-of-the-Art (SoA) and knowledge about the causes of fires in cargo holds and the loss of containers. It examines the most common causes, the identified risk factors and the existing safety measures. The report is supported by case studies and statistical analysis to provide an in-depth understanding of the issue.

This deliverable of task 2.1 includes:

- A detailed analysis of the causes of fires of container ships.
- A listing and analysis of the most relevant existing international, European and national safety guidelines (as well as best practices).
- The identification of gaps and vulnerabilities in current safety protocols.

For this report, the most important open-source accessible fires on container ships since 2008 were considered. However, there may have been other smaller incidents that were not as widely documented.

1. METHODOLOGY

The methodology for conducting the SoA analysis to collect data on container ship fires and container losses over the last 15 years comprises systematic steps. These steps are designed to collect, analyze and evaluate comprehensive and reliable information. This SoA analysis is carried out in three consecutive steps:

1. **Identification of fire accidents (including loss of containers) in the last 15 years**: various sources of information are used to record relevant fire accidents in order to ensure the most comprehensive inventory possible. The literature and database reviews are divided into two main steps. In the first step, relevant databases were identified in order to ensure a comprehensive and well-founded data basis. Three distinct database types were utilized to ensure the inclusion of the maximum amount of freely available data. These types include:

   - Scientific databases;
   - Industry-specific databases;
   - Accident and incident databases.

   First, general search engines such as Google and Google Scholar were used to obtain a broad overview of publicly available information and scientific articles.

   In addition to the conventional database queries, an AI-supported tool was also used to refine the research and track down relevant sources that may have been overlooked. Among other things, this method was used to identify the first relevant databases for the extended search. The tool was also used to compare the resulting list and identify any missing accidents or sources.

   The following sources and databases were used during the research:

   - Allianz Global Corporate & Specialty (AGCS) Safety and Shipping Review;
   - World Shipping Council (WSC);
   - The Standard Club;
   - Marine Accident Investigation Branch (MAIB);
   - The International Union of Marine Insurance (IUMI);
   - Bundesstelle für Seeunfalluntersuchung (BSU);
   - CSIMA, Container Shipping Statistics;
   - Lloyd's List;
   - TradeWinds;
   - International Maritime Organization (IMO);
   - Container Shipping Interchange Management Association (CSIMA);
   - MarineTraffic database.

To minimize the possibility of data lacks, additional (back-up) research in newspapers (both online and offline), social media, professional journals, academic peer-reviewed journals and textbooks focused on fire safety on container ships has been done. Although the probability of discovering new data is low, this process serves to validate the findings of previous investigations.

In the subsequent phase of the investigation, a methodical approach was adopted to develop targeted search strategies to facilitate the identification of relevant keywords. This deliberate process enabled a rigorous and systematic search for information that ensured a comprehensive investigation of all relevant accidents and incidents. Once the preparatory steps were completed, the following keywords were used as search parameters in the systematic database search, ensuring a thorough and comprehensive review of the existing literature:

- fire causes in cargo spaces;
- containership fires;
- container ship safety;
- container ship fire safety;
- container loss incidents;
- container loss on ships;
- cargo space fire causes;
- cargo ship fire incidents;
- cargo ship fire prevention;
- cargo fire statistics;
- dangerous goods transport incidents;
- flammable materials on ships;
- marine fire hazards;
- maritime fire prevention;
- maritime fire risks;
- maritime accident reports;
- global container fire incidents;
- fire-related container loss;
- ship fires container loss news.

2. **Collection of detailed information on the identified fire accident**: once relevant fire accidents have been identified, a list of criteria (rubric) is developed to systematically collect information on the accidents. The list of criteria utilized in this report is substantially derived from the standard documentation for ship fires published by the IMO (MSC-MEPC.3-Circ.4). The rubric for systematically collecting information on maritime fire incidents plays a crucial role in analyzing and understanding key details of each event, facilitating the identification

of trends and critical areas. Each aspect covered by the rubric provides specific insights into future prevention and risk management strategies:

- **Title and Vessel Name**: Clear identification of the vessel involved is essential for comparing similar incidents and conducting a historical analysis of recurring issues on specific ships.
- **Year**: Collecting information on the year of the incident allows for tracking the evolution of fire incidents over time, assessing whether conditions are improving or worsening, particularly with the adoption of new regulations or technologies.
- **Ship Size**: Understanding the ship's capacity, particularly the number of containers transported, provides insights into the scale of the risks associated with cargo and stored materials, as well as the efficiency of fire prevention measures.
- **Cause of the Fire**: Identifying the source of the fire is critical for determining areas where preventive measures need to be strengthened, such as detection systems or hazardous materials management.
- **Time of the Incident**: Analyzing the time of day when fires occur helps in understanding the influence of human factors, such as crew fatigue or vigilance, and the effect of natural lighting conditions.
- **Location of the Incident**: Identifying specific locations where incidents occur.
- **Weather Conditions**: Weather plays a significant role in the development and severity of a fire. Factors such as wind, humidity, and temperature can either accelerate or slow the spread of flames.
- **Brief Description of the Incident**: Providing a summary of the specific circumstances allows for the identification of patterns and similarities between different incidents that may require attention.
- **Damage**: Assessing the extent of damage caused by the fire, both to the ship and the cargo, is essential for understanding the economic and structural impact of the event and improving risk management.
- **Description of Firefighting Equipment (Technical)**: Detailing the tools and systems used to combat the fire helps in identifying best practices or inefficiencies in technical responses to emergencies.
- **How the Incident Was Fought**: Analyzing how the fire was handled enables the identification of effective strategies and potential operational errors in emergency procedures.
- **Loss of Cargo**: Evaluating the extent of cargo loss helps to better understand the financial impact of the incident and the vulnerabilities of the transported goods.

The results and data were validated and, where possible, supplemented by comparison with official reports and statistics from recognized institutions and organizations.

An example of the table used for the analysis can be found in the appendix of the document.

3. **Identification of knowledge gaps in the area of fire causes and container losses:** the information collected was then analyzed to identify existing knowledge gaps. This analysis is relevant to raise awareness of which safety and preventive measures are crucial to prevent and manage fires on board container ships.

   Even if significant research and reporting is available, there are still critical areas where information is lacking. Indeed, potential knowledge gaps include the fact that some fire incidents may be poorly documented, or essential details about the causes, responses, or preventive measures may be missing or not published. Although there are many regulations and guidelines for fire prevention, safety gaps still emerge. Given that container ships operate internationally, numerous stakeholders are involved in fire prevention and response efforts. Coordination and implementation of safety standards across jurisdictions may be problematic. Often, the immediate costs and damages of a fire are the focus, while long-term impacts on the environment and the broader economy may be insufficiently explored.

   Through this systematic methodical approach, the OVERHEAT project ensures that all relevant data and information on fires on container ships and container losses are thoroughly researched, analyzed and evaluated in order to develop well-founded and practical solutions to improve maritime safety.

1.1 Challenges in Documentation and Open Source Access

One of the most critical findings is the challenge of obtaining comprehensive and reliable data on fire incidents and their causes. Despite the global nature of the shipping industry, open access to detailed accident reports remains limited. This lack of transparency complicates efforts to conduct thorough analyses and draw reliable conclusions.

- **Inconsistent Reporting Standards**: Different national authorities and organizations maintain varying standards for reporting fire incidents. As a result, many reports lack the detailed information needed to fully understand the circumstances and causes of fires. Critical data, such as the type of cargo involved, weather conditions, and crew response, is often missing or incomplete.
- **Limited Access to Industry Data**: Some maritime organizations and insurance companies collect comprehensive data on fire incidents, but this information is often proprietary or restricted. The lack of open-source data limits the ability of independent researchers, safety experts, and other stakeholders to perform cross-industry comparisons and analyses.
- **Gaps in Media and Academic Coverage**: While major fire incidents are typically covered in media outlets, many smaller incidents or near misses go unreported. This creates a skewed perception of the true scale of fire risks in the industry. Additionally, academic research on

container ship fires is often fragmented and lacks coordination, further contributing to knowledge gaps.

- **Fragmentation of Data Sources**: Researchers face difficulties in aggregating information from a wide variety of sources, including government databases, industry reports, and academic publications. Without a centralized repository of fire incident data, conducting a comprehensive and systematic analysis remains challenging.

Addressing these documentation challenges requires a concerted effort from all stakeholders involved in maritime safety. Establishing a standardized global database for reporting fire incidents, accessible to researchers, regulators, and industry professionals, would be a crucial step forward. This would allow for better tracking of fire incidents, improved analysis of trends, and the development of more effective preventive measures.

Improved transparency from shipping companies and insurers would also enhance the industry's collective knowledge. Sharing non-sensitive data on fire incidents, particularly near-miss events and smaller-scale fires, could provide valuable insights into potential hazards and best practices for fire prevention and response.

2. RESULTS OF THE STATE-OF-THE-ART (SOA) ANALYSIS

As already claimed in the previous chapters, a data-driven, SoA analysis of the causes of fires and the associated container losses during this period is essential in order to identify safety gaps and develop effective prevention and response strategies.

Fire prevention and firefighting on container ships have become critical areas of focus due to the increasing size of vessels and the complexity of cargo. As reported in the CARGOSAFE Report the number of fire accidents on board the ships is increasing over the years since 1997. OVERHEAT will investigate the fire accidents from 2008 to 2023. The following graph, count the fire accidents occurred over the last 15 years:

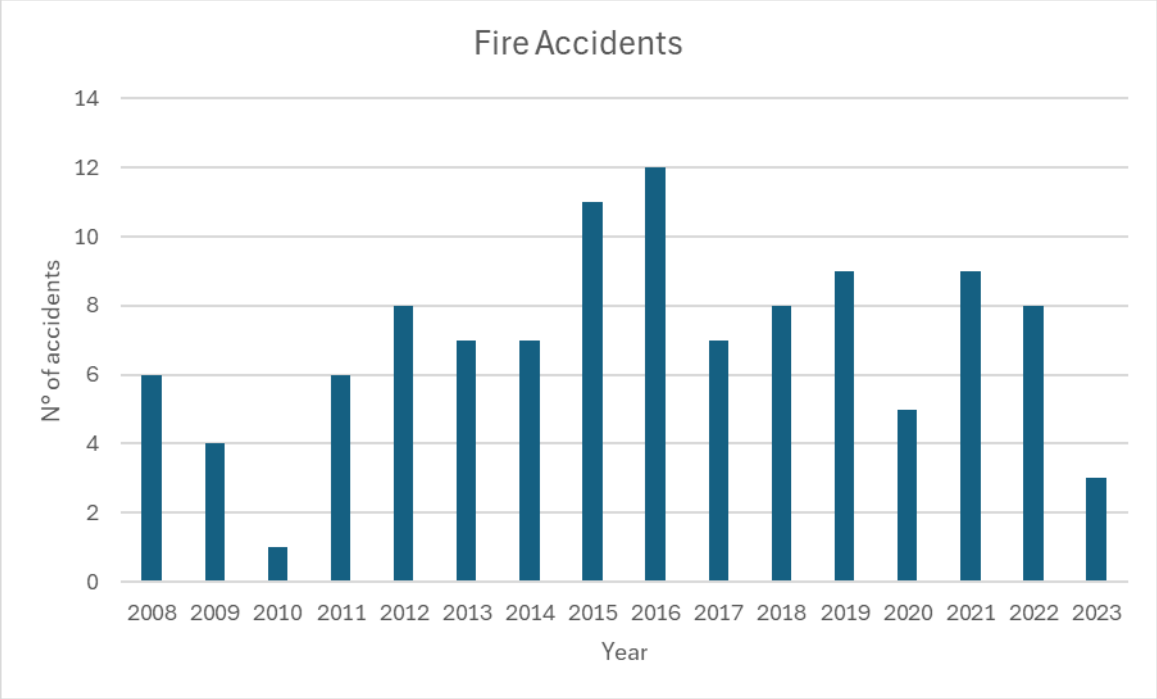

Figure 1 - Fire accidents from 2008 to 2023

The sources are the CARGOSAFE report and the Safety and Shipping Review 2024 developed by Allianz Commercial. The graph takes into consideration all the fire incidents reported and documented for a total of 135. It includes both the cargo stowed in hold and on decks. Over the last 15 years, the number of fire accidents has increased to respond to the continues commercial pushing and increase of vessels size and capacity.

The research and analysis of fire incidents on container ships resulted in an initial identification of 135 fire-related accidents, which were gathered through a comprehensive review of open-source data, including articles, specialized databases, accident reports, and an AI-based database query. However, during the review process, this number was reduced to 85 unique incidents, as 30 to 40 duplicate cases were identified and removed. The differences in reported accident numbers across sources—such as those found in industry reports like the Allianz report—highlight inconsistencies in the data, often due to varying definitions and reporting standards, as described in the Methodology section.

In many cases, incidents were either mentioned by name in reports without detailed data available in open-source formats, or specific accident information was missing altogether. Of the 85 unique incidents, detailed information could be obtained for 31 cases, providing valuable insights into the causes and outcomes of these accidents. This refined list forms the basis for the analysis of fire safety measures and trends on container ships.

2.1 Locations of fire accidents

The CARGOSAFE can be utilized to gain a comprehensive understanding of the locations with the highest probability of fire accidents occurring.

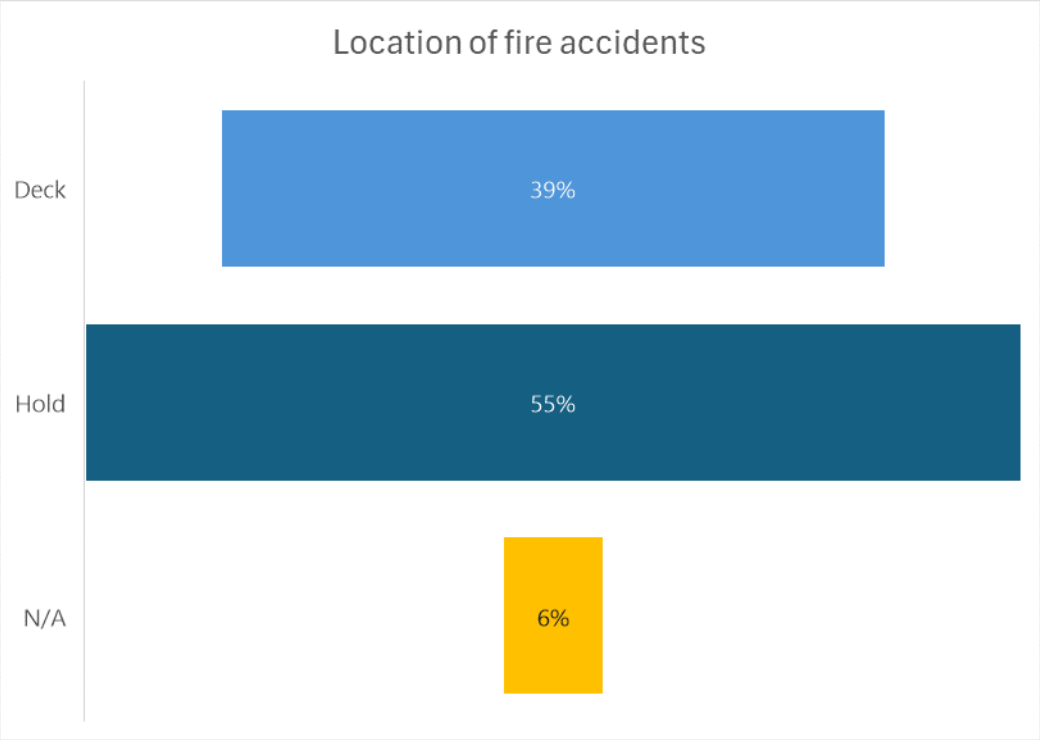

Figure 2 - Fire Accidents location

The area within the hold appears to be the most probable location for a fire accident to occur, with a probability of 55%. This is due to the tendency of loading operators to fill the holds to their maximum capacity. It can be reasonably deduced that in the event of a dangerous cargo being misdeclared (or incorrectly located) in an inaccessible area, it will be impossible to reach it and implement mitigation actions, which could potentially result in destructive damage or, in the worst-case scenario, significant losses. The probability is slightly lower on the deck (39%) due to the loading operators not utilizing the full capacity, leaving some spaces for crew surveillance or, typically, the decks are utilized for transporting empty and lighter containers. In the remaining 6% of cases, no information was available regarding the location of the accident.

2.2 Misdeclared cargo

Another important parameter to take into account is the misdeclared dangerous cargo in the origin of fire occurrence.

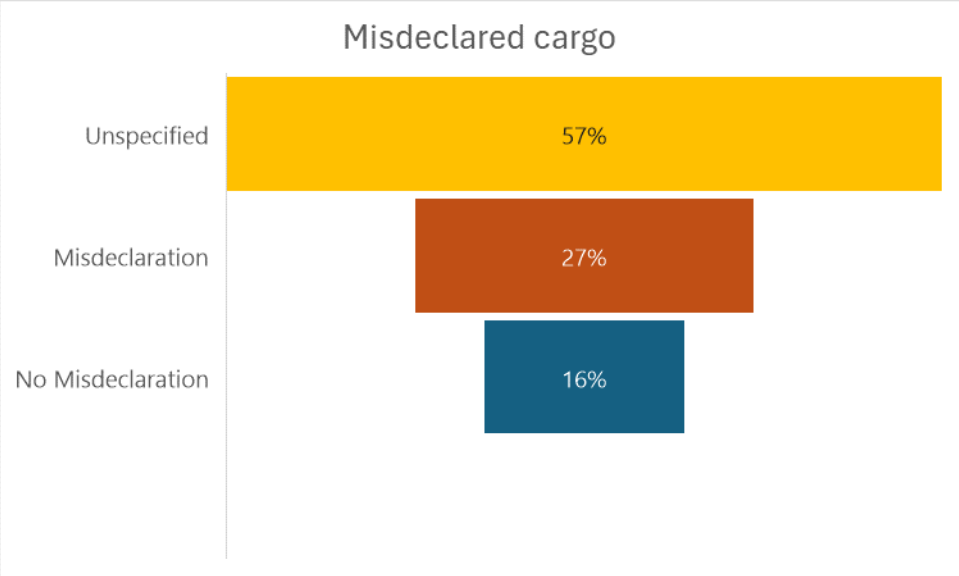

Figure 3 - Misdeclared cargo

As reported in the CARGOSAFE report, most of the fire accidents are "unspecified" due to was not possible to know whether the cargo was correctly located or not. However, for this reason the unspecified cargo will be considered as correctly declared due to there are no mention about misdeclaration. In this perspective, only the 27% of fire accidents are caused by misdeclared cargoes.

The SoA analysis continues with the detail of key parameters such as: (i) Vessel size, (ii) Accident time, (iii) fire cause, (iv) number of accidents (including loss of containers), (vi) extent of the fire, (vi) Location of the accident and (vii) primary causes.

2.3 Sizes of involved vessels

The research encompassed a comprehensive analysis of 85 datasets, which enabled the identification and categorization of vessels based on their respective lengths. The resultant classification revealed a diverse range of vessel types, including: Inland waterway vessels, measuring less than 130 meters in length (n= 3); Container feeders, characterized by lengths of less than 200 meters (n= 6); Panamax vessels, defined by lengths of less than 294 meters (n= 24); Post-Panamax vessels, marked by lengths of less than 370 meters (n= 33); and Ultra-Large Container Vessels, distinguished by lengths exceeding 371 meters (n= 13). A small subset of 6 datasets, however, lacked sufficient data to be accurately classified within these categories.

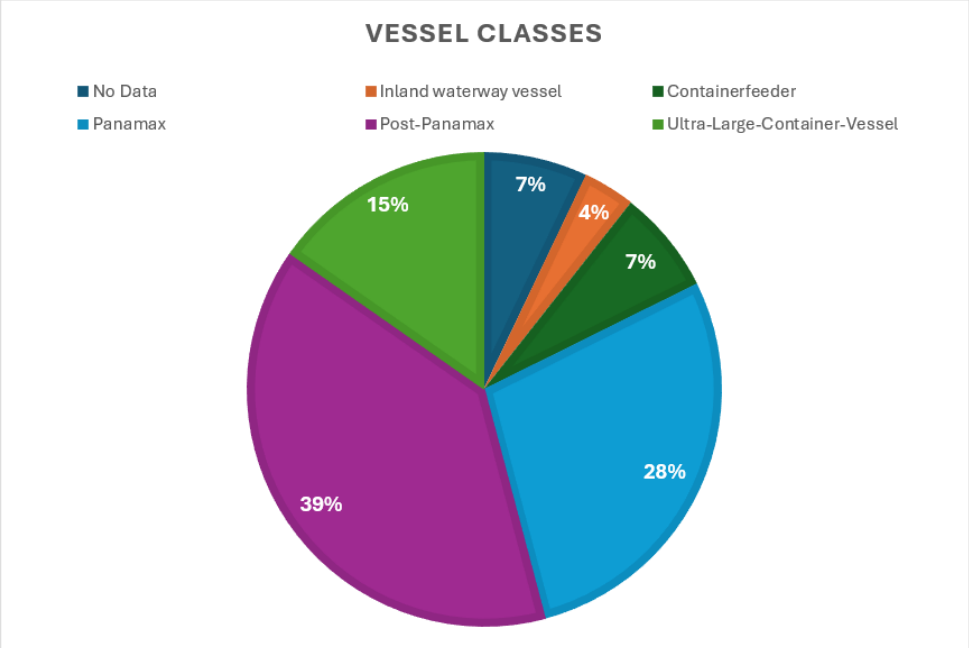

Figure 4 Vessel classes of fire incidents

2.4 Daytime of accidents

26 of the 85 cases that were identified within the research includes reliable information on the daytime of the incident. The analysis of fire incidents on container ships reveals a discernible trend in the timing of these incidents. A significant proportion of incidents occur during the morning hours (06:00-12:00), with a relative frequency of 26.92% (n=7). This concentration of incidents during the morning hours suggests that this period is particularly vulnerable to fire-related risks. Furthermore, the midday period (12:00-14:00) also exhibits a relatively high frequency of incidents, representing 15.38% (n= 4) of all incidents. It is important to note that this is a considerably shorter period of time. In contrast, the evening period (18:00-22:00) is characterized by a markedly lower frequency of incidents, with only two incidents (7.69%) recorded. This reduction in the incidence of accidents can be attributed to a number of factors, including a reduction in vessel activity or the implementation of enhanced safety protocols during this period. The overall number of incidents is highest at night and in the early hours of the morning (22:00-06:00). The probability of documented fires occurring in the dark is 34.61% (n=9).

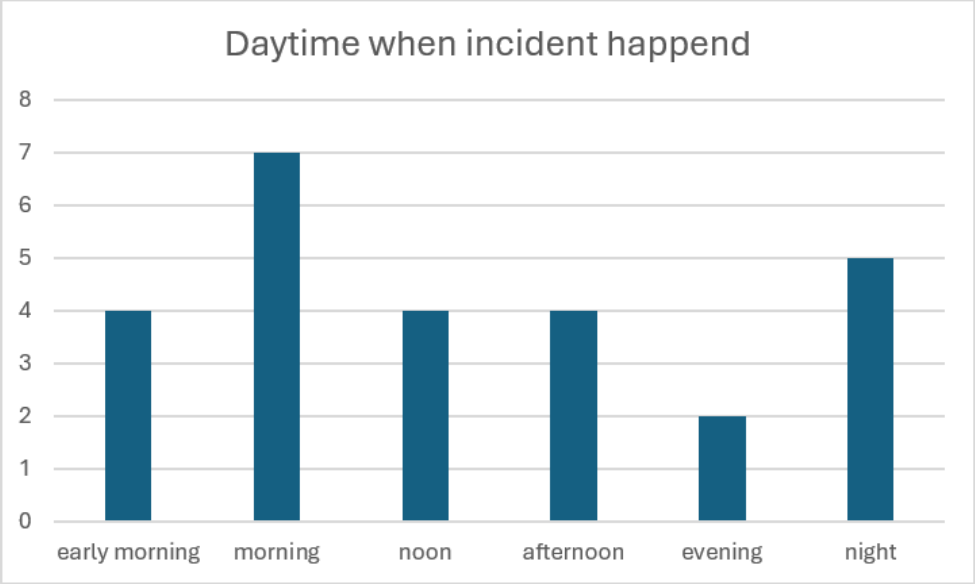

Figure 5 Daytime when the accident happened

2.5 Cause of fire

Of the 85 cases included in the dataset, 27 contain reliable information on the cause of accident. The analysis showed that the majority of fires on container ships (92.6%, n = 25) originated from the cargo itself. This indicates that the cargo being carried poses a significant fire risk, emphasising the need for adequate cargo handling, storage and monitoring procedures. As a rule, these are (chemical) hazardous substances that have the property of spontaneous combustion under certain conditions. In contrast, fires originating from the ship itself accounted for only 7.4% (n = 2) of the incidents, indicating that the ship's systems, machinery and equipment are relatively safe and the risk of fire from these sources is relatively low. It is noteworthy that there were no fires originating from outside the ship (n = 0), indicating that external factors, such as other ships or intentional damage, do not pose a significant fire risk to container ships.

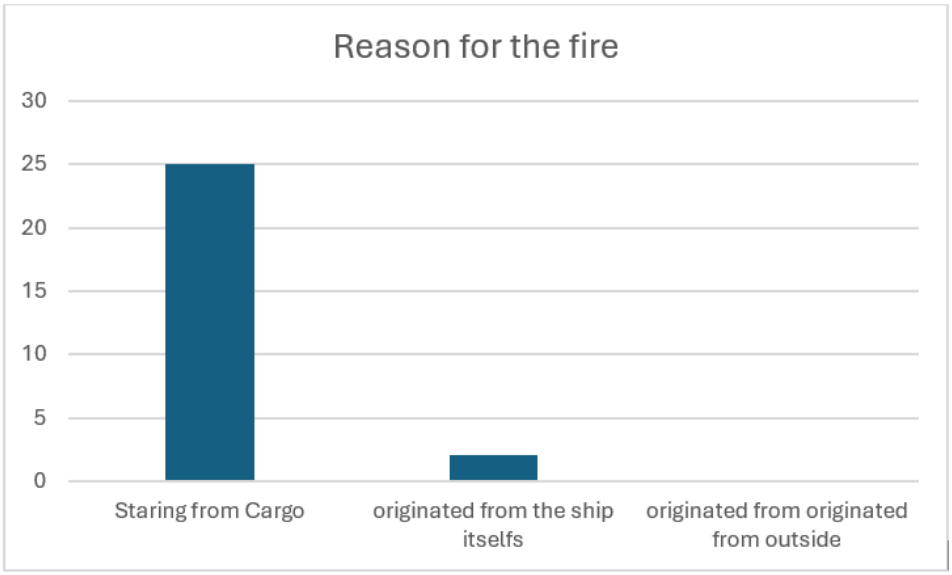

Figure 6 Reason for the fire incident

2.6 Number of accidents with container losses

The availability of reliable data on the loss of containers in such incidents is very limited. Analysis of publicly available data (n=85) suggests that approximately 24.7% (n=21) of ship fires result in a documented container loss, while 75.3% (n=64) do not.

The data used in this study comes from a variety of sources, including news articles, industry reports and government databases. However, the limitations of the data, including lack of consistent reporting, variable reporting standards and incomplete information, may have skewed the results.

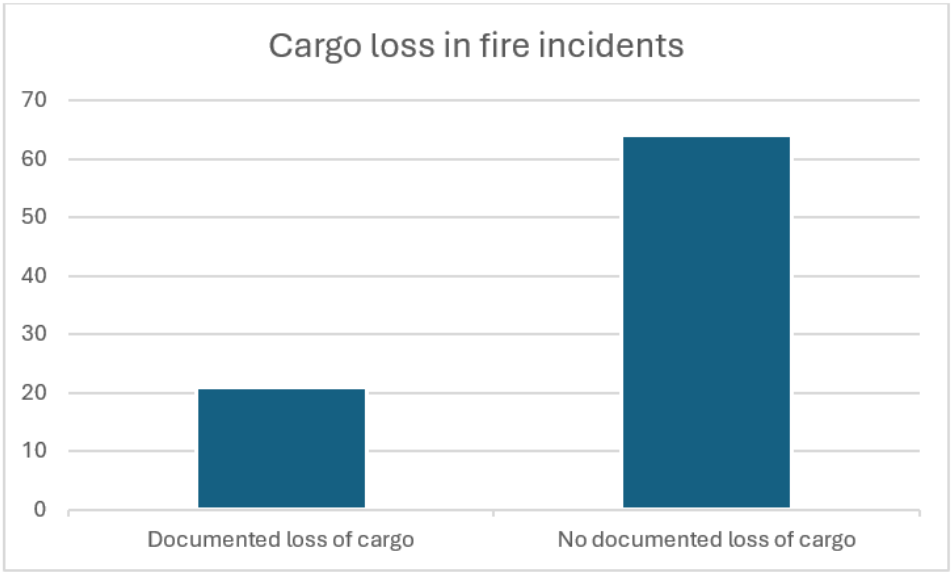

Figure 7 Cargo loss in fire incidents

2.7 Extent of the fire

A total of 32 data records, representing 38% of the total, contain information that can be used to assess the damage caused by the fire on board. Given the notable discrepancies in the quality of the information, damage classes were created to provide a more comprehensive illustration. In instances where fatalities occurred, both material damage and loss of life are accounted for. The damage classes are defined as follows:

- Minor damage = Loss or damage of a few containers (vessel fit to sail)
- Minor structural damage = Smaller damages on the vessel (vessel fit to sail)
- Major damage = Loss or damage of a significant amount of containers (vessel fit to sail)
- Major structural damage = Significant damage on the vessel (vessel not fit to sail)
- Total ship loss = ship sank or was subsequently scrapped (vessel not fit to sail)
- Incidents including deaths = At least one dead person due to the effects of the incident

Examination of the data revealed a statistically significant dichotomy in the severity of marine casualties. Specifically, the cumulative frequency of minor damage, which included both minor damage (n = 13) and minor structural damage (n = 1), was found to account for 43.75% (n = 14) of the total data set (N = 32). Conversely, the total frequency of major damage, comprising major structural damage (n = 8), major damage (n = 5) and total loss of the vessel (n = 5), accounted for 56.25% (n = 18) of the total incidents.

The resulting proportions indicate a discrepancy between the frequency of minor and major damage, with major damage occurring 1.29 times more frequently than minor damage.

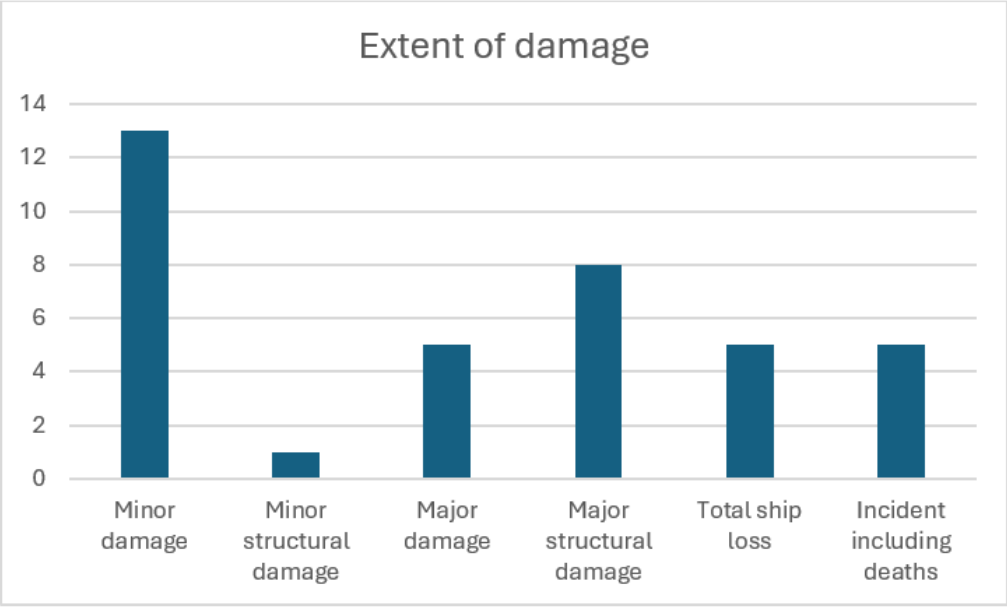

Figure 8 Extend of damage in vessel fire incidents

2.8 Locations of the accidents

A total of 31 of the 85 cases included in the dataset contain reliable information on the accident site. The analysis reveals that the majority of vessel fire incidents (approximately 83.87%; n=26) occurred in open water, while only about 16.13% (n=5) took place in ports. This suggests that vessels are more prone to fire incidents while navigating in open waters, which may be attributed to various factors such as harsh weather conditions, equipment failure, or human error. In contrast, ports, which are generally considered safer due to the presence of firefighting infrastructure and emergency services, witnessed relatively fewer incidents.

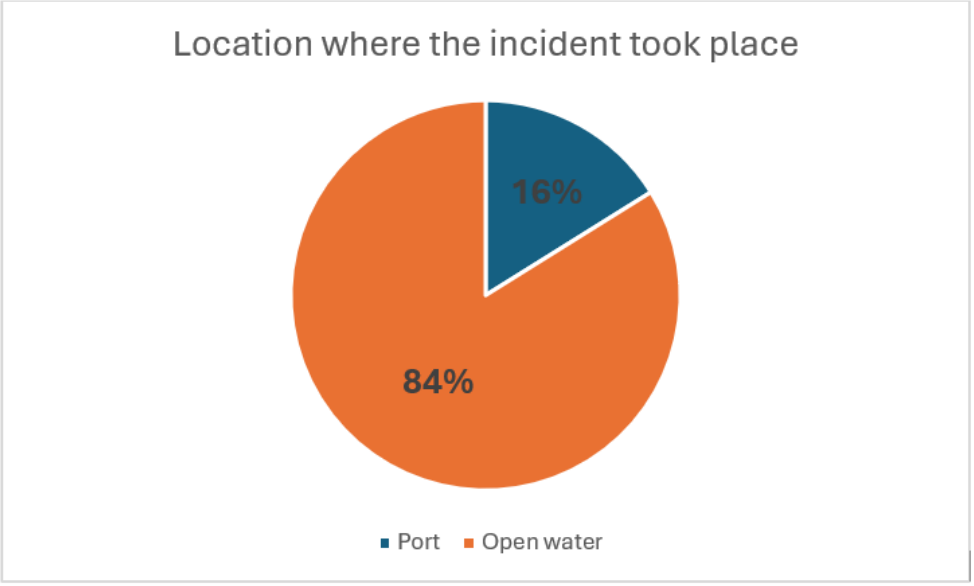

Figure 9 Location where the fire incident took place

It should be noted that, due to the non-transparent nature of the data, only the region in focus (e.g., the sea or the ocean) and no exact coordinates can be displayed in the following illustration. Nevertheless, an analysis of the distribution of accident locations demonstrates a discernible pattern. The sequence of accident locations illustrates the existence of a recognizable line between Europe and China. This is to be expected, given that this is the most heavily trafficked shipping route in the world. Upon closer examination, however, some peculiarities in the data become evident. Firstly, the number of accidents in the waters between Saudi Arabia and Malaysia is significantly higher than in the area between the Mediterranean and Western Europe. Regional climatic conditions and the prevailing weather could possibly explain this, but there is no scientifically verifiable information on this. It is also notable that there were only a few fire accidents away from the Asia-Europe connection mentioned above. Statistically, these low numbers are highly unlikely. It is plausible that there is a lack of publication in publicly accessible data here (n=35, 50x no data).

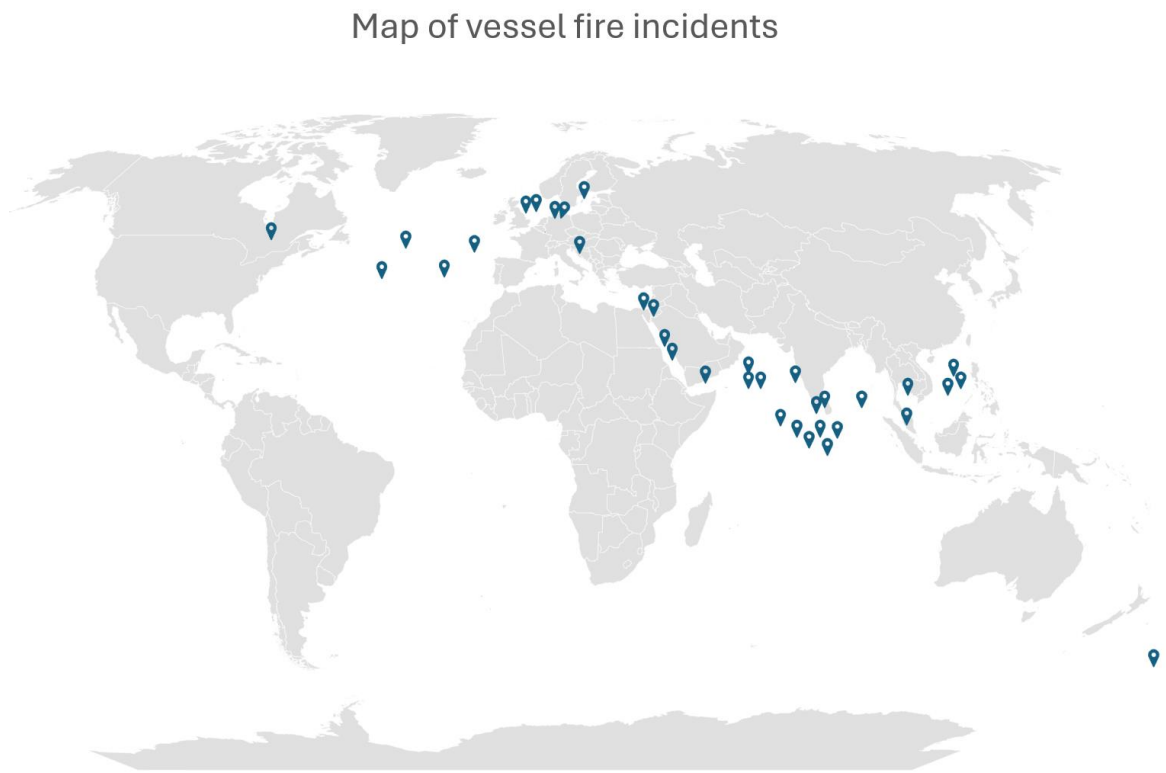

Figure 10 Map of vessel fire incidents

In summary, open sea accidents along major international shipping routes are the most common, with both calm and adverse weather conditions contributing to the frequency of incidents.

The financial losses from fire accidents on cargo vessels between 2008 and 2023 have been substantial. Some of the most expensive incidents include:

- MOL Comfort (2013): Over $400 million.
- Maersk Honam (2017): Around $400 million.
- MSC Flaminia (2012): Over $100 million.
- X-Press Pearl (2022): Over $100 million.

Other incidents, like the Cosco Pacific fire (2020), incurred costs in the range of 50 to 100 million US-Dollar. In total, the estimated costs for fire accidents on cargo ships over the past 15 years exceed 1.5 billion US-Dollar. This includes vessel damage, cargo loss, rescue efforts, and environmental impacts.

A persistent issue is the mishandling of dangerous goods on container ships. These materials can include flammable, explosive, or chemically reactive substances that, when improperly declared or stored, become fire hazards. Examples include lithium-ion batteries, chemicals, paints, and oils. A frequent problem is the mislabeling or under-declaration of hazardous containers, which

complicates fire safety protocols on board. In 2020, a significant fire occurred on the MSC Flaminia due to improperly stored hazardous materials. The fire caused substantial damage to the ship and led to the loss of numerous containers.

Electrical malfunctions and mechanical system failures have been another major cause of fires. Reefer (refrigerated) containers are especially prone to issues, as faults in their wiring or compressor systems can trigger fires. In 2018, the Maersk Honam suffered a devastating fire caused from the decomposition of dangerous cargo that was generating intense heat. The fire escalated into a major blaze, resulting in significant container loss.

Incorrect distribution of containers, particularly hazardous goods, can significantly increase the risk of fire. Poor separation of flammable materials from general cargo can lead to rapid fire spread once a blaze begins. In 2021, the Ever Given, which became infamous for blocking the Suez Canal, also experienced a fire due to improperly stored flammable goods. Fortunately, the fire was extinguished before major damage occurred.

2.9 Primary Fire Causes on Container Ships

The data collected from various sources, including accident reports, peer-reviewed journals, and industry publications, highlights several common fire causes:

- **Misdeclared or Undeclared Dangerous Goods:** One of the most significant contributors to fires on container ships is the misdeclaration or non-declaration of hazardous materials. These goods, especially chemicals, batteries, and flammable materials, often go unnoticed or are improperly handled, leading to catastrophic fires in cargo holds.
- **Electrical Failures in Reefer Containers:** Reefer (refrigerated) containers, often used to transport perishable goods, have been identified as a frequent fire hazard. Faulty wiring or electrical short circuits can ignite a fire that is difficult to detect early due to the location of these containers deep within the ship's cargo holds.
- **Cargo Shifting and Poor Stowage:** Improperly secured cargo can shift during the voyage, causing damage to containers and potentially igniting fires. Particularly when hazardous materials are involved, poor stowage practices are a recurring issue that has led to serious incidents.
- **Human Error and Inadequate Training:** Human factors, including operational errors and inadequate training in fire prevention, detection, and firefighting, have been highlighted as contributing causes. Crew members may fail to follow safety protocols, particularly in emergencies, and insufficient knowledge of the cargo's properties can exacerbate the problem.
- **Mechanical Failures in Ship Systems:** Fires originating from machinery spaces, such as the engine room, continue to be a significant cause of fire incidents. These fires often spread rapidly to cargo areas, especially when fire suppression systems are inadequate or malfunctioning.

- **External factors such as collisions and strandings as well piracy and deliberate arson:** Fires may also occur due to risk factors outside the ship. Collisions and armed attacks include the risk of damaging freight and technical infrastructure which can lead to heat development and electrical short circuit. [3]

Fires on cargo vessels are often attributed to a variety of causes, ranging from human error and mechanical failures to hazardous cargo and poor stowage practices. In fact, almost half (48%) of all incidents are related to Human factors [4]. Furthermore, many fire incidents have been linked to the transport of dangerous goods, such as flammable chemicals, lithium-ion batteries, or hazardous waste, that were improperly declared or handled. These goods, when exposed to high temperatures or physical stress, have caused spontaneous combustion or explosions. Electrical malfunctions, particularly in reefer containers (refrigerated containers), have been a recurring cause of fire. Faulty wiring or short circuits often lead to overheating and subsequent ignition, particularly in the hold where early detection is challenging. Fires originating in the engine rooms of vessels due to mechanical failure, oil leaks, or overheating are another frequent cause. These fires can spread quickly to other parts of the ship if not contained. Operational errors, including improper stowage of cargo, failure to follow safety protocols, and lack of crew training, have contributed to several fire accidents. Mishandling dangerous goods or failure to monitor electrical systems adequately have exacerbated these risks.

The effectiveness of fire containment and suppression largely depended on the technical capabilities of the vessel and the preparedness of the crew. Modern vessels are equipped with fire detection systems, such as heat and smoke detectors, as well as CO_2 or water-based fire suppression systems. However, in many cases, these systems were either inadequate or malfunctioned. For example, on larger vessels, the sheer size and configuration of the cargo space delayed the activation of suppression systems. In most incidents, the initial response from the crew was crucial in determining the extent of the damage. However, in cases where training was insufficient, the crew was unable to contain the fire effectively, leading to larger-scale fires that required external assistance from rescue and firefighting services. In severe cases, external firefighting support was required, often necessitating the coordination of local port authorities, coast guards, and international maritime safety organizations. Delays in response, particularly in remote ocean regions, often exacerbated the scale of damage. (International Maritime Organization, 2020).

2.10 Knowledge Gaps in Fire Prevention and Response

Despite these insights, there are still considerable knowledge gaps in the field, which hinder the industry's ability to develop more effective fire prevention and response measures. Key gaps include:

- **Insufficient Data on Near-Miss Incidents:** While catastrophic fire events are well documented, near-miss incidents, which could provide crucial information for prevention strategies, are underreported. This lack of comprehensive data on smaller fires or near-

misses prevents the industry from fully understanding the scope of fire risks on container ships.

- **Inconsistent Fire Cause Classification:** The classification of fire causes across different jurisdictions and organizations is often inconsistent. This creates challenges in comparing data across regions and understanding global trends. Standardized classification systems for fire incidents are needed to better analyze causes and develop universal preventive measures.
- **Limited Research on Cargo-Specific Fire Hazards:** Although some cargo types, such as hazardous goods, are recognized fire risks, there is limited research on other materials that may also pose a threat under certain conditions. More studies are needed to evaluate the fire hazards of non-hazardous cargo when exposed to environmental factors like heat, moisture, or long-term storage.
- **Fire Containment on Large Vessels:** The growing size of modern container ships introduces new challenges in fire containment and suppression. There is insufficient research on how fires spread in large cargo spaces and how to contain them effectively, especially in multi-deck or multi-tier container arrangements.
- **Inadequate Focus on Ship Design for Fire Safety:** Although shipbuilding has evolved, fire safety considerations are often secondary to efficiency and cargo capacity. Gaps exist in understanding how ship design can be optimized to enhance fire detection, containment, and suppression capabilities, particularly for larger vessels.

2.11 State-of-the-art prevention measures

In light of the fire incidents occurred on board container ships, various preventive measures and safety protocols have been recommended and implemented to reduce the risk of fire aboard cargo vessels. Obviously, one of the most critical preventive measures regard the proper declaration and inspection of dangerous goods, this includes stricter penalties for misdeclaration and enhanced training for personnel responsible for cargo handling. Moreover, modern fire detection and suppression systems are being installed on newer vessels, with a focus on more sensitive sensors and faster response mechanisms. However, the problem is still available for older ships where a solution needs to be developed. Indeed, thermal imaging cameras and drones can also being used to detect potential fire risks in hard-to-access areas of the ship. Training programs have been improved to better equip crew members with the knowledge and skills needed to respond to fire incidents. Also, Regular fire drills, both at sea and in port, are essential for ensuring that the crew can respond quickly and efficiently. Finally new vessel designs are incorporating better firebreaks and compartmentalization to prevent the spread of fire. Additionally, the layout of cargo holds is being reconsidered to allow for quicker access to fire suppression equipment and personnel.

In recent decades, the shipping industry has implemented measures to enhance safety on board ships. A number of technical facilities and strategies have been established in the past with the objective of combating fires on container ships, whether through a preventative or a reactive approach. The most prevalent Risk Control Options (ROCs) are outlined in the CARGOSAFE report (2023) and include the following systems:

- Container screening tool;
- Improved control of Optimizing current smoke detection system;
- Heat detection looking at individual container temperature rise;
- Fixed IR cameras (installed at strategic locations) coupled to a software solution to automate detection;
- CCTV - AI - smoke detection;
- Portable IR cameras for crew to enhance manual detection;
- Increasing effectiveness of current CO2;
- Improved manual firefighting tools for individual container breaching and firefighting;
- Manual firefighting tools that increase;
- Methods for unmanned fire fighting;
- Water mist turbines;
- Active protection underneath hatch covers to protect from fire spread towards the deck;
- Passive protection to protect from fire spread towards the deck;
- On-deck container stack cooling/containment;
- Flooding cargo hold to limited degree.

Despite the implementation of an array of preventive and reactive measures for firefighting on container ships, the incidents that have occurred in recent years (and in the recent past) illustrate the necessity for these measures to undergo continuous development. Indeed, most of them are the core of the OVERHEAT project. The changing initial conditions resulting from larger ships, changing cargo types and growing efficiency pressures mean that detection measures are also constantly exposed to new challenges.

The response to fire incidents on cargo vessels is governed by a mix of national regulations and international safety standards. The IMO sets international regulations, such as the Safety of Life at Sea (SOLAS) convention, which outlines fire safety standards for vessels. These regulations require vessels to have appropriate fire detection and suppression systems and mandate regular fire safety inspections. The flag state under which the vessel is registered is responsible for enforcing compliance with safety regulations. Port state authorities, where vessels dock, also play a key role in ensuring that vessels meet international fire safety standards through inspections and audits. National maritime authorities, such as the European maritime agencies, are involved in accident investigations and impose penalties or sanctions when regulations are breached. They also issue guidelines for fire safety training and emergency preparedness.

A range of stakeholders is responsible for managing fire incidents on cargo vessels. As the vessel operators, shipping companies bear primary responsibility for ensuring fire safety, including maintaining onboard equipment, training crew members, and adhering to cargo handling protocols. When fires occur near or in ports, local authorities play a crucial role in coordinating firefighting efforts, evacuating the crew, and minimizing damage to surrounding infrastructure. Marine insurers

are involved in covering the costs of fire damage, loss of cargo, and legal liabilities. They often investigate the cause of fires and may require specific safety measures to be in place before issuing coverage. Bodies like the IMO are responsible for setting and updating global fire safety standards, while organizations such as the International Association of Classification Societies (IACS) enforce these standards through ship classification and certification. The following chapter will better detail the regulatory framework for the safety of container ship within the EU.

3. REGULATORY FRAMEWORK AND GUIDELINES FOR SAFETY OF CONTAINER SHIPS IN EUROPE

The safety of containers and containerized cargo is of paramount importance in ensuring the secure transport of goods across Europe. Several guidelines and regulations have been established to address various aspects of container safety, from packing and securing cargo to handling and transportation. [5] These different safety guidelines exist because the maritime industry is highly complex, with ships operating under various flags, in diverse regions, and carrying different types of cargo, including hazardous materials. International bodies, such as the International Maritime Organization (IMO), establish broad, mandatory regulations like the SOLAS Convention and the IMDG Code that apply to all member states to ensure a minimum global standard of safety. These regulations are legally binding and must be obeyed by any vessel operating internationally.

At the same time, national maritime authorities, such as the European Maritime Safety Agency (EMSA), and classification societies like Lloyd's Register or Bureau Veritas, may impose additional guidelines specific to regional concerns or particular types of vessels. These can include best practice recommendations that are not mandatory but aim to enhance safety beyond the minimum requirements. Shipping companies and vessel operators must comply with the mandatory regulations of the country under which their vessel is flagged, as well as any specific guidelines set by port authorities or regional regulatory bodies in the areas where they operate.

A detailed list has already been compiled for the deliverable of WP3, where all open source laws and regulations that require or regulate the safety of container ships are listed.

In general, there are various of guidelines applied for safety of containers in Countries, Europe and the World.

3.1 International guidelines for prevention and management of fire causes

3.1.1 Safety of Life at Sea Convention (SOLAS)

The SOLAS Convention, in its successive versions, is widely regarded as the most significant of all international treaties concerning the safety of merchant vessels. Its primary objective is to establish minimum standards for the construction, equipment, and operation of ships, in line with ensuring their safety.

Notably, SOLAS addresses fire safety in Chapter II-2 – Fire protection, fire detection, and fire extinction. This chapter provides detailed fire safety requirements applicable to all ships, with specific provisions for passenger vessels, cargo ships, and tankers.

Key principles include: dividing the ship into main and vertical zones using thermal and structural boundaries; separating accommodation areas from the rest of the ship with similar boundaries; limiting the use of combustible materials; ensuring early detection of any fire at its point of origin; containing and extinguishing fires in the area of outbreak; safeguarding escape routes and access for fire-fighting; ensuring fire-fighting equipment is readily available; and minimizing the risk of ignition from flammable cargo vapours.

Thus, the Convention covers both active fire protection (defining competencies, procedures, and countermeasures in the event of a fire outbreak) and passive fire protection (establishing preventive tools for fire detection, containment, and prevention).

Additionally, SOLAS addresses the carriage of dangerous goods in Chapter VII – Carriage of Dangerous Goods, particularly in Part A – Carriage of Dangerous Goods in Packaged Form. This section includes provisions for the classification, packaging, marking, labelling, placarding, documentation, and stowage of hazardous materials. It mandates that Contracting Governments issue national instructions and enforces the International Maritime Dangerous Goods (IMDG) Code as mandatory under the Convention.

3.1.2 International Maritime Dangerous Goods (IMDG) Code

The IMDG Code, developed by the International Maritime Organization (IMO), provides a comprehensive framework for the safe transportation of dangerous goods by sea. It outlines requirements for classification, packaging, marking, labeling, documentation, stowage, and segregation of dangerous goods in packaged form. [6]

The IMDG Code is specifically designed to address a comprehensive range of aspects related to the handling of dangerous goods in maritime transport. These aspects include, but are not limited to, the following:

- Hazard Classification: Dangerous goods are categorized based on the risks they pose during transport, ensuring appropriate handling measures are applied.
- Proper Packaging: Dangerous goods must be securely packed in containers or tanks of sufficient strength to prevent any leaks or spills and hazard warning labels and other identifying marking have to be used to clearly identify the dangerous goods being transported.
- Documentation: Standardized documentation must accompany the shipment of dangerous goods, ensuring that all necessary information is available for safe handling.
- Segregation: Guidelines are provided to ensure that dangerous goods that may react dangerously with one another are kept apart for safety reasons.

- Stowage: Principles are established regarding the proper placement of dangerous goods on board to ensure the safe transport of these materials.
- Emergency Response: Provisions are made for emergency response procedures in the event of a fire or spillage involving dangerous goods on board the vessel.
- This structured approach ensures the safety of the ship, its crew, and the marine environment during the transportation of hazardous materials.

The IMDG Code is regularly updated on a two-year cycle to incorporate advancements in safety practices and to address new risks.

3.1.3 Maritime Labour Convention (MLC)

The MLC includes provisions for the welfare and safety of seafarers, indirectly impacting container safety by ensuring that those handling containers are working under safe and regulated conditions.

These guidelines and regulations form a robust framework for ensuring the safety of containers in Europe. They cover the entire lifecycle of containers, from construction and certification to packing, handling, and transportation, ensuring that the risks associated with containerized cargo are minimized. Compliance with these guidelines is mandatory and monitored by various regulatory bodies to uphold the highest safety standards in maritime and intermodal transport.

3.1.4 Standard Training, Certification and Watchkeeping for Seafarers (STCW)

The International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers (STCW), established by the International Maritime Organization (IMO), plays a crucial role in ensuring that seafarers are properly trained and certified to manage vessels, handle cargo, and respond to emergencies such as fires. Given the unique challenges associated with fires on container ships and the complexities of handling dangerous goods, the STCW Convention provides a critical framework for equipping crew members with the knowledge and skills required to prevent, manage, and mitigate these incidents. [7]

Under the STCW Convention, seafarers receive comprehensive training in fire prevention and firefighting, which is a mandatory component for all crew members, regardless of rank. This training is divided into various levels. The Basic Firefighting Training (STCW Code, Table A-VI/1-2) includes essential knowledge related to identifying fire hazards, understanding the chemistry of fire, using firefighting equipment such as extinguishers and hoses, and implementing emergency procedures and evacuation strategies [8]. This foundational training ensures that all crew members are capable of responding to fire incidents, particularly in high-risk areas like cargo spaces.

For officers and designated personnel, Advanced Firefighting Training (STCW Code, Table A-VI/3) is required. This training encompasses more sophisticated techniques for fire prevention, detection, and suppression. It covers the coordination of firefighting teams, the management of onboard firefighting operations, and the understanding of fire control systems such as CO2 and water mist systems, which are commonly installed on container ships (Det Norske Veritas Germanischer Lloyd,

2020). This advanced level of training is especially important in dealing with fires involving hazardous materials or electrical faults, which are frequent causes of fires on container vessels. [8]

Moreover, the STCW mandates that all seafarers periodically undergo refresher training to ensure that their firefighting skills remain current and that they are familiar with the latest fire prevention technologies. This is particularly relevant as new systems, such as drones equipped with thermal imaging cameras, are now being used to detect heat and identify potential fire risks in cargo holds [9]. The continuous training ensures that seafarers stay prepared to respond effectively to any fire-related emergencies that may occur onboard.

In addition to firefighting, the STCW Convention addresses the proper handling of cargo, including dangerous goods, which is a critical aspect of fire prevention. The training on dangerous goods (STCW Code, Table A-II/1 and A-II/2) requires seafarers responsible for cargo operations to be trained in the stowage, handling, and documentation of dangerous goods in accordance with the International Maritime Dangerous Goods Code (IMDG Code). This training ensures that crew members understand how to classify and safely manage hazardous materials, minimizing the risk of fires. [10] Proper training in the stowage of these materials is essential, as misdeclared or mishandled dangerous goods are a leading cause of container ship fires, as evidenced by incidents such as the Maersk Honam and the X-Press Pearl. [3]

The STCW also emphasizes the importance of container management for fire safety. Officers are trained in the correct loading, stowage, and securing of containers (STCW Code, Table A-II/1). This training is vital to prevent container shifts during transit, which can cause damage or even fire outbreaks, especially when hazardous materials are involved. For example, poor separation of flammable cargo from general goods can lead to rapid fire spread, as seen in several high-profile incidents. [11] Furthermore, the STCW ensures that crew members are trained to handle reefer containers (refrigerated containers), which have been identified as a frequent source of fires due to electrical faults or malfunctions in their cooling systems. [12]

The STCW's comprehensive approach to both fire safety and cargo handling plays a pivotal role in ensuring the safety of container ships. By combining theoretical knowledge with practical training, the convention equips seafarers with the tools they need to address both traditional and emerging risks in maritime operations. Advanced technologies, such as thermal imaging systems and modern firefighting equipment, complement this training and help crews to detect fires early and respond effectively. [13]

In conclusion, the inclusion of the STCW framework in the fire safety strategy of container ships is essential. It ensures that crews are properly trained to handle dangerous goods and respond to fire emergencies, thus reducing the risks associated with fires in cargo spaces. Adherence to the STCW standards is a critical component of improving fire prevention and response measures on container ships, and it helps ensure safer maritime operations globally [7].

3.1.5 Container Safety Convention (CSC)

The Convention for Safe Containers (CSC) was established to maintain a high level of safety in the handling and transportation of containers. Administered by the IMO, the CSC sets standards for container design, construction, testing, and inspection. Containers must be periodically inspected and maintained to ensure they meet these standards, and containers that do not comply must be removed from service until they are brought up to standard.

3.1.6 European Agreement Concerning the International Carriage of Dangerous Goods by Road (ADR)

While primarily focused on road transport, the ADR includes provisions relevant to containers carrying dangerous goods. It specifies requirements for packaging, labeling, and documentation to ensure that containers are safe for road transport and align with maritime regulations when part of a multimodal transport chain.

3.1.7 International Organization for Standardization (ISO) Standards

Several ISO standards are pertinent to container safety. These include:

- **ISO 668**: Series 1 freight containers—Classification, dimensions, and ratings.
- **ISO 1496**: Series 1 freight containers—Specifications and testing.
- **ISO 3874**: Series 1 freight containers—Handling and securing. These standards ensure uniformity in container construction and handling, facilitating safe and efficient transport.

3.1.8 European Union Legislation and Directives

The EU has enacted various regulations and directives to enhance container safety:

- **Directive 2014/90/EU**: This directive pertains to marine equipment and aligns EU requirements with international standards, ensuring that containers and their equipment meet safety and performance criteria.
- **Regulation (EC) No 1071/2009**: Establishes common rules concerning the conditions to be complied with to pursue the occupation of road transport operator, which impacts the handling and transport of containers by road.

3.2 European guidelines for prevention and management of fire causes

The large number of potential causes of fire and the environmental impact of fires on container ships have also contributed to the existence of specialized laws and guidelines in this context. The fire prevention and management on ships, especially in cargo spaces including the prevention of container loss, are critical aspects of maritime safety. The following several European guidelines, along with international regulations, provide a comprehensive framework for addressing fire risks on ships. These guidelines focus on both prevention measures and effective management strategies in case of a fire incident.

3.2.1 European Maritime Safety Agency (EMSA) Guidelines

The EMSA provides specific guidelines and best practices for fire safety on ships, including cargo spaces. These guidelines are part of EMSA's broader mandate to enhance maritime safety and pollution prevention. EMSA also conducts inspections and audits to ensure compliance with fire safety regulations.

3.2.2 European Union Directives and Regulations

- **Directive 2009/16/EC on Port State Control**: This directive enhances the inspection regime for ships entering EU ports, ensuring they comply with international fire safety standards.
- **Regulation (EU) 2016/1628**: This regulation sets standards for emissions from non-road mobile machinery, which includes emergency generators and other equipment that might be used in fire emergencies.

3.2.3 European Agreement Concerning the International Carriage of Dangerous Goods by Inland Waterways (ADN)

The ADN agreement includes provisions related to the safe transport of dangerous goods, addressing specific fire risks associated with these materials. It complements maritime regulations by ensuring that dangerous goods are safely handled throughout their transport journey, including when transferred to inland waterways.

3.2.4 Best Practices and Industry Standards

Various industry bodies, such as the International Chamber of Shipping (ICS) and the Baltic and International Maritime Council (BIMCO), publish best practice guidelines for fire safety. These guidelines cover:

- Risk assessments and fire safety drills.
- Maintenance of fire detection and suppression systems.
- Training for crew members on fire prevention and response.

3.2.5 Insurance and Classification Society Requirements

Insurance companies and classification societies often have additional fire safety requirements. Classification societies like DNV GL, Lloyd's Register, and Bureau Veritas provide certification and inspection services that ensure ships meet high standards for fire safety. Their guidelines cover:

- Design and construction standards for fire safety.
- Regular inspections and maintenance of fire-fighting equipment.
- Certification of crew training programs.

These guidelines and regulations form a comprehensive framework for fire prevention and management on ships within Europe. By adhering to these standards, shipping companies can significantly reduce the risk of fire incidents and ensure that effective measures are in place to manage any fire emergencies that do occur.

3.3 National Guidelines

In Europe, several countries have developed their own national guidelines and regulations for fire prevention and management on ships, including specific provisions for fire causes in cargo spaces and the prevention of container loss. These national guidelines often complement international regulations such as those provided by the International Maritime Organization (IMO) and the European Maritime Safety Agency (EMSA). Here are some examples of European countries with specific national guidelines:

3.3.1 Germany

- **Bundesstelle für Seeunfalluntersuchung (BSU)**: The Federal Bureau for Maritime Casualty Investigation in Germany provides detailed reports and safety recommendations following maritime incidents, including fires on containerships.
- **See-Berufsgenossenschaft (SeeBG)**: The German Social Accident Insurance Institution for the maritime industry offers guidelines and conducts inspections to ensure compliance with safety regulations, including fire safety on ships.
- **DNV GL**: This classification society, while international, has a significant presence in Germany and provides guidelines on fire safety for vessels, including containerships.

3.3.2 United Kingdom

- **Marine Accident Investigation Branch (MAIB)**: The MAIB investigates maritime accidents and provides recommendations to improve safety, including fire prevention and management on ships.
- **Maritime and Coastguard Agency (MCA)**: The MCA enforces regulations related to fire safety on ships operating under the UK flag, including the implementation of SOLAS regulations and additional national standards.
- **UK Merchant Shipping (Fire Protection) Regulations**: These regulations set out specific requirements for fire safety on UK-registered ships.

3.3.3 France

- **Bureau d'Enquêtes sur les Événements de Mer (BEAmer)**: The French Marine Casualties Investigation Office conducts investigations into maritime accidents and provides recommendations to enhance safety, including fire safety measures.
- **Direction des Affaires Maritimes**: This agency oversees maritime safety regulations in France, including those related to fire prevention and response on ships.
- **French Classification Societies**: Organizations such as Bureau Veritas provide guidelines and certifications for fire safety on ships.

3.3.4 Netherlands

- **Dutch Safety Board (Onderzoeksraad voor Veiligheid)**: This board investigates serious incidents and accidents in various sectors, including maritime, and offers recommendations for improving safety standards.
- **Netherlands Shipping Inspectorate (Inspectie Leefomgeving en Transport)**: This agency enforces maritime safety regulations in the Netherlands, including those related to fire safety on ships.
- **Dutch Classification Societies**: Entities like Lloyd's Register EMEA (based in Rotterdam) contribute to setting and maintaining fire safety standards for ships.

3.3.5 Norway

- **Norwegian Maritime Authority (Sjøfartsdirektoratet)**: This authority oversees maritime safety regulations in Norway, including specific requirements for fire prevention and management on ships.
- **DNV GL**: As a leading classification society based in Norway, DNV GL provides extensive guidelines and certification services for fire safety on ships, including containerships.

3.3.6 Italy

- **Italian Maritime Authority (Capitaneria di Porto)**: This agency enforces maritime safety regulations in Italy, including fire safety standards for ships.
- **RINA (Registro Italiano Navale)**: The Italian classification society provides guidelines and certification for fire safety on ships.

3.3.7 Spain

- **Spanish Maritime Safety Agency (Sociedad de Salvamento y Seguridad Marítima - SASEMAR)**: This agency oversees maritime safety regulations in Spain, including fire safety standards.
- **Bureau Veritas Spain**: This classification society offers guidelines and certification services related to fire safety on ships operating under the Spanish flag.

3.3.8 Sweden

- **Swedish Transport Agency (Transportstyrelsen)**: This agency regulates maritime safety in Sweden, including fire prevention and management on ships.
- **Swedish Classification Societies**: Organizations like Det Norske Veritas (DNV) and Lloyd's Register provide certification and guidelines for fire safety.

3.3.9 Finland

- **Finnish Transport and Communications Agency (Traficom)**: This agency is responsible for maritime safety regulations in Finland, including fire safety standards for ships.
- **Finnish Classification Societies**: Entities like Bureau Veritas and DNV provide guidelines and certifications for fire safety on ships.

3.3.10 Poland

- **State Commission on Maritime Accident Investigation:** The Polish Maritime Accident Investigation Agency is a specialized governmental entity responsible for conducting thorough examinations and analyses of maritime incidents and accidents within the jurisdiction of the Republic of Poland

To provide a comprehensive overview, a selection of countries was chosen to exemplify national guidelines for fire prevention and safety on container ships. These countries were selected based on their significance in global shipping and their developed maritime safety frameworks. By analyzing national regulations from countries such as Germany, the United Kingdom, and the Netherlands, the report highlights how different nations approach fire prevention and management, offering insights into both international standards and specific national practices. These countries have established national guidelines and regulations that enhance the international framework provided by organizations such as the IMO and EMSA. National agencies, classification societies, and maritime authorities work together to ensure that ships operating within their jurisdictions adhere to the highest standards of fire prevention and management, thereby minimizing the risk of fire incidents and the potential loss of containers.

3.4 Best practice guidelines

Also, there are several best practice guidelines available for preventing and managing fires on container ships, especially when it comes to handling dangerous goods and fire safety in cargo spaces. These guidelines are developed by maritime authorities, industry associations, and insurance companies to improve safety standards and reduce the risk of fire incidents at sea. Below are key best practice guidelines related to fire safety on container ships:

3.4.1 Code of Practice for Packing of Cargo Transport Units (CTU Code)

The Code of Practice for Packing of Cargo Transport Units (CTU Code) provides guidelines on the safe packing, securing, and unpacking of cargo in containers. It covers best practices to prevent accidents, ensuring that cargo is properly secured within the container to prevent shifting during transport. This code is a joint publication by the IMO, the International Labour Organization (ILO), and the United Nations Economic Commission for Europe (UNECE).

This code offers guidelines on the safe packing of containers and other cargo units to minimize risks during transport, including fire hazards.

- Correct loading and securing of cargo to avoid shifting that could lead to fire or damage during transit.
- Avoid overpacking containers and ensure proper ventilation to prevent overheating, especially with hazardous goods.
- Comprehensive training for packers and shippers on cargo packing regulations and fire safety requirements.
- Adequate labeling and documentation of dangerous goods to ensure proper handling during loading and unloading.

3.4.2 Insurance and Loss Prevention Guidelines (TT Club, Allianz, etc.)

Marine insurers provide loss prevention guidelines aimed at reducing fire risks and improving safety in the shipping industry.

- Use of fire-resistant materials for container construction and insulation.
- Continuous monitoring of reefer containers to prevent electrical failures, which are a common cause of fires.
- Regular audits and inspections to ensure compliance with safety standards and identify potential fire risks on board.
- Encouragement of new technologies like drones and thermal imaging cameras to detect early signs of fire.

3.4.3 Best Practice Guidelines for Fire Safety on Container Ships (ICS and BIMCO)

The International Chamber of Shipping (ICS) and BIMCO (Baltic and International Maritime Council) provide guidelines focused on fire safety and the handling of fires on container ships.

- Development of detailed fire response plans tailored to the specific ship and its cargo.
- Regular fire risk assessments, especially for large container vessels that are more challenging to manage in a fire emergency.
- Close coordination with port authorities and rescue services to ensure swift assistance in case of fire.
- Implementation of controlled zoning within the cargo hold to contain and suppress fires effectively.

3.4.4 Container Ship Safety Guidelines (World Shipping Council)

Focused on improving safety standards for container shipping, including fire prevention strategies.

- Monitoring of cargo temperatures to identify heat build-up that could lead to combustion.
- Enhancing firefighting capabilities on large container vessels with advanced fire suppression technologies.
- Encouraging better communication between ship owners, cargo owners, and regulatory authorities regarding fire risks.
- Adoption of new firefighting solutions, such as water mist systems and CO_2-based suppression systems for large cargo spaces.

3.4.5 Guidelines from National Maritime Authorities (e.g., US Coast Guard, UK Maritime and Coastguard Agency)

National guidelines may offer additional, region-specific regulations or recommendations for container ship safety.

- Emergency response protocols specific to national waters, including firefighting resources and coordination with local authorities.
- Inspections of ship firefighting systems during routine port state control checks.

- Reporting mechanisms for near-miss incidents to improve safety learning and prevention.

3.5 Summary of Best Practice Areas:

- Dangerous Goods Handling: Ensure proper labeling, stowage, and declaration of dangerous cargo.
- Fire Detection and Suppression: Install and maintain advanced fire detection systems, such as smoke detectors, sprinklers, and automated suppression systems.
- Crew Training and Preparedness: Regular fire drills and training on the handling of hazardous materials and fire emergencies.
- Cargo Management: Follow best practices in container packing and secure hazardous goods in well-ventilated and temperature-controlled conditions.
- Maintenance and Inspection: Conduct regular inspections and audits of firefighting equipment and cargo spaces.
- Technological Innovations: Invest in modern technologies such as drones, thermal imaging, and water mist systems to enhance firefighting capabilities.

These best practice guidelines serve as critical resources for reducing fire risks on container ships. Compliance with the IMDG Code, SOLAS, and other international standards is essential for improving the safety of maritime transport, particularly when dealing with hazardous goods. By following these recommendations, the shipping industry can significantly mitigate the dangers posed by fires on container vessels and improve response times and effectiveness in case of emergencies. [14] [15]

4. TECHNOLOGICAL AND OPERATIONAL MEASURES FOR FIRE PREVENTION AND FIREFIGHTING (BASED ON THE PROCEDURES AND QUANTITATIVE SAFETY TARGETS IN BREMEN)

Fire prevention and firefighting on container ships have become critical areas of focus due to the increasing size of vessels and the complexity of cargo. In response to the rising number of fire incidents, Bremen, a major hub in maritime safety research, has developed a series of technological and operational measures aimed at enhancing fire prevention and firefighting capabilities. These measures are based on established procedures and quantitative safety targets that aim to minimize fire risks and improve emergency response efficiency.

The German Federal Government has a superior strategy with the aim to position the German seaports and inland ports as efficient, sustainable and secure logistics centers that meet the global and European requirements of trade and industry. This National Port Strategy is therefor designed to enhance the efficiency, sustainability, and global competitiveness of Germany's seaports and inland ports. Recognizing these ports as crucial nodes in both national and international logistics networks, the strategy outlines comprehensive measures aimed at modernizing infrastructure, leveraging digital technologies, promoting environmental sustainability, and ensuring robust safety

and security. By addressing these key areas, the strategy seeks to position German ports as leading global hubs, driving economic growth and fostering innovation within the maritime sector.

A key element of the National Port Strategy is the ongoing modernization and maintenance of port infrastructure. This includes the expansion of quay facilities, deepening of shipping channels, and improvement of intermodal connections to rail, road, and inland waterways. The goal is to increase the operational efficiency of ports and prevent bottlenecks in cargo transport.

The German Federal Government places a strong emphasis on digitalization and innovative technologies to boost the efficiency and competitiveness of the ports. This involves implementing intelligent transportation systems, utilizing big data to optimize logistics processes, and expanding digital platforms for information exchange among various port stakeholders. The introduction of 5G technology is seen as a crucial step to enable real-time communication and automation.

Another central goal of the National Port Strategy is the promotion of sustainability and environmental protection. Measures to reduce CO_2 emissions, promote renewable energy, and introduce environmentally friendly technologies are a focus. This includes the electrification of port facilities, the use of shore power for ships, and the promotion of LNG (Liquefied Natural Gas) as an eco-friendly fuel.

The safety of port facilities and protection against threats and risks are essential components of the National Port Strategy. This includes improving IT security, implementing counter-terrorism measures, and protecting against natural disasters. The development of security protocols and regular emergency response drills are of great importance.

The German Federal Government places significant importance on international cooperation and networking of German ports. This includes active participation in international organizations and forums as well as promoting bilateral and multilateral partnerships. The goal is to foster the exchange of best practices and develop common standards and regulations.

Another important area is ensuring a qualified workforce. The German Federal Government supports measures for education and training in the port sector to meet the demands of modern port operations. This includes both technical and business qualifications, aimed at preparing professionals for future challenges.

The National Port Strategy of the German Federal Government represents a comprehensive plan to ensure the future viability of Germany's seaports and inland ports. By combining infrastructure development, digitalization, sustainability, safety, international cooperation, and workforce qualification, the strategy adopts a holistic approach that strengthens ports as efficient and environmentally friendly logistics hubs. The implementation of this strategy helps secure Germany's competitiveness in global trade and contributes significantly to sustainable development.

In regard to this, Bremen has its own Port Security Law. This is a pivotal legislative framework designed to ensure the safety and security of Bremen's key maritime gateway. As a major hub for

international trade and logistics, Bremen's port facilities must adhere to stringent security measures to protect against a range of potential threats, from terrorism to smuggling and other illicit activities. This law outlines comprehensive protocols for safeguarding port infrastructure, regulating access, and coordinating emergency responses. By establishing robust security standards and fostering collaboration among local authorities, port operators, and other stakeholders, the Port Security Law aims to maintain the operational integrity and resilience of Bremen's port, thus supporting its critical role in regional and global trade.

The ports of Bremen are the second largest national transshipment point for the intercontinental exchange of goods. As a crucial link between seaborne and landside transportation, they are dependent on secure access conditions, handling processes and storage facilities. At the same time, there is an increasing global threat from organized crime, sabotage and terrorism. Despite the limited number of documented instances of terrorism in the shipping industry, the increasing geopolitical tensions and global conflicts pose a significant risk. Terrorist attacks frequently result in fires and explosions. For these reasons, the preventive protection of maritime shipping and the port industry against external attacks has been improved in recent years. Risk assessments based on the International Ship and Port Facility Security Code (ISPS) - Port Facilities have been and continue to be carried out to secure the ports of Bremen on the basis of statutory provisions, and security concepts have been developed and implemented by the authorities and facility operators on this basis.

All authorities involved in the security process, such as the Senator for Economics, Ports and Transformation, the port captain and the water police, the handling companies, the port service companies and infrastructure service providers work closely together, taking into account the local particularities.

4.1 The legal basis for port security is as follows:

- EU Regulation 725/2004
- Directive 2005/65/EC
- Bremen Port Security Act (BremHaSiG)

The Bremen Port Security Act (BremHaSiG) [16] establishes a comprehensive framework of procedures, rules, guidelines, and quantitative safety targets for container transport within the Port of Bremen. These measures are designed to ensure security in port operations and address potential security risks effectively.

4.2 Technological Measures

Technological advancements play a crucial role in the early detection and suppression of fires on board container ships. The following technologies are being implemented to meet the safety targets set by Bremen's maritime safety authorities:

The installation of advanced fire detection systems is a fundamental measure for improving safety on container ships. These systems include smoke, heat, and gas detectors that can rapidly identify the presence of fire or hazardous fumes. Linked to an automated alarm system, these detectors can quickly alert the crew to potential dangers, allowing for rapid response before the fire escalates.

Fire suppression technologies have evolved significantly, with modern systems being designed to control and extinguish fires in large cargo holds. Water mist systems and CO_2-based suppression systems are widely used on container ships but have a very limited effect on fighting fires of lithium-ion batteries or dangerous chemical goods. The water mist system releases fine water droplets that can cool the fire and reduce its spread, while the CO_2 system displaces oxygen in the fire zone, effectively smothering the flames.

Drones equipped with thermal imaging cameras are being deployed to enhance the monitoring of cargo holds. These devices can detect heat build-up in specific containers, allowing early intervention before a fire starts. This technology also enables better assessment of fire progression in areas that are difficult to access, providing valuable real-time data to the crew and firefighting teams. [17]

A significant portion of fire incidents in recent years has been linked to reefer containers where electrical faults can cause fires. To mitigate this risk, new monitoring systems have been developed that provide constant surveillance of reefer container temperatures and electrical systems. These systems can automatically disconnect faulty units from the power supply to prevent short circuits that could ignite fires.

4.3 Operational Measures

Operational procedures are equally important in preventing and managing fires on board container ships. The following operational measures, based on Bremen's safety procedures, aim to enhance crew readiness and ensure compliance with fire safety protocols:

Regular fire drills are mandatory for container ship crews. These drills simulate real-life fire emergencies, allowing crew members to practice their roles in the event of a fire. Drills include the use of firefighting equipment, evacuation procedures, and coordination with shore-based emergency services. Bremen's procedures emphasize the importance of frequent training to ensure that all crew members are prepared for various fire scenarios.

Proper cargo loading and stowage are critical for preventing fires. Bremen's operational guidelines focus on the separation of hazardous materials from general cargo and the proper ventilation of containers that could pose a fire risk. These procedures include detailed documentation and labeling of dangerous goods, ensuring that hazardous cargo is stored in easily accessible areas for quick firefighting intervention.

Effective communication during a fire emergency is vital for coordinating firefighting efforts. Bremen's protocols establish clear communication lines between the ship's crew, the captain, and external rescue teams. These protocols are designed to ensure that all relevant parties are informed

of the fire situation and can take appropriate action swiftly. Miscommunication can cause fires or, as in the case of the Freemantle Highway (2023), make the effects of a fire much worse.

After a fire incident, Bremen's safety procedures require a detailed review of the event, including an analysis of the causes and the effectiveness of the response. This process is crucial for identifying any weaknesses in the existing fire prevention measures and for improving future safety protocols. The lessons learned from each incident are integrated into the ship's safety management system to prevent recurrence. [18] [16]

4.4 Quantitative Safety Targets

Quantitative safety targets refer to measurable goals set to improve safety, reduce risks, and enhance operational performance, especially in areas such as fire prevention, firefighting response, and minimizing losses. In the context of fire safety on container ships, these targets are essential for tracking improvements, ensuring compliance with safety regulations, and guiding best practices. Europe has established a number of specific quantitative safety targets aimed at reducing the occurrence and impact of fire incidents on container ships.

One of the primary quantitative safety targets set by European maritime authorities is the reduction in fire incidents on container ships. The EMSA, which monitors maritime safety across Europe, has set goals to decrease the number of fire-related accidents each year. EMSA coordinates with national maritime authorities and the broader shipping industry to ensure compliance with fire safety regulations and to encourage improvements in ship design, fire detection systems, and crew preparedness. [19] [20] These efforts are part of a broader strategy to improve overall safety at sea and reduce the economic and environmental impact of such accidents.

In addition to reducing the number of fire incidents, there is a strong focus on minimizing cargo loss caused by fires on container ships. Organizations such as the IUMI and classification societies like Bureau Veritas and DNV GL set specific targets to limit the amount of cargo lost due to fire. These targets are achieved by optimizing fire containment systems, improving firefighting technology, and enforcing stricter regulations on cargo stowage and handling. By aiming to reduce the percentage of containers lost during fire incidents, these organizations help to protect both the financial interests of shipping companies and the safety of the global supply chain. [21]

Another critical quantitative safety target relates to improving fire detection and response times. Rapid detection and response are essential for minimizing the damage caused by fires on container ships. European agencies, including Lloyd's Register and EMSA, aim to shorten the time between the detection of a fire and the activation of firefighting systems. This is achieved through the implementation of advanced fire detection technologies, such as thermal imaging systems and automated alarms, which allow crew members to respond more quickly and effectively to emerging fires. Shorter response times are directly linked to lower rates of cargo loss and reduced damage to vessels. [22]

The reduction of environmental impact from fires is another key quantitative safety target in Europe. Fires on container ships can lead to significant environmental hazards, particularly when hazardous materials are involved. European maritime regulations, such as those set by EMSA and the IMO, establish targets for minimizing pollution and environmental damage resulting from fires. These targets are designed to reduce the amount of hazardous substances released into the sea during fire incidents by enforcing stricter controls on the handling of dangerous goods and improving firefighting systems. The focus is not only on extinguishing the fire but also on preventing spillage and other environmental contamination. [1]

Perhaps the most critical target is the zero-fatality goal for crew members in fire incidents. This target emphasizes the importance of improved training and preparedness among seafarers, as outlined in the STCW. European maritime agencies, through organizations like EMSA, work closely with ship operators to ensure that crew members receive proper fire safety training and conduct regular drills. The ultimate aim is to prevent any loss of life during fire emergencies on container ships. Achieving this goal requires a combination of better

training, more advanced firefighting systems, and improved communication and coordination during emergencies. [23]

In conclusion, the quantitative safety targets related to fire accidents on container ships in Europe focus on several key areas: reducing the number of incidents, minimizing cargo loss, improving response times, lowering the environmental impact, and preventing crew fatalities. These measurable goals are established by organizations such as EMSA, IUMI, and Lloyd's Register, and they play a vital role in enhancing safety across the maritime industry. Continuous improvements in technology, regulations, and crew training are necessary to meet these ambitious targets and ensure safer maritime operations.

CONCLUSION

Over the past 15 years, numerous fire accidents on cargo vessels have been recorded, revealing key patterns in terms of causes, locations, weather conditions, technical responses, preventive measures, and the stakeholders involved. This analysis provides an overview of significant incidents each year from 2008 to 2023, highlighting common risks and gaps in safety protocols across the industry.

One of the most consistent findings across the incidents is that the primary causes of fires on cargo vessels stem from hazardous materials, electrical faults, and improper storage of dangerous goods. For example, the 2012 MSC Flaminia incident resulted from a chemical reaction due to misdeclared calcium hypochlorite, leading to the tragic loss of life and significant damage to the vessel. Similarly, in 2017, the Maersk Honam experienced a catastrophic fire in the Arabian Sea due to hazardous cargo, which claimed five crew members' lives. Electrical failures, particularly in refrigerated containers, have also been a recurring cause, as seen in the 2011 MSC Daniela and 2018 Yantian

Express incidents. These types of incidents have led to stricter regulations regarding the handling of dangerous goods and the design of fire suppression systems on cargo vessels.

The majority of fire incidents occurred on open seas, often in international waters, such as the MSC Chitra collision and subsequent fire in the Indian Ocean in 2009, and the APL Vancouver fire in the South China Sea in 2019. While some of these incidents were exacerbated by rough weather conditions, such as high seas and storms (e.g., Zim Kingston in 2021 off the coast of Vancouver), others occurred in relatively calm conditions, where factors like cargo mishandling played a more prominent role.

Port areas are also prone to fire incidents, especially due to the presence of dangerous cargo and the complexities of loading and unloading. For instance, the Cosco Pacific fire in 2020 occurred in the port of Nansha, China, where improperly stored flammable goods caused a major incident. This underscores the need for stricter regulations and oversight in port operations, particularly regarding the storage and transport of hazardous materials.

Fire incidents have affected vessels of all sizes, from smaller carriers like the 2,743 TEU X-Press Pearl, to ultra-large container vessels such as the 15,000 TEU Maersk Honam. A notable trend is the difficulty in managing fires on larger vessels, which often house more dangerous goods and pose greater challenges in terms of fire containment and evacuation. For example, the fire on the MSC Flaminia took days to control due to its size and cargo composition, while the smaller Wan Hai 307 experienced a much more contained fire in 2015.

Crew responses have varied significantly, with some crews managing to control fires with onboard equipment, while others were forced to abandon ship due to the severity of the incidents. In the 2023 Fremantle Highway fire, which was caused by an electric vehicle (EV) battery, firefighting efforts were complicated by the unique challenges posed by EVs. This highlights the increasing complexity of cargo types and the evolving risks that crews must manage.

The technical responses to these fires have evolved over time, driven by technological advancements and regulatory pressures. Firefighting tugs, onboard fire suppression systems, and improved stowage plans have played key roles in mitigating the damage caused by these incidents. However, the response times have often been prolonged, especially when fires occur far from the shore. In the case of the MSC Flaminia, the fire burned for days before firefighting teams could bring it under control, indicating that more efficient fire containment methods are needed for larger vessels.

Organizationally, several incidents have led to major reviews of safety protocols, such as improved stowage and handling guidelines for dangerous goods, stricter declaration requirements, and enhanced training for crew members. The 2017 Maersk Honam incident was a turning point in the industry's approach to fire safety, leading to revised protocols for the declaration and stowage of dangerous goods.

Several preventive measures have been implemented across the industry in response to these incidents. Stricter regulations on hazardous materials and enhanced fire detection systems, especially in reefer containers, have been introduced. The Yantian Express incident in 2018, for example, prompted a review of fire detection in refrigerated containers, leading to improvements in the technology used to prevent electrical fires. Similarly, the APL Vancouver fire in 2019 spurred the industry to enhance monitoring of cargo that could spontaneously combust.

Another key preventive measure has been the development of stricter stowage plans for dangerous goods. Several incidents, such as the X-Press Pearl and Zim Kingston fires, have demonstrated the importance of properly securing and segregating hazardous materials to prevent fire outbreaks. [24] [25]

The financial impact of these fires has been substantial, with damages often exceeding millions of dollars. The costliest incident was the MOL Comfort structural failure and fire in 2013, which resulted in over $400 million in losses, including the complete loss of the vessel. Other incidents, such as the Maersk Honam and MSC Flaminia, have similarly incurred damages in excess of $100 million, not including the environmental and reputational costs associated with these disasters.

In addition to the direct costs, these incidents have led to increased insurance premiums and more stringent inspections by port authorities and classification societies. Shipowners and cargo owners are often the most financially impacted stakeholders, but environmental agencies and local governments are also involved, particularly in cases where fires result in pollution or hazardous spills, as seen in the X-Press Pearl disaster.

The regulatory response to these incidents has been multifaceted, with significant contributions from the International Maritime Organization (IMO), local port authorities, and classification societies. Regulations on the handling of dangerous goods, such as the International Maritime Dangerous Goods (IMDG) Code, have been continually updated in response to major incidents. For example, after the Maersk Honam fire, the IMO introduced stricter rules regarding the declaration and stowage of dangerous goods to prevent future disasters.

Key stakeholders in these incidents include shipowners, cargo owners, port authorities, insurance companies, and regulatory bodies. Each of these parties plays a vital role in ensuring that preventive measures are followed and that lessons from past incidents are incorporated into future safety protocols. [26]

The analysis of fire accidents on cargo vessels from 2008 to 2023 reveals a pattern of recurring risks, including hazardous materials, electrical faults, and inadequate stowage procedures. While significant improvements have been made in terms of fire suppression technology, crew training, and regulatory frameworks, there remain critical knowledge gaps, particularly in dealing with newer challenges such as electric vehicle battery fires. Continued collaboration between stakeholders, along with stricter enforcement of regulations, is essential to reducing the risk of future fire incidents and improving the overall safety of global maritime operations.


OVERHEAT

REFERENCES

[1] International Maritime Organization, "Environmental protection and fire safety on vessels," IMO Publishing, 2020.

[2] Allianz Commercial, "Safety and Shipping Review 2024," Allianz Global Corporate & Specialty SE, Munich, 2024.

[3] International Union of Marine Insurance, "Cargo fire safety report," 2019.

[4] T. A. R. G. V. K. F. &. D. M. Baalisampang, "Review and analysis of fire and explosion accidents in maritime transportation," *Ocean Engineering,* vol. 158, pp. 350-366, 2018.

[5] European Maritime Safety Agency, "CARGOSAFE REPORT. Study investigating cost-efficient measures for reducing the risk of cargo fires on container vessels," 2023.

[6] International Maritime Organization, "International Maritime Dangerous Goods (IMDG) Code," 2020.

[7] International Maritime Organization, "International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) including the 2010 Manila Amendments," IMO Publishing, 2017.

[8] International Maritime Organization, "STCW including 2010 Manila Amendments: Basic and Advanced Firefighting Training Requirements (STCW Code, Table A-VI/1-2 and A-VI/3).," IMO Publishing, 2010.

[9] International Maritime Organization, "STCW: Periodic Refresher Training for Firefighting and Safety at Sea (STCW Code, Section A-VI/1-4)," IMO Publishing, 2011.

[10] International Maritime Organization, "STCW Code: Training standards for handling dangerous goods in maritime transport (STCW Code, Table A-II/1 and A-II/2," IMO Publishing, 2020a.

[11] International Maritime Organization, "International Maritime Dangerous Goods Code (IMDG Code)," IMO Publishing, 2020b.

[12] Lloyd’s Register, "Electrical systems safety on container vessels," 2021.

[13] Det Norske Veritas Germanischer Lloyd, "Fire safety measures for cargo ships: A focus on STCW fire prevention training," DNV GL Publications, 2020.

[14] International Chamber of Shipping, "Best practices for fire safety on container ships.," 2020.

[15] TT Club, "Loss prevention: Fire safety," 2022.

[16] Bremen Port, "Bremen Port Security Act.," [Online]. Available: https://www.bremen.de/fileadmin/user_upload/verwaltung/bremer_gesetze/Bremen_Port_Security_Act.pdf.

[17] Bureau Veritas, "Technological advancements in fire safety for container ships.," 2021.

[18] German Federal Government., "National Port Strategy," [Online]. Available: https://www.bmvi.de/SharedDocs/EN/Documents/national-port-strategy.pdf.

[19] European Maritime Safety Agency, "Maritime safety strategy: 2023 safety goals and targets," 2023.

[20] European Maritime Safety Agency, "Fire safety guidelines," 2023.

[21] International Union of Marine Insurance, "Cargo loss prevention in fire incidents," 2021.

[22] Lloyd's Register, "Fire safety performance standards for cargo ships. Lloyd's Register," 2020.

[23] International Maritime Organization, "STCW: Crew safety and training standards," IMO Publishing, 2017.

[24] Insurance Marine News, "Container ship fires: Prevention and loss mitigation," Insurance Marine News, 2023.

[25] International Maritime Organization (IMO), "Fire safety on ships: Challenges and future directions. IMO.," 2022.

[26] Lloyd's Register, "Electrical systems safety on container vessels," 2021.

APPENDIX

Table 1 - Accident Rubric

Nr.	Title / Accident / Name	Year	Size of ship	Database/ Source	Cause	Starting from cargo? (spontaneous combustion of the cargo)	Originating from the ship itself?	Originating from outside? (collision etc.)	Time	Location of accident	Harbor / open water	weather conditions	Brief description of the accident	Costs / damage caused	Description of crew (how many people on board and who)?	Description of (technical) equipment (firefighting)	How was the accident fought?	Stakeholder (Who is responsible to deal with accident?)	Loss of cargo?
Accidents with verified / accessible information																			
1	UND Adriyatik	2008	193	newspaper	Fire breaks out inside the ship	-	-	-	early morning	Adriatic Sea	open water	-	The Turkish RoRo freighter UND Adriyatik (22,900 GT) with 200 trucks and nine tons of hazardous goods on board caught fire in Croatian territorial waters near the town of Rovinj. The 22 seamen and nine passengers were rescued by a Greek ship. The ship was scrapped after the fire was extinguished.	ship was scrapped after fire	22 (+ 9 passengers)	not mentioned	Fire-fighting aircraft and boats from Croatia, later Dutch fire-fighting specialists called in	Shipowners, crew, flag state, maritime insurers, firefighting specialists, responding states in whose area the accident occurred	yes
2	MSC Lugano	2008	241 x 32	ATSB TRANSPORT SAFETY REPORT	fire in engine room	no	yes	no	noon	Southern Ocean	open water	sky was partly cloudy, the seas were rough and there was a strong breeze.	a fire started in the engine room, the fire was extinguished by measures from crew	minor damage	24	fire alarm, portable CO2 fire extinguishers	closed the dampers for the engine room fans and the funnel vents and rigged fire hoses to boundary cool the engine room casing and funnel, activate the ship's fixed fire extinguishing system	Shipowners, crew, flag state, maritime insurers, firefighting specialists, responding states in whose area the accident occurred	
3	Lisco Gloria	2010	197	newspaper	technical defect	no	yes	no	night	Baltic Sea	open water	not mentioned	The Lithuanian-flagged RoPax ferry Lisco Gloria catches fire on its journey from Kiel to Memel around 6 nautical miles north of Fehmarn. Most of the 236 people on board were transferred to lifeboats or jumped into the water, but were all rescued by the Federal Police, the Coast Guard and the DGzRS. The ship was severely damaged by the fire and was initially towed to Munkeboe and later scrapped in Memel. The cause of the fire was a technical defect. It was suspected that a refrigeration unit of a truck had caught fire.	Total loss after severe fire damage	32 (+ 203)	not mentioned	not mentioned	Shipowners, crew, flag state, maritime insurers, firefighting specialists, responding states in whose area the accident occurred	yes
4	Charlotte Maersk	2010	346.98	Danish Maritime Accident Investigation Board	fire on deck, Self-ignition of methyl ethyl peroxide (MEKP)	yes	no	no	morning	Malacca Street	open water	not mentioned	fire was located on the deck	only minor damages to the hull and deck and some deformation due to heat on two hatches of cargo hold no. 6. Approximately	21	The fire alarm was activated	the crew mustered according to the muster plan and started the fire fighting efforts.After approximately 24 hours of fire fighting by the	Shipowners, crew, flag state, maritime insurers, firefighting specialists, responding states in whose area the	yes

														160 containers were damaged.			crew members, support ships and a fire fighting aeroplane	accident occurred	
5	MSC FLAMINIA	2012	299	newspaper article	explosion, Presumption: chemical processes (hazardous goods) in the cargo led to the fire	yes	no	no	early morning	North Atlantic Ocean	open water	not mentioned	Explosion and subsequent fire between Canada and Great Britain around 1000 nautical miles from the nearest land on an easterly course	considerable damage to ship, 3 people died	23	not mentioned	Firefighting by several institutions, later towed to the port of Wilhelmshaven, controlled burning there	Shipowners, crew, flag state, maritime insurers, firefighting specialists, responding states in whose area the accident occurred, Stolt-Nielsen und Deltech	yes
6	ZIM Rio Grande	2012	260	SIMPLIFIED SAFETY INVESTIGATION REPORT	Decomposition of thiourea dioxide on Deck midship, loading bay 34	yes	no	no	noon	Red Sea	open water	Clear, visibility 10 nautical miles. North-northwest winds at 12 knots. Air temperature recorded at 40°C.	observed smoke from one of the containers, the master was immediately informed and took control of the situation.	one container	22	not mentioned	container with smoke was identyfied , crew members followed the Material Safety Data Sheet and holes were drilled and water hoses directed inside the container with thiourea dioxide, to cool and extinguish the fire	Shipowners, crew, flag state, maritime insurers, firefighting specialists, responding states in whose area the accident occurred	
7	MV Amsterdam Bridge	2012	260	newspaper article	fire started in a container that was carrying HNS (Fire of diacetone alcohol on deck)	yes	no	no	afternoon	Arabian Sea	open water	not mentioned	caught fire on Sunday evening (approximately 5pm local time) shortly after departing the Indian port of Nhava Sheva enroute to Colombo, Sri Lanka with approximately 1,550 containers. Fire could be completely stopped	no injuries of people, Serious structural damage and 33 containers damaged	20	not mentioned	not mentioned	Shipowners, crew, flag state, maritime insurers, firefighting specialists, responding states in whose area the accident occurred	yes
8	Eugen Maersk	2013	398	Danish Maritime Accident Investigation Board	fire on cargo deck, Cotton fi re due to the friction heatafter collapse of container stack	yes	no	no	morning	Gulf of Aden	open water	Wind – direction and speed:SW – 6-7 m/sWave height:2 mVisibility:10 nmLight/dark:DaylightCurrent:Northeast , 1 knot	crew on board noticed thick smoke from the aftermost loading bay on the main cargo deck, Inspection confirmed a fire in two cargo containers, as well as considerable weather damage to containers and lashings in the area. The fire alarm was raised, the crew mustered accordingly and firefighting efforts were initiated.	Minor structural damage andseveral burnt containers	23	fire alarm	Firefighting assistance from tug and on board.	Shipowners, crew, flag state, maritime insurers, firefighting specialists, responding states in whose area the accident occurred	yes
9	Hansa Brandenburg	2013	176	newspaper article	Explosion on hold of undeclared IMDG cargo – calcium chlorate	yes	no	no	morning	Indian Ocean	open water	not mentioned	A fire broke out in a container stowed in front of the deckhouse, which could not be extinguished with on-board resources. After the fire spread to other containers and parts of the deckhouse, the crew of 17 left the ship	total loss	17	not mentioned	Employees of Five Oceans Salvage and Smit Salvage, who were commissioned to salvage the ship, were able to bring the fire under control days later and finally extinguish it. The	Shipowners, crew, flag state, maritime insurers, firefighting specialists, responding states in whose area the accident occurred	yes

																	ship was then towed to Mauritius.		
10	Maersk Kampala	2013	299 m	newspaper article	Fire started in the container stackbottom and spread to others	yes	no	no	evening	Suez Canal	open water	not mentioned	A fire has broken out on the container ship "Maersk Kampala" in the Red Sea. According to the shipping company, a fire broke out in the forward section of the containers on the voyage from Jebel Ali to the Mediterranean	Minor structural damage, 6 burntcontainers	-	not mentioned	The shipping company had two tugs chartered immediately after the first alarm and sent specialists to fight the fire on the northbound ship.	Shipowners, crew, flag state, maritime insurers, firefighting specialists, responding states in whose area the accident occurred	yes
11	Maersk Londrina	2015	300	newspaper article	Explosion/fi re of IMDG cargo in hold – calcium chlorate	yes	no	no	-	Indian Ocean	open water	not mentioned	suffered explosion in one of her cargo holds, Having been disabled by the fire, Maersk Londrina was drifting for a couple of hours before she managed to resume power and head to Port Louis.	Several burnt containers	-	not mentioned	not mentioned	Shipowners, crew, flag state, maritime insurers, firefighting specialists, responding states in whose area the accident occurred	yes
12	Hanjin Green Earth	2015	353	Isle of Man Ship Registry Casualty Investigation Report No. CA124	fire in Cargo Hold - Mis-declared calcium chlorite	yes	no	no	night	Suez Canal	open water	not mentioned	vessel caught fire approximately 48 km to the south of the canal, while passing it through. At least five salvage vessels and Egyptian navy resources have been included in the firefighting.	Major structural damage, several hundred containers burnt and damaged, 3 people died	21	not mentioned	The ship's fixed CO2 system was used to try and extinguish the fire, no effect on the fire which continued to burn and escalate. Firefighting tugs from the Suez Canal Authority attended the scene and managed to contain and then reduce the fire.	Shipowners, crew, flag state, maritime insurers, firefighting specialists, responding states in whose area the accident occurred	yes
13	Caroline Maersk	2015	347 x 43	The Danish Maritime Accident Investigation Board	Mis-declared cargo of charcoaltablets - fire on hold	yes	no	no	afternoon	South China Sea	open water	Wind – direction and speed: ESE 3.4-5.5 m/sWave height: 0.5-1.0 mVisibility: ClearLight/dark: Daylight	a fire broke out in a container in a cargo hold on board the ship. At the time of the accident, the ship was positioned approximately 50 nm from the coast of Vietnam, underway from Chiwan, China to Tanjung Pelepas, Malaysia.	3 containers, minor structural damage	22	smoke detector alarmindicating smoke	Firefighting assistance on board (Svitzer).Unloading of burning container (PTP).	Shipowners, crew, flag state, maritime insurers, firefighting specialists, responding states in whose area the accident occurred	
14	UASC Barzan	2015	400 x 58,60	newspaper	(Explosion/fi re in cargo hold) Undeclared IMDG cargo, very likely calcium chlorite	yes	no	no	morning	North Atlantic Ocean	open water	not mentioned	The fire was detected in the hold. The crew managed to put out the fire, however; the giant ship was diverted to the Port of Rotterdam for discharging of cargo and necessary inspection. There have been no reports of injuries.	9 containers burnt and serious structural damage in CH No.2	-	not mentioned	crew managed fire	Shipowners, crew, flag state, maritime insurers, firefighting specialists, responding states in whose area the accident occurred	Yes

15	MSC Katrina	2015	366 x 48	BSU	self-ignition of charcoal in cargo hold	yes	no	no	night	Elbe	open water	not mentioned	The fire broke out in a container containing charcoal giving off heat and smoke. The crew attempted to contain the fire and was later aided by two firefighting teams from Cuxhaven who were able to extinguish the blaze. The MSC Katrina proceeded to Hamburg where it unloaded the damaged containers.	One container burnt, several otherdamaged	24	not mentioned	crew and fire fighting teams	Shipowners, crew, flag state, maritime insurers, firefighting specialists, responding states in whose area the accident occurred	
16	Ludwigshafen Express	2016	366 x 48	BSU	Self-ignition of charcoal on deck	yes	no	no	afternoon	Red Sea	open water	not mentioned	fire broke out, that was noticed during an inspection, The fire was reported on a container which was located directly on a hatch cover. Its location made it easier for the crew to tackle the fire quickly and effectively, by using the equipment that was available onboard the ship	One burnt container, 2 damaged	24	not mentioned	crewmember had to deal with the fire completely on their own with equipment on board	Shipowners, crew, flag state, maritime insurers, firefighting specialists, responding states in whose area the accident occurred	
17	CMA CGM Rossini	2016	278 / 40	newspaper	Explosion/fi re of lithium-ion batteries in cargo hold	yes	no	no	morning	Colombo, Sri Lanka	Port	not mentioned	a fire broke out in a hold on board the vessel while it was berthing in Colombo, Sri Lanka	2 burnt and 38 damaged containers	-	not mentioned	extinguished successfully after efficient intervention of crew members and firemen.	not mentioned	yes
18	CCNI Arauco	2016	300 / 49	newspaper	Explosion/fire of undeclaredIMDG cargo – paint thinner	yes	no	no	morning	Hamburg, Germany	Harbor	not mentioned	caught fire while berthed in Hamburg, fire started while welding work on a container in the aft cargo hold, flames then spread through the lower decks, some 300 fire fighters along with several fire boats arrived on scene	130 burnt and damaged containers,major structural damage	-	not mentioned	It took four days to extinguish the fire. Authorities took the risk of flooding her holds, and breaking her back, due to thermal shock, when local fireboats couldn't extinguish the fire	Shipowners, crew, flag state, maritime insurers, firefighting specialists, responding states in whose area the accident occurred	yes
19	APL Austria	2017	295	newspaper	Explosion/fi re of mis-declared calcium chlorite	yes	no	no	-	Indian Ocean	open water	not mentioned	ship was on its voyage from European ports to Asian ports with 8,235 containers when a fire broke out in the ship's middle cargo hold	Several hundred burnt and damaged containers, major structural damage	-	not mentioned	not mentioned	Shipowners, crew, flag state, maritime insurers, firefighting specialists, responding states in whose area the accident occurred	yes
20	MSC Daniela	2017	366 / 51	newspaper	IMDG cargo fire – polystyrene	yes	no	no	-	Indian Ocean	open water	not mentioned	The fire started in the ship's cargo area, firefighting continued 24 hours as the ship was brought closer to shore	Several hundred burnt and damaged containers, major structural damage	22	not mentioned	fire extinguished - Sri Lankan Coast Guard, Navy, and Indian Navy, along with smaller craft and commercial tugboats, participated in the rescue operation	Shipowners, crew, flag state, maritime insurers, firefighting specialists, responding states in whose area the	yes

																		accident occurred	
21	Maersk Honam	2018	353	newspaper	Sodium dichloroisocyanurate dehydrate (SDID)/form of calcium chlorite	yes	no	no	afternoon	Arabian Sea	open water	not mentioned	while enroute in the Arabian Sea towards Suez, a major fire occurred in cargo hold, crew engaged in firefighting, vessel was towed to Jebel Ali during the salvage operation	5 crew members died, 2000 burnt and damaged containers, major structural damage, third of the ship's structure replaced	27	CO2 fire suppression system and other fire-fighting equipment	crew members tried to extinguish, 3 days later brought under control by the ICGS Shoor and two offshore vessels	Shipowners, crew, flag state, maritime insurers, firefighting specialists, responding states in whose area the accident occurred	yes
22	Yantian Express	2019	320	BSU	Self-ignition of mis-declaredcoconut charcoal on deck and cargo hold	yes	no	no	early morning	North Atlantic Ocean	open water	Deteriorating weather conditions during extinguishing work	crew tried to fight the fire (did not manage to contain the fire with shipboard resources), 19 days after the fire broke out, the salvage company declared the containers stowed on deck extinguished	Several hundred burnt anddamaged containers, majorstructural damage	22	not mentioned	crew members and severel institutions (	Shipowners, crew, flag state, maritime insurers, firefighting specialists, responding states in whose area the accident occurred	yes
23	APL Vancouver	2019	328 / 45	newspaper article	Lithium-ion batteries not declared (undeclared) as IMDG cargo	yes	no	no	early morning	South Chinese sea	open water	not mentioned	fire broke out in one of the cargo holds whilst the vessel was on passage from Shekou to Singapore	582 burnt and damaged containers, major structural damage	24	not mentioned	not mentioned	Shipowners, crew, flag state, maritime insurers, firefighting specialists, responding states in whose area the accident occurred	yes
24	ER Kobe	2019	277 x 40	newspaper article	Fire of charcoal	-	-	-	-	South and East chinese sea	open water	not mentioned	on its way from Haiphong (Vietnam) to Qingdao (China), a fire occurred in three containers on deck loaded with charcoal. The vessel was diverted to Hong Kong, where all containers concerned were safely unloaded, vessel continued its journey towards China, when another three containers got on fire while approaching the port of Shanghai	15 burnt and damaged containers	-	not mentioned	The crew reacted quickly and prudent and brought the fire under control	Shipowners, crew, flag state, maritime insurers, firefighting specialists, responding states in whose area the accident occurred	
25	KMTC Hong Kong	2019	168.5 x 27	newspaper article	Explosion/fire of mis-declaredcalcium chlorite	yes	no	no	morning	Laem Chabang	Harbor	not mentioned	fire breaked out while docked, several undeclared container with hazardous goods	35 burnt and damaged containers, injuries of people from smoke and heat, evacuation of many communities around the seaport	not directly mentioned - "More than 130 people were transferred to hospital after an explosion and fire onboard"	not mentioned	not mentioned	Shipowners, crew, flag state, maritime insurers, firefighting specialists, responding states in whose area the accident occurred	

26	COSCO Pacific	2020	349 / 46	newspaper article	Lithium-ion batteries not declared (undeclared) as IMDG cargo	yes	no	no	noon	underway from Port Klang, Malaysia to India's Nhava Sheva Port	open water	not mentioned	container which was loaded from Nansha and destined for Nhava Shevaby, had been falsely declared as spare parts and accessories and caused fire	2 burnt containers	-	CO2 suppressant	The fire was put under control by the ship's crew using the cargo hold's CO2 suppressant	Shipowners, crew, flag state, maritime insurers, firefighting specialists, responding states in whose area the accident occurred	
27	MV X-Press Pearl	2021	186 x 35	article	Leak in a tank container with nitric acid	no exact knowledge, ship arrived in several ports despite leak (cargo + human error?)	no	no	evening	Colombo, Sri Lanka (Arabic Sea)	in front of Habour	Fire further fanned by strong winds	fire spread, fire extinguished after 13 days, towing attempt failed	multiple containers overboard, Significant environmental damage	-	not mentioned	crew, tugboats, specialists from the salvage company Smit Salvage, helicopters from the Sri Lankan Navy and ships from the Indian Coast Guard came to the rescue - 13 days to extinguish	Shipowners, crew, flag state, maritime insurers, firefighting specialists, responding states in whose area the accident occurred	multiple containers overboard
28	Felicity Ace	2022	200 x 32	article	fire of batteries from cars	yes	no	no	noon	North Atlantic Ocean	open water	not mentioned	car transporter loaded with around 4000 vehicles, a fire broke out on one of the vehicle decks for unknown reasons, attempts to extinguish it failed, after three days the fire had burned out, then sank to the ground	total loss of ship	22	not mentioned	not mentioned	Shipowners, crew, flag state, maritime insurers, firefighting specialists, responding states in whose area the accident occurred	yes
29	Fremantle Highway	2023	199	newspaper article	Fire caused by electric vehicle (EV) battery ignition	yes	no	no	night	north sea	open water	Calm seas, moderate weather	car transporter caught fire, burnt for almost one week, the crippled ship has been towed into port of Eemshaven	around 150 million dollars, one person died	23	Updated fire suppression systems for EV battery fires	battled for days, EV batteries complicated, 1 crew member fatality	Shipowners, car manufacturers, regulatory bodies, insurers	yes
30	Maersk Frankfurt	2024	255 / 40	newspaper article	speculation points to a combination of potentially hazardous cargo and mechanical or electrical malfunctions	-	-	-	night	Indian Ocean	open water	not mentioned	while sailing off the western coast of India, en route from Mundra, India, to Colombo, Sri Lanka. The fire, which claimed , started after an explosion in the vessel's cargo area.	1 dead person, damage on the vessel and containers	21	not mentioned	crew's efforts; assistance from the Indian Coast Guard (ICG), which deployed multiple vessels and aircraft to combat the blaze. The fire was exacerbated by the hazardous conditions on board, including likely flammable cargo such as	Shipowners, crew, flag state, maritime insurers, firefighting specialists, responding states in whose area the accident occurred	

																	chemicals or lithium batteries		
31	Zim Kingston	2021	260	article	fire within container	yes	no	no	-	Constance Bank	habour	-	While at anchor on Constance Bank, , reported a fire onboard the vessel within their cargo containers	container loss	21	-	firefighting assistance was requested	-	

Funded by
the European Union

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement Project No: 101076633. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them.