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ABSTRACT

This deliverable provides a comprehensive framework for designing, classifying and analysing navigation safety occurrences related to container transport at sea and in port terminals. Building on an extensive regulatory review, a structured hazard identification process and a comparative assessment of risk-analysis methodologies, the document introduces a unified conceptual model and taxonomy for describing safety-relevant events across different operational contexts. This "navigation safety occurrence design" forms the foundation for a consistent interpretation of hazards, triggers, initiating mechanisms, consequences and safety barriers within the OVERHEAT project.

The deliverable evaluates the applicability of established maritime and industrial risk-assessment methods—such as FMEA, FTA, ETA, HAZOP and What-If analysis—and examines the transferability of advanced safety-management practices from aviation to maritime operations. The unified taxonomy is applied across four representative European use cases (Spanish, German, Italian and Polish), supporting scenario development, qualitative and semi-quantitative risk assessments, and the evaluation of preventive and mitigating measures.

The results demonstrate that container-transport safety is shaped by a complex interaction of regulatory, technical, operational and human-factor elements. The conceptual and analytical structures proposed in this deliverable provide the essential basis for subsequent WP3 tasks, including simulation-supported assessment and the development of integrated fire-prevention and mitigation strategies. Overall, D3.1 establishes a coherent, harmonized and operationally relevant foundation for improving safety performance in maritime and terminal environments.

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ACRONYMS

Acronym	Definition
D	Deliverable
e.g.	exempli gratia
ETA	Event Tree Analysis
FMEA	Failure Mode and Effects Analysis
FSA	Formal Safety Assessment
FTA	Fault Tree Analysis
GDPR	General Data Protection Regulation
HAZOP	HAZard and OPerability studies
IMO	International Maritime Organization
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RCT	Risk Contribution Tree
RI	Risk Index
RPN	Risk Priority Number
SoA	State-of-the-Art
WP	Work Package

INTRODUCTION

The increasing scale and complexity of global containerized transport have intensified the need for robust safety frameworks capable of addressing diverse operational risks across maritime and port environments. Fires on container vessels, misdeclared dangerous goods, electrical failures, cargo-handling deviations, human-factor shortcomings and external disruptions continue to challenge the integrity of intermodal transport chains. As ships grow larger, cargo becomes more heterogeneous, and logistics systems become more interdependent, a structured and harmonized approach to hazard identification, risk assessment and safety management is essential.

At the international level, regulations such as SOLAS, the IMDG Code and IMO guidelines, complemented by European directives and national legislation, define the baseline for safe container transport. However, gaps persist in the practical integration of these requirements, particularly regarding early-stage detection of hazardous conditions, cross-modal information exchange, and the systematic assessment of fire scenarios. The maritime sector also faces increasing pressure to adopt more predictive, data-driven and system-oriented approaches similar to those successfully implemented in the aviation domain.

This deliverable provides the conceptual and methodological foundation for Work Package 3 of the OVERHEAT project, which aims to improve the understanding, assessment and prevention of fire-related risks in container transport. A central contribution of D3.1 is the formulation of a Navigation Safety Occurrence Design, which establishes a unified structure for describing safety-relevant events, linking hazards, triggers, occurrences, consequences and safety barriers into a coherent analytical chain. This occurrence design is complemented by a harmonized taxonomy that enables consistent scenario development and cross-case comparison across ships and port terminals.

In addition to defining this conceptual backbone, the deliverable offers:

- a consolidated review of the regulatory and operational landscape governing container safety;
- a structured identification and classification of hazards relevant to maritime and terminal operations;
- a comparative evaluation of established risk-assessment methodologies and their applicability to fire scenarios;
- an analysis of safety-management practices in aviation for potential transfer to the maritime sector;
- scenario-based assessments for four national use cases that demonstrate the operational application of the proposed framework.

Together, these elements position D3.1 as a key enabler for the subsequent WP3 tasks, including simulation-supported risk analysis, the refinement of safety criteria and the development of integrated strategies for fire prevention and mitigation. The introduction of a common occurrence design ensures that all partners operate under a shared analytical logic, ultimately strengthening the consistency, comparability and impact of the project's safety outcomes.

EXECUTIVE SUMMARY

Deliverable D3.1 provides the conceptual, methodological and analytical foundation for Work Package 3 of the OVERHEAT project, which focuses on improving safety and reducing fire-related risks in container transport at sea and in port terminals. The document integrates regulatory analysis, hazard classification, risk-assessment methodologies and scenario-based evaluations into a unified framework that supports consistent safety assessments across all project partners.

A central achievement of this deliverable is the development of a Navigation Safety Occurrence Design—a structured model that defines how hazards, triggers, events, scenarios and consequences are analytically connected. This model is complemented by a harmonized taxonomy that enables clear and systematic classification of navigation safety occurrences. Together, these elements provide the backbone for WP3, ensuring that risk assessments, simulations and mitigation strategies are based on a shared understanding of safety-relevant events.

The deliverable includes an extensive state-of-the-art review of international, European and national regulations governing container transport safety, highlighting strengths, inconsistencies and gaps in the current framework. It further examines key hazard categories such as misdeclared dangerous goods, electrical failures in reefer containers, cargo shifting, poor stowage, human error, mechanical failures and external threats. For each hazard, underlying causes, pathways and possible consequences are identified.

A comparative analysis of risk-assessment methodologies evaluates the applicability of tools such as FMEA, FTA, ETA, HAZOP and What-If analysis to the maritime domain. The study also investigates advanced safety-management concepts from aviation—such as structured reporting, predictive analysis and Safety Management Systems—to determine their potential transferability to container transport.

The methodology developed in D3.1 is applied to four representative use cases (Spanish, German, Italian and Polish), where scenarios are constructed, KPIs selected, and pre- and post-mitigation risk assessments performed. These assessments demonstrate how the occurrence design and hazard taxonomy support real-world analyses across different operational environments.

Overall, Deliverable D3.1 establishes the foundation for the subsequent tasks of WP3, including simulation-supported risk analysis and the development of improved fire-prevention and mitigation strategies. The outcomes of this work ensure methodological consistency across partners, reinforce analytical rigor and contribute to enhancing the safety and resilience of container transport operations.

1 STATE OF ART

This section provides an overview of the regulatory, operational and technical frameworks governing container transport safety at the international, European and national levels. Its purpose is to identify the legal context and existing safety requirements that influence hazard identification and risk assessment within WP3. The analysis establishes the baseline upon which the navigation safety occurrence design and the subsequent scenario-based evaluations are built.

1.1 COLLECTION AND CLASSIFICATION OF GUIDELINES (LAWS, REGULATIONS, CONVENTIONS) ON CONTAINER TRANSPORT SAFETY APPLICABLE IN EUROPE

Container transport is a critical component of global trade, facilitating the movement of goods across international borders with remarkable efficiency. In Europe, the safety and security of container transport are governed by a complex framework of guidelines, laws, regulations, and conventions designed to address various aspects of the supply chain, from port operations to overland transport. These regulatory measures are essential for mitigating risks, ensuring compliance, and safeguarding the integrity of containerized cargo.

This collection and classification of guidelines focus on the legislative and regulatory landscape underpinning European container transport safety. It includes a comprehensive overview of the key legal instruments and standards that regulate safety practices in ports, terminals, and transportation networks. This encompasses international conventions, European Union regulations, and national laws that together create a robust safety framework.

International Conventions, such as the International Maritime Organization's (IMO) Safety of Life at Sea (SOLAS) Convention and the International Maritime Dangerous Goods (IMDG) Code set forth global standards for maritime safety and the handling of hazardous materials. These conventions are integral to the European regulatory environment, ensuring international safety standards are met across European ports and shipping lines.

European Union Regulations, like the EU Regulation 725/2004 on enhancing ship and port facility security and the EU Regulation 1072/2009 on the common rules for access to the international road haulage market, provide detailed safety requirements that member states must implement. These regulations address both maritime and land transport, ensuring a cohesive approach to container transport safety within the EU.

National Laws further refine these international and European standards, providing country-specific requirements that cater to local conditions and operational practices. In Germany, for example, the *Bremische Hafenverordnung* (Bremen Port Regulation) outlines specific safety and operational guidelines for the port of Bremen, one of Europe's major ports.

By examining these guidelines, we gain insight into Europe's comprehensive and multi-layered approach to container transport safety. Understanding how these laws and regulations interrelate and are applied is crucial for stakeholders in the logistics and transport sectors, from policymakers to industry professionals, ensuring that safety standards are upheld and continuously improved to meet evolving challenges in global trade.

1.1.1 Collection and classification of the most important regulations

Safety in container transportation in Europe is regulated by many international, regional and national directives, laws and regulations. Table 1 and Table 2 collects and classify the most important regulations relating to container safety in general.

	Name	Publisher	Description
1	SOLAS International Convention for the Safety of Life at Sea	International Maritime Organization (IMO)	It is the most important international convention on safety at sea. It contains detailed requirements for the safety of ships, including container ships, and covers topics such as ship design, equipment, operation and safety management systems.
2	IMDG Code International Maritime Dangerous Goods Code	International Maritime Organization (IMO)	It regulates the transport of dangerous goods by sea and contains regulations for packaging, labelling, documentation and handling of dangerous goods containers.
3	MARPOL International Convention for the Prevention of Pollution from Ships	International Maritime Organization (IMO)	It contains regulations for the prevention of pollution of the marine environment from ships, including regulations for the prevention of fires and the handling of hazardous substances.
4	ISPS Code International Ship and Port Facility Security Code	International Maritime Organization (IMO)	It is a comprehensive security program that contains measures to protect ships and port facilities from terrorist threats and other security-related risks.

Table 1. International regulations documents

	Name	Description
1	Directive 2002/59/EC of the European Parliament and of the Council	It concerns the introduction of a Community vessel traffic monitoring and information system. It obliges the Member States to monitor ship movements and ensure that dangerous goods and environmental hazards are detected at an early stage.
2	Regulation (EU) No. 2015/757	It aims to monitor, report and verify greenhouse gas emissions from maritime transport. It also concerns the safety of ships in relation to pollution.
3	Directive 2009/16/EC on port state control	It lays down requirements for the inspection of ships by port State authorities to improve safety at sea and the prevention of marine pollution.
4	Regulation (EC) No 725/2004 on enhancing ship and port facility security	It aims to strengthen security measures on board ships and in port facilities to minimize terrorist threats and other security-related risks.
5	Regulation (EC) No 336/2006 on the implementation of the International Safety Management (ISM) Code	It obliges ship operators to implement the ISM Code, which prescribes safety management systems on board ships.

Table 2. European regulations documents

Container transportation safety in Europe is ensured by a combination of international, European and national regulations. These regulations cover various aspects of ship safety, including fire prevention and control, the handling of dangerous goods and general ship safety. It is important that all parties involved in the maritime sector comply with these regulations to ensure safety at sea and prevent accidents. The guidelines described above are only the most relevant or most common general guidelines. In addition, other important guidelines (laws, regulations, conventions) are relevant to container safety.

1.1.2 Further regulations in connection with container safety

In addition to the primary safety frameworks governing container transport, there are several further regulations that play a crucial role in enhancing container safety. These additional regulations encompass a range of measures designed to address specific challenges, improve operational standards, and ensure comprehensive protection against potential threats. Table 3 and Table 4 explore these supplementary regulations, highlighting their significance in fortifying container safety and maintaining the integrity of global supply chains.

	Name	Publisher	Description
1	International Safety Management (ISM) Code	International Maritime Organization (IMO)	It sets out the international standards for the safe management and operation of ships and the prevention of pollution. It requires ship operators to set up a Safety Management System (SMS)
2	Maritime Labor Convention (MLC)	International Labor Organization (ILO)	It lays down minimum standards for the working and living conditions of seafarers, including safety and health requirements.
3	International Convention on Load Lines (LL Convention)	International Maritime Organization (IMO)	It regulates the minimum freeboard requirements for ships to ensure that they are safely loaded and have sufficient buoyancy to prevent overloading and potential sinking.
4	International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM Convention)	International Maritime Organization (IMO)	It aims to prevent the spread of harmful aquatic organisms through the management and control of ballast water.
5	Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention)	International Maritime Organization (IMO)	It regulates the prevention of marine pollution caused by the dumping of waste and other matter into the sea.
6	International Convention on the Control of Harmful Anti-fouling Systems on Ships (AFS Convention)	International Maritime Organization (IMO)	It prohibits the use of environmentally hazardous anti-fouling coatings on ships.
7	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW)	International Maritime Organization (IMO)	It establishes minimum standards for the training, certification and watchkeeping of seafarers to ensure safety at sea.
8	Code of Practice for Packing of Cargo Transport Units (CTU)	International Maritime Organization (IMO) International Labor Organization (ILO) United Nations Economic Commission for Europe (UNECE)	It provides instructions for the safe packing and securing of cargo in containers and other transport units to prevent accidents and damage.
9	International Convention for Safe Containers (CSC)	International Maritime Organization (IMO)	It regulates the safety standards for containers to ensure safety in container transportation.

Table 3. International regulations in connection with container safety

	Name	Description
1	Directive 2014/90/EU on the equipment of ships	It ensures that the equipment used on ships complies with international safety standards. It contains provisions on the approval, inspection and conformity assessment of marine equipment.
2	Regulation (EU) 2017/352 establishing a framework for the provision of port transport services and ensuring the financial transparency of ports	It promotes the efficiency and safety of port services in the EU and ensures that port infrastructure is designed for the safe operation of ships.
3	Directive 2005/65/EC on enhancing port security	It complements the ISPS Code and aims to strengthen security measures in EU ports to reduce the threat of terrorism and other security-related risks.
4	Directive 1999/32/EC on the reduction of Sulphur emissions from ships	It obliges ships to use low-Sulphur fuel in order to reduce air pollution from Sulphur oxides.
5	Directive 2010/65/EU on reporting formalities for ships arriving in and/or departing from ports of the Member States	It harmonizes the reporting formalities for ships in the EU in order to improve the safety and efficiency of maritime transport.
6	Regulation (EU) No 1257/2013 on the recycling of ships	It lays down requirements for the environmentally sound recycling of ships and aims to improve safety and environmental standards in ship dismantling.
7	Directive 2014/94/EU on the deployment of alternative fuels infrastructure	It promotes the development of infrastructure for alternative fuels, including the provision of Liquefied Natural Gas (LNG) as a clean fuel for ships.
8	Directive 2008/68/EC on the inland transport of dangerous goods	It regulates the transport of dangerous goods by road, rail and inland waterway within the EU and contributes to the safety of the entire multimodal transport chain.
9	Regulation (EU) no. 1177/2010 concerning the rights of passengers when traveling by sea and inland waterway	It protects the rights of passengers traveling by sea and inland waterway and ensures that safety standards are met to guarantee passenger safety.
10	European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways (ADN)	It regulates the transportation of dangerous goods on inland waterways in Europe and supplements the regulations for maritime transport.
11	Directive 2009/18/EC on the investigation of accidents in the maritime transport sector	It regulates the investigation of accidents and incidents in maritime transport to improve maritime safety.
12	European Maritime Safety Agency (EMSA) Guidelines	It regularly publishes guidelines and recommendations to improve maritime safety in the EU.
13	UNECE ADR European Agreement concerning the International Carriage of Dangerous Goods by Road	Regulates the international transportation of dangerous goods by road and supplements the regulations for maritime transport.

Table 4. European regulations in connection with container safety

In the complex landscape of container transport, ensuring safety and compliance involves not only adhering to international standards but also integrating these standards into national legal frameworks. National guidelines, including laws, regulations, and conventions, play a pivotal role in the effective transposition of international directives into domestic law. This integration is crucial for maintaining a consistent and high level of safety across borders while accommodating local conditions and operational practices.

The following list provides a comprehensive overview of national guidelines relevant to container transport safety, detailing how these laws and regulations reflect and incorporate international directives. It highlights how international conventions and directives are transposed into national legislation, ensuring that global safety standards are effectively implemented at the local level.

International Directives, such as those issued by the International Maritime Organization (IMO) and the European Union set forth broad safety frameworks that member states are required to adopt. These directives include conventions like the International Maritime Dangerous Goods (IMDG) Code and regulations such as the SOLAS (Safety of Life at Sea) Convention, establishing essential safety protocols for container transport and handling.

National Guidelines are the mechanism through which these international standards are translated into actionable and enforceable rules within individual countries. For instance, in Germany, national regulations, such as the *Bremische Hafenverordnung* (Bremen Port Regulation) serve to implement and adapt international and European directives to meet national needs and contexts.

Relevance and transposition involve aligning national laws with international expectations while addressing specific local challenges and requirements. This process ensures that national guidelines not only comply with global safety standards but also reflect country's unique operational and environmental conditions. By understanding how international directives are adapted into national legislation, stakeholders can better navigate the regulatory landscape, ensuring compliance and promoting safety in container transport operations.

This list and analysis aim to provide a detailed understanding of the national guidelines governing container transport safety, illustrating their relevance in the broader context of international regulations and the importance of their effective transposition into domestic law.

The following paragraph includes a list of important players and port areas / transshipment points in Europe with the national guidelines issued in Germany (Table 5), Great Britain (Table 6), France (Table 7), Netherlands (Table 8), Italy (Table 9), Spain (Table 10) and Denmark (Table 11).

Country	Name	Description
Germany	Maritime Tasks Act (SeeAufgG)	It regulates the tasks and powers of the German Coast Guard and other maritime authorities regarding safety at sea.
	Ship Safety Ordinance (SchSV)	It contains specific regulations on the safety of ships, including regulations on the prevention of fires and the handling of dangerous goods.
	Maritime Safety Ordinance (Maritime Safety Ordinance - MSV)	It regulates the safety measures in German ports and onboard ships to prevent security risks.
	Ordinance on the Security of Seagoing Ships (SchiffSiVO)	This ordinance contains detailed regulations on security onboard seagoing vessels flying the German flag.
	Ordinance on Maritime Security (SeeFSicherungsV)	It contains provisions on maritime security, including measures to prevent piracy and terrorist attacks.
	Seeschifffahrtsstraßen-Ordnung (SeeSchStrO)	It regulates the traffic regulations on German maritime waterways and contains provisions for the safety of shipping.
	Ship Manning Ordinance (SchBesV)	It regulates the minimum manning of ships flying the German flag to ensure the safety and safe operation of the ships.
	Ordinance on Maritime Piloting (SeeLV)	It regulates the requirements and duties of sea pilots who contribute to safe navigation and the protection of ships and the environment.

Table 5. German national regulations in connection with container safety

Country	Name	Description
Great Britain	Merchant Shipping Act 1995	It comprehensively regulates the safety of ships, including regulations on ship safety and the handling of dangerous goods.
	Maritime Labor Convention (MLC)	The UK has ratified the MLC, which sets out minimum requirements for the safety and welfare of seafarers.
	Safety of Life at Sea Regulations	It transposes the provisions of the SOLAS Convention into national law and contains detailed regulations on ship safety.
	Dangerous Goods Shipping Regulations	It governs the safe transportation of dangerous goods by sea and transposes the provisions of the IMDG Code into national law.
	Merchant Shipping (Maritime Labor Convention) (Minimum Requirements for Seafarers etc.) Regulations 2014	It transposes the provisions of the MLC into national law and lays down minimum requirements for the working and living conditions of seafarers.
	Merchant Shipping (Port State Control) Regulations 2011	It governs the control of ships by port states to ensure compliance with international safety and environmental standards.
	Merchant Shipping (Accident Reporting and Investigation) Regulations 2012	It governs the reporting and investigation of shipping accidents in order to determine the causes of accidents and prevent future accidents.
	Merchant Shipping (Ship-to-Ship Transfers) Regulations 2010	It sets out safety requirements for the transfer of cargo between ships at sea in order to minimize the risk of accidents and pollution.

Table 6. Great Britain national regulations in connection with container safety

Country	Name	Description
France	Code des transports	It contains comprehensive regulations on maritime safety and the prevention of accidents and environmental damage.
	Décret n° 84-810 relatif à la sauvegarde de la vie humaine en mer, à l'habitabilité à bord des navires et à la prévention de la pollution	It regulates the safety standards for ships, including the requirements for fire prevention and firefighting.
	Arrêté du 23 novembre 1987 relatif à la sécurité des navires	It contains comprehensive provisions on ship safety, including requirements for the prevention of fires and the handling of dangerous goods.
	Décret n° 2014-761 du 2 juillet 2014 relatif aux mesures de sûreté des navires et des installations portuaires	It lays down security measures for ships and port facilities to minimize threats from terrorism and other security-related risks.
	Code de l'environnement	It contains comprehensive regulations for the protection of the environment, including regulations for the prevention of pollution from ships.
	Arrêté du 25 novembre 2008 relatif à la prévention des risques professionnels à bord des navires	It governs the measures for the prevention of occupational accidents and diseases on board ships.
	Arrêté du 9 novembre 2007 relatif à la sécurité des navires transportant des marchandises dangereuses	It contains specific provisions for the safety of ships transporting dangerous goods.
	Code du travail maritime	It contains labour regulations for seafarers, including safety and health requirements.

Table 7. French national regulations in connection with container safety

Country	Name	Description
Netherlands	Wet ter voorkoming van verontreiniging door schepen (Wvvs)	It aims to prevent pollution from ships and contains regulations on safety and the handling of dangerous goods.
	Schepenwet	It contains comprehensive regulations on the safety of ships and the prevention of accidents at sea.
	Veiligheidswet schepen (Safety of Ships Act)	It regulates the safety of ships flying the Dutch flag and contains regulations on the prevention of accidents and the handling of dangerous goods.
	Havenbeveiligingswet (Port Security Act)	This act lays down security measures for Dutch ports to reduce the threat of terrorism and other security-related risks.
	Wet havenstaatcontrole (Port State Control Act)	This act regulates the port state control of ships in Dutch ports to ensure compliance with international safety standards.
	Besluit gevaarlijke stoffen zeescheepvaart (Decision on Dangerous Goods in Maritime Transport)	It governs the transportation of dangerous goods by sea and transposes the provisions of the IMDG Code into national law.
	Scheepvaartverkeerswet (Shipping Traffic Act)	It regulates shipping traffic in Dutch waters and contains regulations on safety and the prevention of accidents.
	Wet voorkoming verontreiniging door schepen (Pollution Prevention from Ships Act)	It contains regulations on the prevention of pollution from ships and transposes the provisions of the MARPOL Convention into national law.

Table 8. Netherlands national regulations in connection with container safety

Country	Name	Description
Italy	Codice della Navigazione (Shipping Code)	It regulates maritime legislation in Italy, including safety regulations for ships and port facilities.
	Decreto Legislativo 27 luglio 1999, n. 271 (Regulation on the safety of work on board ships)	It contains regulations to ensure occupational safety on board ships.

Table 9. Italian national regulations in connection with container safety

Country	Name	Description
Spain	Ley de Puertos del Estado y de la Marina Mercante (Act on State Ports and the Merchant Marine)	It regulates the organization and security of state ports and the merchant marine in Spain.
	Real Decreto 1616/1987 (Ordinance on the regulation of cargo securing on board ships)	It contains specific regulations for securing cargo on board Spanish ships.

Table 10. Spanish national regulations in connection with container safety

Country	Name	Description
Denmark	Søfartsstyrelsens bekendtgørelse om skibes sikkerhed (Ordinance for ship's safety at sea).	It regulates the safety requirements for ships flying the Danish flag.
	Bekendtgørelse om sikkerhed ved sejlads med farligt gods (Ordinance for the safety of dangerous goods transport at sea).	It contains specific regulations for the safe transportation of dangerous goods by sea.

Table 11. Denmark national regulations in connection with container safety

This additional collection of directives and regulations shows that safety in container transport in Europe is comprehensively covered by many regulations at international, European and national level. These statements also show that many detailed regulations and technical standards support safety in container transport in Europe. These regulations cover various aspects of ship safety, environmental protection and working conditions on board ships and help to minimize risks and ensure safety in the maritime sector.

Although the directives, regulations and laws mentioned so far comprise the essential regulations on safety in container transport in Europe, there may be other specific regulations and technical standards, particularly in the countries' national laws, which contribute to this.

1.1.3 Relevant international and European regulations relating to fires on container ships

In today's globalized trade environment, the safe transport of containers at sea is crucial for maintaining an efficient and reliable supply chain management system. Protecting against fires aboard container ships and handling container loss are central aspects of safety management. International and European guidelines, laws, regulations, and conventions are designed to address these risks proactively and ensure effective damage control measures. This list provides a comprehensive overview of the relevant international and European regulations specifically targeting fires on container ships and the loss of containers. It includes:

- **International Conventions and Guidelines** (Table 12) that establish worldwide standards for fire protection and the management of container loss; key documents, such as the SOLAS and the IMDG Code are instrumental in setting safety protocols for container ships and handling hazardous materials; these conventions include detailed provisions for fire suppression, ship stability, and emergency planning to minimize risks,
- **European Regulations and Laws** (Table 13) that harmonize and specify international standards within the European Union. Regulations, such as EU Regulation 725/2004 on enhancing ship and port facility safety and directives concerning the handling and prevention of hazardous goods accidents, ensure that safety measures and emergency procedures are rigorously followed in European waters,
- **National Regulations and supplementary guidelines** (Table 14 and Table 15) in various European countries provide additional details and specific requirements that adapt international and European standards to national contexts; these regulations include

national fire protection rules for ships, specific requirements for container loading and securing, and protocols for mitigating damage in the event of container loss.

	Name	Description
1	SOLAS (International Convention for the Safety of Life at Sea)	It contains comprehensive regulations on fire prevention, firefighting and fire protection on ships. Chapter II-2 (Construction, fire prevention, fire detection and fire extinguishing) is particularly relevant.
2	MARPOL (International Convention for the Prevention of Pollution from Ships)	It regulates the prevention of pollution by harmful substances that may be caused by fires.
3	IMDG Code (International Maritime Dangerous Goods Code)	It contains regulations for the safe transport of dangerous goods to minimize the risk of fire.
4	ISM Code (International Safety Management Code)	It sets out requirements for a ship's safety management system to manage risks, such as fires.
5	STCW (International Convention on Standards of Training, Certification and Watchkeeping for Seafarers)	It contains training requirements for the crew for firefighting and hazard prevention.
6	LL Convention (International Convention on Load Lines)	It refers to the safe loading and stability of the ship to prevent fires and container losses.
7	International Convention for Safe Containers (CSC)	It establishes safety standards for containers to prevent accidents and fires.

Table 12. International regulations and conventions

	Name	Description
1	Directive 2002/59/EC establishing a vessel traffic monitoring system	It promotes the safety and efficiency of maritime transport, including the prevention and management of fires.
2	Directive 2008/68/EC on the inland transport of dangerous goods	It regulates the transport of dangerous goods to minimize the risk of fires at sea.
3	Directive 2014/90/EU on the equipment of ships	It ensures that the equipment used on ships complies with international safety standards, including fire safety measures.
4	Regulation (EU) No 1257/2013 on the recycling of ships	It sets out requirements for the environmentally sound recycling of ships, including the handling of hazardous substances that could cause fires.
5	Directive 2010/65/EU on reporting formalities for ships arriving in and/or departing from ports of the Member States	It harmonizes reporting formalities for ships in the EU, including information on cargo safety and fire prevention.
6	Directive 1999/32/EC on the reduction of sulphur emissions from ships	It requires ships to use low-sulphur fuel to reduce the risk of fire from emissions.
7	Directive 2009/18/EC on the investigation of accidents in the maritime transport sector	It regulates the investigation of accidents and incidents in maritime transport, including fires and container losses.

Table 13. European regulations

	Name	Publisher	Description
1	ISO 9001 - Quality Management Systems	International Organization for Standardization (ISO)	It regulates quality management systems that are also relevant for fire protection.
2	ISO 14001 - Environmental Management Systems	International Organization for Standardization (ISO)	It regulates environmental management systems that also include fire prevention measures.
3	ISO 28000 - Security Management Systems for the Supply Chain	International Organization for Standardization (ISO)	It specifies requirements for security management systems for the supply chain, including fire prevention measures.
4	ISO 45001 - Occupational Health and Safety Management Systems	International Organization for Standardization (ISO)	It regulates occupational health and safety management systems that are also relevant to fire safety.
5	ISO 9712 - Non-Destructive Testing	International Organization for Standardization (ISO)	It specifies requirements for the qualification and certification of personnel who carry out non-destructive tests on ship structures and containers to identify potential fire risks.
6	ISO 6346 - Freight Containers - Coding, Identification and Marking	International Organization for Standardization (ISO)	It standardizes the coding, identification and marking of freight containers.
7	EN 12195-1 - Load Restraint Assemblies on Road Vehicles	European Committee for Standardization (CEN)	It specifies requirements for lashing devices for securing loads on road vehicles.
8	EN 12642 - Securing of Cargo on Road Vehicles	European Committee for Standardization (CEN)	-

Table 14. Technical standards

	Name	Description
1	IMO Resolution MSC.380(94)	This resolution contains specific amendments to existing regulations to enhance safety in container transport, including fire safety measures.

Table 15. Specialized regulations and standards

The aim of this lists is to provide a comprehensive picture of the regulatory requirements designed to enhance safety aboard container ships and minimize the risk of fires and container loss. A thorough understanding of these guidelines and regulations is essential for all stakeholders in the maritime sector to ensure that both preventive and reactive safety measures are effectively implemented. The national guidelines also contain specific rules on fire protection and management on container ships, as exemplified by the following regulations (Table 16, Table 17 and Table 18).

Country	Name	Description
Germany	Maritime Sicherheitsverordnung - MSV (Maritime safety regulation)	It regulates security measures in German ports and on-board ships, including fire protection.
	Verordnung über die Sicherung von Seeschiffen - SchiffSiVO (Regulation on the security of vessels)	It contains safety regulations on board seagoing vessels, including firefighting

Table 16. German national regulation on fire protection and management on container ships

Country	Name	Description
Great Britain	Safety of Life at Sea Regulations	It transposes the provisions of the SOLAS Convention into national law, including fire safety measures.
	Merchant Shipping (Accident Reporting and Investigation) Regulations 2012	It regulates the reporting and investigation of ship accidents, including fires and container losses.

Table 17. Great Britain national regulation on fire protection and management on container ships

Country	Name	Description
France	Arrêté du 23 novembre 1987 relatif à la sécurité des navires	It includes ship safety regulations, including fire safety measures.
	Décret n° 2014-761 du 2 juillet 2014 relatif aux mesures de sûreté des navires et des installations portuaires	It establishes safety measure/s for ships and port facilities, including fire protection.

Table 18. French national regulation on fire protection and management on container ships

This list contains the most important international and European regulations as well as some national examples and technical standards relevant to fire protection on container ships and loss of containers. In this regard, it is important to regularly check the availability of their most recent versions to ensure that all applicable requirements are considered.

1.1.4 Critical discussion

Container transport safety in Europe is ensured by a combination of international, European and national regulations. These regulations cover various aspects of ship safety, including fire prevention and control, the handling of dangerous goods and general ship safety. It is important that all parties involved in the maritime sector comply with these regulations to ensure safety at sea and prevent accidents.

The landscape of guidelines, general and specific regulations concerning fires on container ships and container loss is a testament to the international and regional commitment to maritime safety. A complex framework of international conventions, European regulations, and national laws establishes a robust safety net to address the multifaceted risks associated with container transport by sea.

International Conventions like the SOLAS Convention and the IMDG Code lay the foundational standards for fire safety and hazardous materials management. These conventions mandate comprehensive safety protocols that are essential for preventing and responding to fires on container ships. They provide detailed instructions on fire suppression systems, emergency response plans, and the safe stowage of dangerous goods, thereby mitigating the risk of catastrophic incidents.

European Regulations further refine these international standards, ensuring uniformity and compliance across EU member states. Regulations, such as EU Regulation 725/2004 enhance the safety of ships and port facilities, incorporating stringent measures for fire prevention and emergency preparedness. These regulations foster a cohesive approach to maritime safety, emphasizing the importance of consistent safety practices across all European ports and shipping lanes.

National Laws and Specific Regulations provide additional layers of safety by adapting international and European guidelines to the unique operational contexts of individual countries. These laws address specific challenges and conditions, offering tailored solutions that enhance the overall effectiveness of fire safety measures. National regulations often include rigorous inspections, crew training programs, and detailed container handling and securing protocols, ensuring that preventive and reactive measures are both comprehensive and contextually relevant.

In conclusion, the synergy between international conventions, European regulations, and national laws creates a comprehensive safety framework that significantly reduces the risk of fires on container ships and container loss. This integrated approach ensures that safety standards are not only universally high but also adaptable to specific regional and national needs. By adhering to these guidelines and continuously improving safety practices, the maritime industry can safeguard lives, protect the environment, and maintain the integrity of global trade.

The European directives on container transport safety are part of a comprehensive legislative framework aimed at ensuring safety and security of maritime and intermodal transport across the European Union. These directives align with international standards and conventions such as those set by the International Maritime Organization (IMO) and the World Customs Organization (WCO). They are characterized by detail and comprehensive explanations, ensuring clarity in their implementation and provide specific requirements for safety assessments, plans, and measures, detailing the responsibilities of various stakeholders, including ship operators, port authorities, and national administrations. For example, Regulation (EC) No 725/2004 outlines the roles of ship safety officers, company safety officers, and port facility safety officers. Also, the directives include thorough explanatory notes and annexes, offering guidance on how to meet the requirements. Directive 2005/65/EC, for instance, contains annexes detailing the risk assessment methodology and the security measures to be implemented.

About this, the effectiveness and comprehensiveness of these directives can be evaluated based on several criteria:

- **Alignment with International Standards:** the directives are well-aligned with international conventions, such as the ISPS Code and the WCO SAFE Framework of Standards, ensuring that European regulations are consistent with global practices,

- **Risk-Based Approach:** the directives employ a risk-based approach to safety, requiring regular assessments and updates to safety plans based on evolving threats. This ensures that safety measures remain relevant and effective,
- **Integration and Interoperability:** the directives promote the integration of safety measures across different transport modes and jurisdictions, enhancing the overall safety of the supply chain; The Union Customs Code, for example, facilitates the secure and efficient movement of goods through the recognition of AEO status,
- **Technological Adaptation:** the directives encourage the use of modern technology for security and monitoring, such as electronic reporting systems mandated by Directive 2010/65/EU; this enhances the accuracy and speed of information exchange, crucial for timely safety responses,
- **Stakeholder Involvement:** the directives involve a wide range of stakeholders in the safety process, from government authorities to private operators, ensuring a comprehensive approach to safety management,

The European directives on container transport safety are effective and comprehensive, providing a robust framework that addresses the current needs of the shipping industry. They offer detailed descriptions and comprehensive explanations, ensuring that all stakeholders understand their roles and responsibilities. By aligning with international standards, adopting a risk-based approach, promoting integration and interoperability, leveraging technology, and involving multiple stakeholders, these directives enhance the safety and efficiency of container transport in Europe.

The aim of the European directives and regulations on fire safety and container loss in cargo is to create a robust framework to address the current requirements of shipping. This evaluation will consider their adequacy and comprehensiveness based on various criteria, including alignment with international standards, scope of coverage, enforcement mechanisms, and adaptability to emerging challenges.

The directives cover a wide range of safety aspects, ensuring comprehensive protection against fire and container loss in cargo spaces:

- **Fire Safety Equipment and Systems:** Directive 2014/90/EU specifies standards for fire protection systems and materials, ensuring that all equipment used on ships meets high safety standards; this includes fire detection, alarm systems, and firefighting equipment,
- **Cargo Securing Measures:** the Directives mandate robust cargo securing practices to prevent container loss; this includes regular inspections and maintenance of securing equipment and adherence to best practices for container stowage,
- **Inspections and Audits:** regular inspections by port state control officers ensure compliance with safety regulations; non-compliant vessels face penalties, detentions, and other enforcement actions.
- **Incident Investigation and Reporting:** Directive 2009/18/EC ensures thorough investigation of maritime accidents, including fires and container loss incidents; The findings from these investigations are used to improve safety regulations and practices.

- **Port State Control:** Directive 2009/16/EC mandates inspections of foreign ships to ensure compliance with international and EU safety standards, including fire safety and cargo securing.

The European directives on fire safety and container loss in cargo spaces are generally adequate and comprehensive in meeting the current shipping requirements. They provide a robust framework that addresses a wide range of safety aspects, ensures compliance with international standards, and incorporates effective enforcement mechanisms. Their adaptability to emerging challenges further enhances their effectiveness:

- **Comprehensive Coverage**: the directives cover many critical aspects of fire safety and container securing, providing detailed requirements and guidelines,
- **International Alignment**: the alignment with SOLAS and the IMDG Code ensures consistency with global standards,
- **Effective Enforcement:** regular inspections and incident investigations enforce compliance and drive continuous improvement,
- **Technological Integration:** encouragement of modern technologies enhances the ability to detect and suppress fires.

However, the wide range of policies and guidelines of the different institutions make it more difficult to transcend and implement them. Often the relevant directives do not go into sufficient detail, or they lack a specific orientation or timeliness, or there is a large room for interpretation of those directives. Therefore, there would be other important points that would contribute to improving the directives:

- Continuous Update: Regular updates to the directives are necessary to keep pace with technological advancements and evolving risks,
- Enhanced Training: Improved training programs for ship crews and port state control officers can further enhance compliance and safety,
- Data Sharing and Collaboration: Increased collaboration and data sharing among EU member states can improve incident response and prevention strategies.

To sum up, the European directives on fire safety and container loss in cargo spaces provide a comprehensive and effective framework to meet the current shipping requirements. Their alignment with international standards, detailed coverage of safety aspects, robust enforcement mechanisms, and adaptability to emerging challenges ensure a high level of maritime safety in the EU. Continuous updates, enhanced training, and improved collaboration can further strengthen this framework to address future challenges.

1.2 SPECIAL REQUIREMENTS FOR TERMINAL EQUIPMENT, RAIL AND ROAD TRANSPORT, AND QUALIFICATION REQUIREMENTS FOR PERSONNEL

Ensuring the safety of container transport, particularly regarding fire protection and container loss, is critical in the shipping industry. The European Union has established a robust regulatory framework to address these concerns, encompassing directives and regulations that set stringent safety standards. These measures are supported by best practice guidelines, which provide detailed recommendations for implementing effective fire safety and container securing protocols. This comprehensive approach includes specific requirements for terminal equipment, rail and road transport, and personnel qualifications, ensuring a high level of preparedness and risk mitigation across all stages of container handling and transport.

The relevant sources for these special requirements include:

1. **Directive 2009/16/EC on Port State Control**: it focuses on inspections of foreign ships in EU ports to ensure compliance with international safety standards, including fire safety and cargo securing measures,
2. **Directive 2014/90/EU on Marine Equipment**: it sets standards for marine equipment, including fire protection systems and materials, ensuring high safety standards on ships,
3. **Regulation (EU) No 2016/1625 on the European Maritime Safety Agency (EMSA)**: EMSA supports member states in implementing maritime safety legislation, conducting inspections, and investigating incidents related to fire and container loss,
4. **Directive 2002/59/EC establishing a community vessel traffic monitoring and information system (VTMIS)**: it requires monitoring and reporting of ship movements and cargo information, enhancing the ability to detect and respond to incidents, such as fires and container loss,
5. **Directive 2009/18/EC establishing the fundamental principles governing the investigation of accidents in the maritime transport sector**: it mandates thorough investigations of maritime accidents, including fires and container loss, to improve safety regulations and practices,
6. **International Maritime Dangerous Goods (IMDG) Code**: it provides guidelines for the classification, labelling, and documentation of hazardous materials, stowage, segregation, and training requirements to ensure safe transport of dangerous goods,
7. **International Convention for the Safety of Life at Sea (SOLAS)**: it establishes comprehensive safety standards, including the Fire Safety Systems Code (FSS Code) and emergency response plans,
8. **European Union Maritime Safety Agency (EMSA) Guidelines** offers best practices for port and terminal safety, container securing practices, and fire safety measures in ports and terminals.

These sources provide the foundation for understanding the regulatory and best practice landscape for container safety and fire protection in the shipping industry.

1.2.1 Technical and Legal Requirements for Terminal Equipment Regarding the Safety of Container Transport at Ports in Europe

Ensuring the safety of container transport at ports across Europe is paramount to maintaining efficient and safe maritime operations. Both technical and legal requirements are in place to safeguard against accidents, protect personnel, and manage the risks associated with handling containers, including hazardous materials. These requirements encompass a broad range of regulations, from the design and maintenance of terminal equipment to compliance with international safety standards. This overview highlights the critical technical and legal measures implemented to enhance the safety and reliability of container transport at European ports.

Fire Detection and Suppression Systems: terminal equipment must be equipped with advanced fire detection and suppression systems. This includes automatic sprinklers, fire alarms, and smoke detectors. These systems should be regularly inspected and maintained to ensure they are in working order.

Handling and Storage Procedures: there are strict guidelines for the handling and storage of containers, especially those containing hazardous materials. Containers should be stored in designated areas away from ignition sources, and proper spacing should be maintained to prevent the spread of fire.

Emergency Response Equipment: terminals must have readily accessible fire extinguishers, firefighting hoses, and other emergency response equipment. This equipment must be regularly inspected and maintained.

Firefighting Training for Personnel: personnel working at terminals must receive training in firefighting techniques and emergency response procedures. This training should be refreshed regularly to ensure readiness in the event of a fire.

Technical Requirements

1. **Container cranes (Gantry cranes):**
   - Load Monitoring Systems: monitoring the loads during lifting and lowering to avoid overloading,
   - Automatic Safety Devices: required emergency stops, anti-sway, and anti-collision systems,
   - Regular Maintenance and Inspection: regulations mandate it to ensure operational safety.
2. **Crane safety:**
   - Strength and Stability: testing crane systems for strength and stability to withstand the demands of heavy containers,
   - Electrical Safety: components must meet current safety standards, including protection against short circuits and overvoltage.
3. **Transport vehicles (straddle carriers, reach stackers, etc.):**
   - Stability Controls: equipment with systems that monitor stability and prevent tipping,
   - Brake and Steering Assistance Systems: enhancing safety when manoeuvring in the terminals,
   - Visibility and Lighting: adequate lighting and surround cameras to improve visibility and safety.
4. **Automated Storage Systems:**
   - Safety Barriers and Fences: protective barriers around automated storage areas to prevent unauthorized access,
   - Emergency Stop Switches: easily accessible emergency stop switches on all automated systems,

- Fire Suppression Systems: integrated systems to quickly address fires.

5. **Hazardous Material Containers (Hazmat):**
   - Special Storage Areas: Separating hazardous goods with enhanced safety measures,
   - Ventilation Systems: adequate to prevent the accumulation of dangerous gases,
   - Fire Detection and Suppression Systems: highly sensitive fire detectors and appropriate fire extinguishing agents.
6. **IT Systems and Data Management:**
   - Access Controls: restricted to IT systems managing container movements and inventory,
   - Data Security Protocols: to secure data integrity and confidentiality,
   - Backup Systems: Regular backups and disaster recovery plans.

Legal Requirements

1. **EU Directives and Regulations:**
   - Directive 2005/65/EC: Directive on enhancing port security,
   - Regulation (EU) 2017/352: Regulation establishing a framework for the provision of port services and financial transparency of ports,
   - Directive 2014/90/EU: Directive on marine equipment and its safety.
2. **International Maritime Organization (IMO) Standards:**
   - SOLAS (International Convention for the Safety of Life at Sea): Global safety standards, including container loading and securing,
   - IMDG Code (International Maritime Dangerous Goods Code): Guidelines for the safe transport of dangerous goods by sea.
3. **National Regulations:**
   - Occupational Safety Laws: National occupational safety laws and regulations specifying safety requirements for personnel and equipment at terminals,
   - Environmental Protection Regulations: Regulations to protect the environment, including the safe storage and handling of hazardous goods and waste.
4. **Certifications and Inspections:**
   - ISO Certifications: ISO 9001 (Quality Management), ISO 14001 (Environmental Management), and ISO 45001 (Occupational Health and Safety Management).
   - Regular Safety Inspections: Mandatory inspections by national and international authorities to ensure compliance with safety standards.

1.2.2 Technical and Legal Requirements for Rail and Road Transport Regarding the Safety of Container Transport at Ports in Europe

Ensuring the safety of container transport at European ports also involves stringent technical and legal requirements for both rail and road transport. These requirements are designed to prevent accidents, safeguard personnel, and ensure the secure handling of containers, including those carrying hazardous materials. This overview highlights the essential technical standards and legal regulations that govern the safety of container transport by rail and road, emphasizing the measures implemented to maintain high safety standards and efficient operations across Europe.

1. **Vehicle and Equipment Standards:** vehicles used for transporting containers by rail and road must meet specific safety standards, including having fire suppression systems on board. For example, trucks transporting hazardous materials may be required to have fire extinguishers and heat shields.
2. **Container Securing Methods:** proper securing of containers is critical to prevent accidents that could lead to fires. Guidelines specify the use of twist locks, lashing bars, and other securing devices to ensure containers are firmly attached to the transport vehicle.
3. **Inspection and Maintenance:** regular inspection and maintenance of transport vehicles are mandatory to ensure that all safety systems, including those for fire prevention and suppression, are functioning correctly.
4. **Drivers and Operators Training:** drivers and operators must be trained in the safe transport of containers, including the handling of hazardous materials. They should also be familiar with emergency procedures in case of fire.

Technical Requirements

1. **Rail Transport**
   - **Wagon Construction**: rail wagons must be designed and reinforced for container transport to ensure stability and safety during transit,
   - **Load Securing**: use of twist locks, tension belts, and other securing devices to safely attach containers to the wagons,
   - **Brake and Safety Systems**: rail wagons must be equipped with reliable brake and safety systems to ensure safe stopping and manoeuvring,
   - **Track Quality and Maintenance**: Regular maintenance and inspection of tracks to ensure safe and smooth transport,
   - **Loading and Unloading Facilities**: Use of modern lifting devices and cranes designed for the safe handling of containers.
2. **Road Transport**
   - **Vehicle Construction:** trucks and trailers must meet technical requirements for container transport, including reinforced frames and appropriate loading surfaces,
   - **Load Securing:** use of twist locks, stanchions, tension belts, and anti-slip mats to securely fix containers on the loading surface,
   - **Brake and Stability Systems:** equipped with ABS (Anti-lock Braking System), EBS (Electronic Braking System), and ESP (Electronic Stability Program) to enhance vehicle safety,
   - **Regular Maintenance and Inspection:** vehicles must be regularly maintained and checked for technical defects,
   - **Monitoring Systems:** use of telematics systems to monitor vehicle and container position and ensure compliance with safety regulations.

<u>Legal Requirements</u>

1. **EU Directives and Regulations**
   - **Directive 2008/68/EC:** on the inland transport of dangerous goods, setting safety regulations for the transport of dangerous goods by road and rail,
   - **Regulation (EC) No 1071/2009:** establishing common rules for the admission to the occupation of road transport operator,
   - **Directive 2014/47/EU:** on the technical roadside inspection of the roadworthiness of commercial vehicles.
2. **International Standards**
   - **ADR - European Agreement concerning the International Carriage of Dangerous Goods by Road:** International agreement on the transport of dangerous goods by road, setting technical requirements and safety regulations,
   - **RID -** Regulations concerning the International Carriage of Dangerous Goods by Rail): for the international transport of dangerous goods by rail.
3. **National Regulations**
   - **Road Traffic Regulations (StVO):** national regulations on road safety, including specific requirements for freight transport,
   - **Rail Transport Regulations:** national regulations setting safety standards for rail transport,
   - **Working Hours Laws:** regulations limiting working hours and rest periods for truck drivers to prevent fatigue and accidents.
4. **Certifications and Inspections**
   - **Technical Vehicle Inspections:** regular technical inspections of trucks and trailers to ensure roadworthiness.
   - **Safety Audits and Inspections:** audits and inspections by national and international authorities to ensure compliance with safety standards.
   - **ISO Certifications:** companies can be certified according to ISO 39001 (Road Traffic Safety Management) to document and improve their safety standards.

The requirements for rail and road transport in Europe to ensure the safety of container transport are comprehensive and cover both technical and legal aspects. They aim to prevent accidents, ensure the safe handling of containers, and make transport efficient and secure. Regular inspections, maintenance, and adherence to international and national standards maintain a high level of safety.

1.2.3 Qualification and Equipment Requirements for Personnel at Ports and Cargo Terminals Regarding the Safety of Container Transport in Europe

Ensuring the safety of container transport at European ports and cargo terminals is a multifaceted task that requires well-trained personnel and appropriate equipment. Both qualifications and equipment standards are critical in maintaining high safety levels, preventing accidents, and ensuring the efficient handling of containers, including those carrying hazardous materials. This overview highlights the essential qualification and equipment requirements for personnel at ports and cargo terminals, focusing on the measures implemented to uphold safety standards in container transport across Europe.

<u>**Qualification Requirements**</u>

1. **General Education and Training**:
   - **Basic Training: p**ort and terminal workers must undergo basic training in logistics and container handling,
   - **Vocational Training:** many employees have specific vocational training, such as being a logistics specialist for port operations,
   - **Onboarding and Internships:** new employees often go through onboarding programs and internships to gain practical experience.
2. **Safety Certifications:**
   - **Dangerous Goods Officer:** training and certification for the safe handling of hazardous materials according to ADR/RID regulations,
   - **First Aid Courses:** regular training in first aid to respond quickly and effectively in emergencies,
   - **Fire Safety Training:** training in fire safety, including the use of fire extinguishers and emergency plans,
3. **Specific Training:**
   - **Crane Operators:** training and certification for operating cranes and other lifting equipment,
   - **Vehicle Operators:** special training for operating straddle carriers, reach stackers, and other terminal vehicles,
   - **Load Securing:** training in properly securing containers on transport vehicles and in storage areas.
4. **IT and Technology Training:**
   - **Terminal Operating Systems (TOS):** training on using TOS for managing container movements and inventory,
   - **Telematics and Monitoring Systems:** training on using telematics and monitoring systems for overseeing vehicles and containers.
5. **Regular Continuing Education:**
   - **Refresher Courses:** regular refresher courses to keep employees' knowledge up to date.
   - **New Regulations and Technologies:** continuing education on new safety regulations and technological developments.

<u>**Equipment Requirements**</u>

1. **Personal Protective Equipment (PPE):**
   - **Helmets:** safety helmets to protect against head injuries,
   - **Safety Shoes:** steel-toed shoes to protect feet,
   - **High-Visibility Clothing**: reflective clothing to increase the visibility of workers,

- **Gloves:** protective gloves for handling heavy and sharp objects,
- **Hearing Protection:** ear protection in noisy work environments.

2. **Safety Equipment:**
   - **Fire Extinguishers:** Easily accessible fire extinguishers at strategic points,
   - **First Aid Kits:** First aid kits that are regularly checked and restocked,
   - **Emergency Exits and Escape Routes:** Clearly marked and easily accessible emergency exits and escape routes.
3. **Technical Equipment**
   - **Cranes and Lifting Equipment:** modern and well-maintained cranes and lifting devices for safe container handling,
   - **Vehicles:** regularly maintained and inspected vehicles such as straddle carriers and reach stackers,
   - **Monitoring Systems:** cameras and sensors for monitoring storage areas and container movements,
   - **Communication Tools:** radios and other communication tools to ensure quick and efficient communication.
4. **IT and Management Systems**
   - **Terminal Operating Systems (TOS):** Integrated systems for managing container movements and inventory,
   - **Telematics Systems:** systems for monitoring and managing vehicles and containers,
     - **Access Control Systems:** systems for controlling and monitoring access to sensitive areas.

The qualification and equipment requirements for personnel at ports and cargo terminals in Europe are comprehensive and aimed at ensuring the safety of container transport. Well-trained personnel and modern equipment are crucial to preventing accidents, enhancing efficiency, and complying with international and national safety standards. Regular training and continuing education, along with the provision of high-quality protective equipment and technical tools, significantly contribute to maintaining high safety standards.

Qualification Requirements for Personnel

1. **Training Programs:** comprehensive training programs for personnel involved in container handling, transport, and storage are essential. These programs cover fire safety, emergency response, handling hazardous materials, and proper use of firefighting equipment.
2. **Certification and Continuous Education:** the personnel should obtain certifications demonstrating their competence in fire safety and emergency response. Continuous education and periodic refresher courses are recommended to keep their skills and knowledge up to date.
3. **Drills and Simulations:** regular fire drills and emergency simulations help ensure that personnel are prepared for real-life scenarios. These exercises should be conducted frequently to maintain a high level of readiness.

Moreover, several best practice guidelines complement the regulatory framework, offering concrete measures for enhancing container safety and fire protection in shipping.

International Maritime Dangerous Goods (IMDG) Code

1. **Classification and Labelling:** guidelines for the classification, labelling, and documentation of hazardous materials to ensure they are handled safely throughout the transport chain.
2. **Stowage and Segregation:** recommendations on the stowage and segregation of hazardous materials to prevent dangerous reactions and the spread of fire.
3. **Training Requirements:** specific training requirements for personnel involved in the transport of dangerous goods, ensuring they are aware of the risks and proper handling procedures.

International Convention for the Safety of Life at Sea (SOLAS)

1. **Fire Safety Systems Code (FSS Code):** detailed specifications for the design, installation, and maintenance of fire safety systems on ships, including fire detection and suppression equipment.
2. **Emergency Response Plans:** guidelines for developing comprehensive emergency response plans, including firefighting strategies and evacuation procedures.

European Union Maritime Safety Agency (EMSA) Guidelines

1. **Best Practices for Port and Terminal Safety:** recommendations for the implementation of fire safety measures in ports and terminals, including the use of fire-resistant materials and the design of safe storage areas.
2. **Container Securing Practices:** guidelines for the proper securing of containers during transport to prevent accidents that could lead to fires.

Concrete Measures

1. **Firefighting Equipment:** ensuring all terminal equipment, vehicles, and personnel have access to and training on the use of firefighting equipment, such as extinguishers and hoses.
2. **Regular Inspections:** conducting regular inspections and maintenance of all equipment used in the handling, storage, and transport of containers to ensure compliance with safety standards.
3. **Emergency Drills:** regularly conducting emergency drills and simulations to prepare personnel for fire incidents, ensuring they can respond quickly and effectively.
4. **Hazardous Material Handling:** implementing strict procedures for the handling and storage of hazardous materials, including proper labelling, documentation, and segregation to prevent dangerous interactions and fires.
5. **Risk Assessments:** performing regular risk assessments to identify potential fire hazards and implementing measures to mitigate these risks.

The European Union has established a comprehensive and robust framework to address the critical issues of fire safety and container loss in the shipping industry. Through a combination of directives, regulations, and best practice guidelines, the EU ensures that all aspects of container transport, from terminal equipment to rail and road transport, are covered by stringent safety standards.

Adequacy and Comprehensiveness

Alignment with International Standards: the directives are well-aligned with international conventions, such as SOLAS and the IMDG Code. This alignment facilitates global cooperation and ensures that the EU's safety standards are consistent with those of other major maritime nations. This not only enhances safety but also streamlines operations for international shipping companies.

Detailed Requirements for Equipment and Operations: the directives specify detailed requirements for terminal equipment, including advanced fire detection and suppression systems, proper handling and storage procedures, and regular maintenance of firefighting equipment. For rail and road transport, the focus is on vehicle and equipment standards, container securing methods, and regular inspection and maintenance protocols. These detailed requirements ensure that every aspect of container handling and transport is addressed, minimizing the risk of fires and container loss.

Personnel Training and Qualifications: a significant emphasis is placed on the training and qualification of personnel. Comprehensive training programs, certifications, and continuous education ensure that personnel are well-prepared to handle fire safety and emergency situations. Regular fire drills and simulations further reinforce their readiness, ensuring that they can respond effectively in real-life scenarios.

Enforcement and Compliance: effective enforcement mechanisms are crucial for the success of these directives. Regular inspections by port state control officers, mandatory reporting and investigation of incidents, and stringent penalties for non-compliance ensure that shipping companies adhere to safety standards. This enforcement not only enhances safety but also promotes a culture of continuous improvement in the industry.

Adaptability and Innovation: the directives are designed to be adaptable to emerging challenges. Encouraging the adoption of modern technology, such as advanced sensors and automated firefighting systems, ensures that the industry can respond to new risks effectively. The risk-based approach, which involves regular assessments and updates to safety measures, ensures that the directives remain relevant and effective in the face of evolving threats.

Best Practices

IMDG Code and SOLAS: best practice guidelines such as the IMDG Code and SOLAS provide additional layers of safety. The IMDG Code's guidelines for the classification, labelling, and handling of hazardous materials are critical for preventing fires. SOLAS, with its Fire Safety Systems Code and emergency response plans, sets high standards for fire safety systems on ships.

EMSA Guidelines: the European Union Maritime Safety Agency (EMSA) provides best practices for port and terminal safety, container securing practices, and fire safety measures. These guidelines are instrumental in helping ports and shipping companies implement effective safety measures and improve their overall safety performance.

While the current framework is comprehensive and robust, continuous improvement is necessary to keep pace with technological advancements and emerging risks. Regular updates to the directives, enhanced training programs, and increased collaboration among EU member states can further strengthen the framework.

Technological Advancements: embracing technological advancements, such as artificial intelligence and IoT for fire detection and suppression can significantly enhance safety. These technologies can provide real-time monitoring and automated responses, reducing the time taken to detect and respond to fire incidents.

Enhanced Training and Collaboration: improved training programs that incorporate the latest best practices and technologies can enhance the readiness of personnel. Additionally, increased collaboration and data sharing among EU member states can lead to better incident response and prevention strategies.

Risk Assessments and Continuous Monitoring: performing regular risk assessments and continuous monitoring of compliance can help identify potential vulnerabilities and address them proactively. This approach ensures that the safety measures remain effective and can adapt to new challenges.

The European directives on fire safety and container loss in cargo spaces provide a robust and comprehensive framework that effectively addresses the current requirements of the shipping industry. By aligning with international standards, specifying detailed requirements, ensuring effective enforcement, and promoting adaptability and innovation, the EU ensures a high level of safety in container transport. Continuous improvement and proactive risk management will further enhance the effectiveness of this framework, ensuring the safety and security of maritime operations in the EU.

2 NAVIGATION SAFETY OCCURRENCE DESIGN AND CLASSIFICATION

The purpose of this section is to establish a common conceptual foundation for describing, structuring and classifying navigation safety occurrences relevant to the OVERHEAT project. While hazards and risks are addressed throughout several parts of the document, this section introduces a unified occurrence design and a harmonized taxonomy that enable all project partners to adopt the same analytical structure when defining scenarios, evaluating risks, and developing mitigation strategies across the four use cases.

As a first step, a common conceptual model of navigation safety occurrences is defined. This model clarifies how hazards, triggers, events, scenarios and consequences relate to one another, and provides a structured basis for the risk assessments presented later in the deliverable.

2.1 CONCEPTUAL MODEL OF NAVIGATION SAFETY OCCURRENCES

In the context of the OVERHEAT project, “navigation safety occurrences” are understood as all events or sequences of events that may compromise the safe transport, handling or stowage of containers at sea and in port terminals, with a particular focus on fire-related scenarios. These occurrences can range from deviations and unsafe conditions (near-misses, anomalies) to full-scale accidents resulting in damage to people, assets, cargo, or the environment.

To support a consistent risk assessment across the different use cases and transport modes considered in WP3, a common conceptual model of navigation safety occurrences is required. This model establishes a clear chain of elements linking:

- **Context and operating conditions** (ship type, voyage phase, terminal layout, traffic conditions, cargo mix);
- **Hazardous states** (presence of dangerous goods, technical degradation, human error, organisational weaknesses);
- **Initiating events or triggers** (e.g. misdeclared DG, overheating in a reefer container, electrical short circuit, cargo shifting, collision, grounding);
- **Navigation safety occurrences** (e.g. localized fire in a container stack, loss of containment, escalation to deck or hold, loss of manoeuvrability);
- **Consequences** (injuries or fatalities, damage to ship and port infrastructure, environmental pollution, interruption of operations, economic losses);
- **Mitigating and preventive barriers** (technical, operational, organisational, regulatory).

Within this model, a navigation safety occurrence is not reduced to the final accident only, but it is characterised as a **structured chain of cause–event–consequence**, in line with the logic of FTA, ETA, FMEA and IMO Formal Safety Assessment. This enables:

- a harmonised description of events across the five OVERHEAT use cases;
- a transparent traceability between hazards, their initiating mechanisms, and observable outcomes;
- an explicit representation of where preventive and mitigating measures act along the chain.

The occurrence model thus becomes the backbone for scenario definition and for the subsequent quantitative or semi-quantitative risk assessment in WP3, ensuring that different partners, data sources and modelling approaches remain aligned to a common structure.

Building on the conceptual model, a harmonised taxonomy is required to ensure consistency in how navigation safety occurrences are classified and compared across ships, terminals and national contexts. The following subsection introduces the classification dimensions adopted in the OVERHEAT project.

2.2 TAXONOMY AND CLASSIFICATION DIMENSIONS

In order to make navigation safety occurrences comparable across different vessels, ports and national contexts, a common taxonomy is required. The taxonomy proposed in this deliverable organises navigation safety occurrences along a set of **classification dimensions** that can be combined as needed for the specific use case:

1. **Phase of operation**
    - At sea: ocean passage, coastal navigation, approach / departure, pilotage, anchorage;
    - In port and terminals: arrival, berthing, loading/unloading, yard handling, gate operations, rail/road interface.
2. **Location and system domain**
    - On board: cargo hold, deck stacks, engine room, accommodation areas, electrical rooms, reefer bays;
    - In the terminal: yard blocks, rail tracks, road lanes, gate area, storage of dangerous goods, workshops.
3. **Primary hazard category** (aligned with Sections 8 and 9)

- Misdeclared or undeclared dangerous goods;
- Declared dangerous goods (including lithium-ion batteries);
- Electrical failures (especially in reefer containers and power supply systems);
- Cargo shifting and poor stowage;
- Human error and inadequate training;
- Mechanical failures in ship or terminal systems;
- External factors (collisions, strandings, severe weather, piracy, deliberate arson).

4. **Immediate cause mechanism**
    - Technical failure (component degradation, design flaw, maintenance issues);
    - Operational deviation (non-compliance with procedures, improper handling);
    - Information failure (misdeclaration, lack of data, delayed reporting);
    - Organisational / systemic factor (staffing, planning, safety culture, communication).
5. **Severity of consequences** (qualitative scale aligned with the risk matrix in Section 7)
    - Negligible, Minor, Moderate, Major, Catastrophic (covering impacts on safety, environment, assets and continuity of operations).
6. **Frequency / likelihood class**
    - From very rare to frequent, following the probability classes defined in Section 7.

Each navigation safety occurrence relevant for the OVERHEAT use cases is therefore described as a **multi-dimensional vector**:

(phase of operation, location, hazard category, cause mechanism, severity class, frequency class).

This structured description ensures that:

- hazards and occurrences identified in Sections 8 and 9 are consistently labelled;
- risk matrices and KPIs in the national case studies (Section 11) are comparable;
- the same classification approach can be used as input for simulation-based analyses in subsequent WP3 tasks.

A summary Table (Table 19) of the main occurrence types, classified according to these dimensions, is provided below.

Dimension	Categories / Classes	Examples
1. Phase of operation	Ocean passage, Coastal navigation, Approach / departure, Pilotage- Anchorage, Port arrival, Berthing, Loading / unloading, Yard handling, Gate / rail interface	Fire in hold during ocean passage; overheating during loading operations
2. Location / system domain	**On board:** Deck stack, Cargo holds, Reefer bays, Engine room, Electrical rooms **In terminals:** Yard blocks, Gate lanes, Rail terminal, DG storage area	Fire in reefer stack; electrical failure in terminal yard
3. Primary hazard category	Misdeclared/undeclared DG, Declared DG (incl. Li-ion batteries), Electrical failures, Cargo shifting, Poor stowage, Human error- Mechanical failures, External factors	Misdeclared flammable DG; reefer compressor failure
4. Immediate cause mechanism	Technical failure, Operational deviation, Information failure, Organisational factor	Improper maintenance; incorrect loading plan
5. Severity class	Negligible, Minor, Moderate, Major, Catastrophic	Major: fire spreading across deck stacks
6. Likelihood / frequency class	Very rare, Rare, Possible, Likely, Frequent	Possible: overheating in reefer due to electrical issue
7. Occurrence type (result)	Localised fire, Smoke emission, Thermal runaway, Loss of containment, Escalation to adjacent containers, Explosion, System failure	Thermal runaway in Li-ion battery cargo
8. Consequence domain	Personnel safety, Environmental impact, Asset damage, Operational disruption	Terminal shutdown due to DG container fire

Table 19. Navigation Safety Occurrence Taxonomy

Once the conceptual model and taxonomy are defined, it is essential to clarify how these elements are operationally connected to the hazard identification and scenario-building processes used in WP3. The following subsection establishes this link.

2.3 LINK BETWEEN HAZARDS, OCCURRENCES, SCENARIOS AND CONSEQUENCES

The navigation safety occurrence design developed in this deliverable establishes an explicit link between:

- **Hazards** identified at regulatory, technical, operational and human-factor level;

- **Navigation safety occurrences** as observable events or sets of events;
- **Risk scenarios** used for assessment and, later, for simulation;
- **Consequences and KPIs** relevant for the OVERHEAT project.

In particular:

- Sections 1, 2 and 3 provide the **regulatory and methodological context** in which hazards are defined and analysed;
- Sections 8 and 9 list and discuss the **main hazard categories** and their associated risks (e.g. misdeclared DG, electrical failures in reefers, human error);
- Section 7 introduces the **risk matrix and scenario-building approach**, translating the occurrence design into risk evaluation tools;
- Section 11 applies this framework to the **Spanish, German, Italian and Polish use cases**, using the common taxonomy and occurrence structure to define and compare scenarios;
- Sections 10, 12 and 13 identify **risk treatment strategies and preventive / mitigating measures**, which can be mapped back to specific points in the occurrence chain (prevention, detection, response, recovery, learning).

This integrated view is essential to avoid treating hazards, occurrences and scenarios as separate lists. Instead, they are organised into a **consistent safety logic**, where:

- hazards represent potential sources of danger;
- occurrences represent the way such hazards become manifest in real operations;
- scenarios represent structured combinations of occurrences and context;
- consequences and KPIs provide a measurable output for evaluating risk and the effectiveness of mitigation measures.

The navigation safety occurrence design proposed in this Section therefore serves as the **conceptual and operational bridge** between the regulatory state of the art, the hazard identification work, and the practical risk assessments carried out in the OVERHEAT use cases.

The following subsections integrate the navigation safety occurrence design with the existing hazard identification work performed in this deliverable, ensuring alignment between the conceptual structure introduced above and the safety practices applied in ports and terminals.

2.4 PORT SELF-PROTECTION PLAN

All port authorities should create and execute a thorough port protection plan along with related policies and procedures. Additionally, the port should regularly practice the plan. From a general perspective, when developing a strategy for implementing port safety and security operations, it is crucial to consider the following criteria: a) the susceptibility of the port to potential threats; b) the implications of safety measures on the port's efficiency and functionality; c) practical constraints imposed by the physical attributes of port infrastructure; d) the availability of financial resources; e) alternative measures that may be accessible; and f) the assessment of all available capabilities, both internal and external. This document is also intended to be a living one, and its content should be periodically reviewed and updated.

In synthesis, the Port's Self-Protection Plan is a comprehensive report that establishes the necessary measures and procedures to ensure the safety and protection of people, assets, and facilities within the port area. This plan is developed in compliance with current regulations and is designed to effectively manage any emergencies that may arise in the port.

Risks and hazards identification is a fundamental component of the Self-Protection Plan. A thorough analysis identifies all potential risks that could trigger emergencies, ranging from industrial accidents and natural events to technological failures and human errors. This identification process is essential for understanding the port's vulnerabilities and developing specific strategies to mitigate risks, prepare appropriate responses, and minimize the impact of potential incidents.

The Self-Protection Plan not only defines the procedures to follow in case of an emergency but also includes a detailed inventory of existing preventive and protective measures. These measures are designed to address the identified risks and ensure that the port is prepared to respond efficiently and in a coordinated manner to any contingency, thereby protecting people, facilities, and the environment.

The hazard identification process described here builds upon the occurrence model presented earlier, enabling a systematic classification of hazardous conditions and their contribution to navigation safety occurrences.

2.5 HAZARD IDENTIFICATION AND CLASSIFICATION

The elements, facilities, and activities present in the service area of the Port that can generate risk, danger, or emergency situations, or that could exacerbate the development of such situations, are highly varied. This heterogeneity includes critical infrastructures and everyday operational activities, all of which can potentially trigger incidents with significant consequences, especially in a dynamic port environment.

Within the Port Authority’s self-protection plan, various accidents and emergencies that have already occurred in the Port of Valencia or other ports are described, some of which have been recorded in recent years. These events have highlighted the importance of being prepared for a wide range of risks that can impact both the health and safety of individuals and the preservation of material assets and the environment.

The identified risks are classified into three major categories: natural, anthropogenic, and technological. Natural risks, though of low probability, include geological events, such as earthquakes and tsunamis, and meteorological and hydrological phenomena like floods, heavy rains, hurricanes, and maritime storms. Despite their low frequency, these risks could have catastrophic consequences in specific areas of the port or throughout its entirety.

On the other hand, anthropogenic risks refer to those resulting from human activities developed over time, closely linked to human behaviour and actions in the port. Finally, technological risks are those caused using advanced and industrial technologies, reflecting the consequences of progress and technological innovation in the port environment.

These classifications allow for a deeper understanding of the dangers the port faces, facilitating the development of appropriate mitigation and response strategies for each identified risk.

In the risk map established in the plan, fires occurring aboard vessels are classified under anthropogenic risks, specifically within the subcategory of nautical accidents. This classification is because on-board fires are often linked to potential operational failures or accidents that can happen during navigation or while the vessels are at anchorage. These fires could result from a range of factors, including mechanical failures, mishandling of cargo, or unforeseen incidents at sea.

Conversely, fires that occur on vessels docked in the port's terrestrial service area are also categorized as anthropogenic risks but are placed under the subcategory of *Other General Risks in the Port's Terrestrial Service Area*. This distinction is made because such fires may arise from failures in the port's cargo handling operations or from deficiencies in the port's infrastructure. Issues such as inadequate maintenance of loading equipment, improper storage of hazardous materials, or structural flaws in the port facilities can contribute to these incidents.

Both types of fire scenarios necessitate tailored approaches for effective mitigation and response. For onboard fires, strategies must focus on enhancing safety protocols for vessel operations, improving onboard fire detection and suppression systems, and ensuring crew preparedness through rigorous training. For fires in the port's terrestrial service area, attention should be directed towards robust safety measures in cargo handling, regular inspection of port facilities, and emergency response planning tailored to the unique risks of the port environment. By addressing these distinct contexts, the plan ensures comprehensive management of fire risks across various operational settings.

This subsection refines the identification of risks by connecting hazards, occurrences and consequences according to the taxonomy and event structure previously introduced.

2.6 IDENTIFICATION OF RISKS

In Chapter 3 of the Port of Valencia's self-protection plan, a thorough identification of potential risks, hazards, and accidents has been conducted to address scenarios that could trigger emergencies or adversely impact emergency response efforts. This comprehensive risk assessment covers both common incidents and specific situations that may arise within the port environment, ranging from minor occurrences to large-scale emergencies. Specifically, the scenarios related to fires in port terminals include:

Fire in a Tank of Vegetable Oil, Vegetable Fats, or Esters

This risk involves fires in storage tanks containing vegetable oils, fats, or esters, which can be highly flammable and pose significant hazards due to the chemical properties and potential for rapid spread.

Stationary Fire of Solid Combustible Goods in the Open Air

This scenario covers fires involving piles of solid combustible goods such as coal, wood, bulk cereals, rolls of paper, or other non-dangerous goods stored in the open air. These fires may occur in storage areas or truck boxes and can vary in scale from minor incidents to larger conflagrations.

Fire in a Covered Shed

This risk pertains to fires occurring in covered sheds, which may house various materials or equipment. The presence of a roof can complicate firefighting efforts and containment.

Fire in Closed Sheds, Warehouses, or Storage Facilities

Fires in closed sheds, warehouses, or storage facilities pose challenges due to confined spaces and the potential for rapid fire spread. These structures may contain valuable goods or hazardous materials.

Fire of Machinery (Cranes, Forklifts, etc.) or Transport Vehicles (Tractor Heads, Semi-Trailers, Platforms)

This scenario involves fires affecting port machinery, such as cranes and forklifts, as well as transport vehicles like tractor heads, semi-trailers, and platforms. These fires can disrupt port operations and pose risks to personnel and equipment.

Fire in an Electrical Energy Transformer Substation

Fires in transformer substations can have severe implications due to the high voltage equipment and potential for electrical hazards. Such incidents require specialized firefighting approaches to manage electrical risks.

Fire in the Maintenance Workshop of a Concession or Facility

Fires occurring in maintenance workshops, which are crucial for the upkeep of port equipment and infrastructure, can disrupt operations and pose risks due to the presence of flammable materials and tools.

Fire in a Building Used for Offices

Office buildings within the port may contain administrative records, equipment, and personnel. Fires in these buildings can affect port management and administrative functions.

Fire in a Maritime Station Building

Fires in maritime station buildings, which serve as key operational hubs for port activities, can significantly impact port operations and necessitate prompt and effective response measures.

It is also essential to consider the evolving fire risks, as the ports industry is moving from manual operations to machine-led processes involving global automation and vehicle electrification. This optimization enhances efficiency and productivity while impacting the fire industry.

On the one hand, the recent pandemic emergency accelerated the port industry's automated vehicles, enabling operations to continue with workers staying a safe distance from each other and allowing ports to operate more cost-effectively. As a matter of fact, as the number of people operating vehicles on-site decreases, it becomes more challenging to detect fire risks. In this context, when manual fire detection systems are used with automated vehicles, there may be a delay in releasing suppression agents. This delay occurs because the system relies on the vehicle to communicate with the operator, who then needs to react and administer the suppression agent to eliminate the risk.

On the other hand, global ports increasingly use electricity as a sustainable fuel source, which impacts both on-site machinery and the transportation of large lithium-ion (Li-ion) batteries.
The transition to electric vehicles brings new fire risks due to the lithium-ion batteries they use. These batteries can undergo a "thermal runaway" process if a fault in their cells is caused by overcharging, overheating, overvoltage, or physical damage. This can lead to temperature increases, toxic gas emissions, potential explosions, and fire.

3 METHODS FOR HAZARD IDENTIFICATION AND RISK ANALYSIS METHODOLOGY DEFINITION

This section reviews established hazard identification and risk analysis methodologies relevant to container transport. It evaluates the suitability of methods such as FMEA, FTA, ETA, HAZOP and What-If analysis for analysing fire-related scenarios and complex cargo-handling operations. The goal is to determine which tools best support the occurrence design and scenario definition used in WP3.

3.1 HAZARD IDENTIFICATION IN THE MARITIME SECTOR

The purpose of hazard identification is to identify a list of hazards, which can contribute to accidents and to screen them using a combination of available data and judgement. The hazard identification should be performed at the beginning of the development, considering functions and systems typical of the ship type. For instance, information must be considered, such as the type of ship, the payload, communication, manoeuvrability and so on.

The approach used for hazard identification generally requires that the process is proactive, considers previous knowledge (e.g. applicable regulations and codes, available statistical data on accident categories, lists of hazards to personnel, hazardous substances, ignition sources, etc.) and hazards that have not materialized into accidents, thanks to structured group of experts aiming at identifying the causes and effects of accidents.

Huang et al. (2023) [2] assess that hazard identification consists in determining whether the system can withstand the negative impact of an anomaly and identify the original factors that trigger the event. The hazard identification methods available provide a functional approach to face the problem, but their effectiveness depends mainly on the brainstorming phase of the analysis and on the user’s expertise in the specific field, as long as on the availability of a large set of historical data and statistical studies. Huang et al. analysed a large variety of papers regarding Maritime Transport Risk Assessment focusing on the methods adopted. Figure 1 shows a classification of the most used methods.

The analysis may be conducted by using established techniques, to be chosen according to scope, whenever possible. FSA, a systematic methodology provided by the IMO [1], suggests the following hazard identification techniques:

- Fault Tree Analysis (FTA),
- Event Tree Analysis (ETA),
- Failure Mode and Effect Analysis (FMEA),
- Hazard and Operability Studies (HAZOP),
- *What-If* analysis.

These methodologies are presented in the following subsection.

Method	No. of studies	Percentage
Bayesian network	92	7.79%
Markov model	61	5.17%
Fuzzy logic	57	4.83%
Monte Carlo simulation	54	4.57%
Formal Safety Asseeement(FSA)	52	4.40%
Fault tree	42	3.56%
Event tree	34	2.88%
Dynamic Bayesian network	31	2.62%
Analytic Hierarchy Process(AHP)	18	1.52%
Evidential Reasoning	16	1.35%
Cluster analysis	14	1.19%
Quantified risk assessment(QRA)	13	1.10%
Bow-Tie Diagram	11	0.93%
Regression model	11	0.93%
Association rule	9	0.76%
Human Factors Analysis and Classification System (HFACS)	9	0.76%
System-Theoretic Accident Model and Processes (STAMP)	9	0.76%
Decision analysis	9	0.76%
Human Reliability Analysis(HRA)	8	0.68%
Statistical analysis	8	0.68%
Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS)	7	0.59%
Failure Mode and Effect Analysis (FMEA)	7	0.59%
Principal component analysis (PCA)	6	0.51%
Delphi method	6	0.51%
Human Error Identification and Reduction Technique (HEART)	6	0.51%
Cognitive Reliability and Error Analysis Method (CREAM)	5	0.42%
Hazard and Operability Analysis (HAZOP)	5	0.42%
Systems-Theoretic Process Analysis(STPA)	5	0.42%

Figure 1. Most used methods in Maritime Transport Risk Assessment

3.1.1 Fault Tree Analysis (FTA)

The FTA is a top-down approach that can be used for both qualitative and quantitative analysis. It aims to identify the relationship between fault events (called undesired top event) and their root causes, using Boolean logic to combine events.

The main steps of an FTA are:

- Definition of top-level hazard event,
- Determination of all credible single faults and failure combinations of the system functional blocks at the next lower level,
- Lower-level faults are appropriately linked to their higher-level event by means of Boolean logic,
- The analysis proceeds iteratively down through successively more detailed levels,
- Once primary events (which do not need to be broken down to a finer level of detail) are uncovered the fault tree is complete,
- Minimal cut sets are individuated, and the failure probability can be computed.

The analysis allows to identify the failure cause, determine the frequency of occurrence of dangerous states, and identify critical components of the system.

3.1.2 Event Tree Analysis (ETA)

ETA is a top-down approach, used to build an object model of probability for risk analysis. ETA method is based on a graphical model depicting the relationship between cause and effect in an event.

Hazard identification begins by determining the initialization event and considering all possible strings of events, which are consequences of the initialization event. The probability of the effect is determined by multiplying the probability of all the events. There are two approaches to this method: before an accident and after an accident. The technique used before an accident is applicable when there is a need to determine possible events and the likelihood of their occurrence. The technique used after an accident seeks to analyse and identify the functional safety system failures. Figure 2 presents the method for conducting an analysis of data using an ETA.

3.1.3 Failure Mode and Effect Analysis (FMEA)

FMEA is a bottom-up approach that can be used for both qualitative and quantitative analysis. The purpose of the FMEA is to identify failures and how to avoid or mitigate their effects. This is achieved by determining the cause-and-effect relationships, considering the risk factors.

FMEA main steps are:

- Identification of the characteristics of the system and its basic functions and minimum requirements that determine its operation,
- Identification of possible malfunctions and system failure,
- Identification of the consequences of each system failure,
- Determination and evaluation of methods to detect system failure,
- Description of the reduction and elimination of adverse effects.

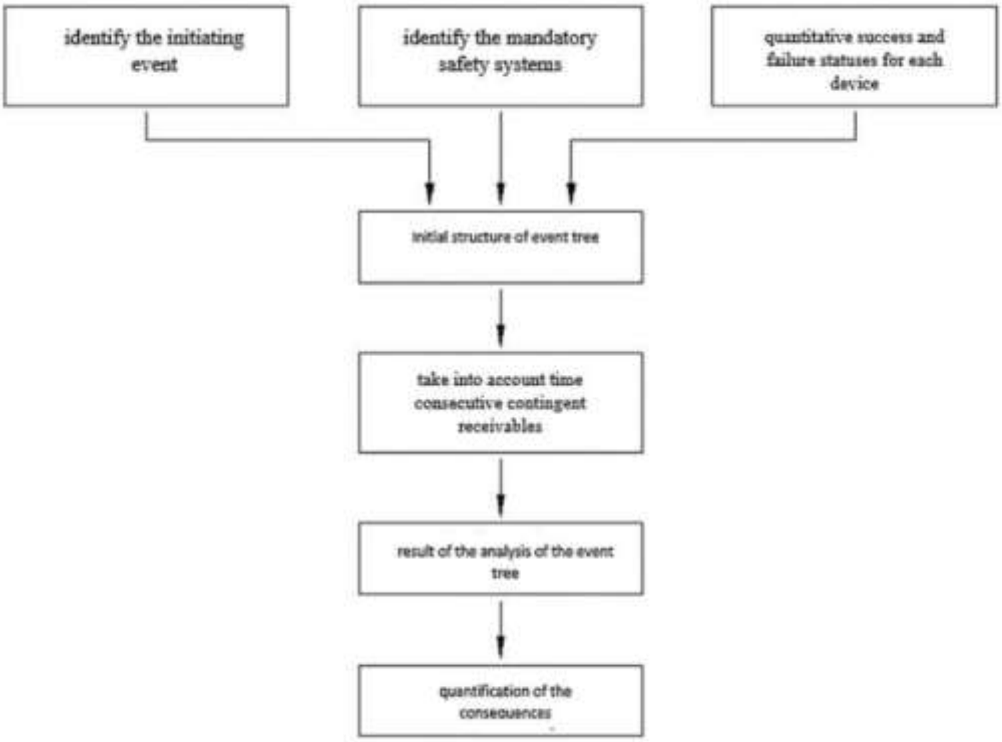


Figure 2. ETA stages

The analysis of failure mode can be performed considering three aspects of each failure mode:

- Severity (*S*), scaling the risk of the event considering its consequences,
- Detection (*D*), ability to detect the emergence of events before their occurrence,
- Occurrence (*O*), likelihood of occurrence of the event.

Based on the determination of these values, the level of priority, measured as a Risk Index (RI) of the actions is computed by:

$$RI = S\ x\ D\ x\ O \qquad (1)$$

The analysis can be considered qualitative if the ranking is determined by literature; it can be considered quantitative if the ranking is determined by using data collected from the observation of the behaviour on the field.

Thanks to this process, continuous improvements are possible by carrying out in-depth analyses and introducing improvements, which are aimed at eliminating the sources of defects and enhancing the performance of the product.

3.1.4 Hazard and Operability studies (HAZOP)

HAZOP analysis focuses on working environments and identify the dangers to which these environments expose workers, structures, and the natural environment. It is a structured qualitative top-down analysis based on guideword which aim to:

- Identify all deviations from the way a system is intended to function,
- Decide whether actions are required to control hazards or operability problems, and identify the ways in which the problems can be solved,
- Identify cases where a decision cannot be made immediately,
- Ensure that actions decided are followed up,
- Make operator aware of hazard and operability problems.

Figure 3 shows the main steps of an HAZOP procedure.

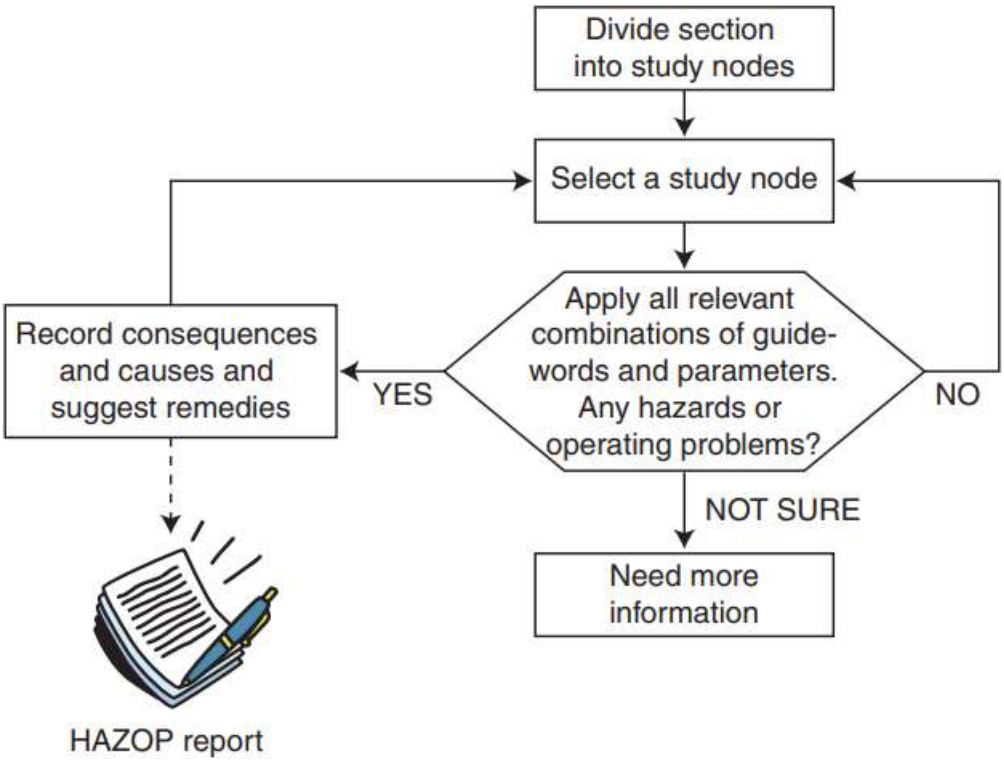


Figure 3. HAZOP procedure

3.1.5 *What-If* analysis technique

The *What-If* technique is a structured method for determining the potential consequences of the failures that could occur and judging the likelihood of those consequences. This technique combines structured brainstorming with guidewords and prompts to:

- Identify risks
- Determine the effects of the occurrence of each event

- Designate possible measures/methods of reducing risks

Brainstorming is led by a facilitator, in assessing what could go wrong based on their past experiences and knowledge of similar situations. Guide words can be used to help facilitate the brainstorming process.

The method is divided into three stages:

- Stage 1. Preparation: involves the analysis of the current situation, as well as examining with the applicable rules and procedures. During this stage, the experience of the analysts plays a crucial role.
- Stage 2. Review: the problem is defined, and the analysts brainstorm for risks identification and develop a remedial procedures plan. *What-If* questions can be formulated by the experts around human errors, process upsets, and equipment failures, based on their experience of the related operations and systems. Questions describing consequences/concerns need to be explored further and restated for risk assessment (e.g. What-If there is a fire?)
- Stage 3. Documentation – the conclusions, recommendations, and the outcome of the What IF analysis are collected in a final report, including the identified hazards and their effects.

Figure 4 shows an example of worksheet for a What-If report.

NAME…………………………………………………..		DATE…………………	
DOCUMENTATION NO…………………………………...			
MEMBERS OF THE TEAM……………………………...			
WHAT-IF	CONSEQUENCES/HAZARD	REMEDIES	RECOMMENDATIONS

Figure 4. What "IF" analysis worksheet example

3.2 HAZARD IDENTIFICATION ON CARGO SHIPS: FIRE HAZARD

Hazard identification is a process that requires the selection of an appropriate systematic method based on the characteristics of the project being analysed. These characteristics represent the input for the analysis. Output of the analysis shall be a list of hazards and associated scenarios and the assessment of the accident scenarios.

In particular, the current section focuses on hazards related to fires on a cargo ship. Firefighting on cargo ships is a broad subject, which combine several functions as prevention, detection, alarm, containment, suppression, personnel safety and evacuation. Moreover, the application of a methodology shall be able to match the requirements.

However, experience indicates that very broad FSA studies can be harder to manage [1]. According to IMO guidelines for FSA a possible solution may be to rely on qualitative analysis for the relevant ship type or hazard category, to include all aspects of the problem under consideration and avoid excessive and superfluous analysis. Subsequent analysis will then increase the degree of detail.

Considered methodologies are deductive analysis, thus considering the hazards until the identification of causes. According to statistics, the cause of fire and explosion in marine operations are to be address in large measure to human causes (Figure 5) [**Errore. Il segnalibro non è definito.**3] [4], due to factors, such as competency, health, stress, and strength. Most of the cases are related to skill-based errors, inadequate supervision and inadequate organizational process, which brought to mechanical failures, chemical reactions, and electrical fault. Moreover, up to 43% of human error arose from maintenance related activities.

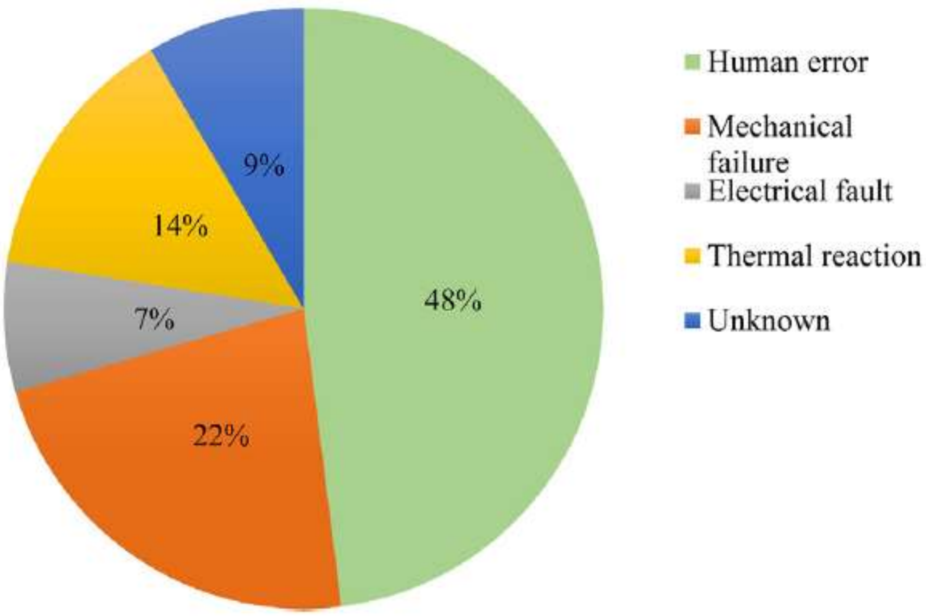


Figure 5. Percentages of fire and explosion accidents

4 COMPARATIVE ANALYSIS OF METHODOLOGIES

This section compares the most relevant risk-analysis methods and safety frameworks applied in maritime and related transport sectors. By examining their strengths, limitations and applicability, it supports the selection of consistent and operationally appropriate analytical tools for the OVERHEAT use cases and subsequent WP3 activities.

4.1 IMO FORMAL SAFETY ASSESSMENT

To identify and analyse the risks pertinent to the OVERHEAT project, it is imperative to take into consideration the operational environments. The formal methodology for risk analysis, within the maritime industry, is carried out in strict adherence with the *Guidelines for Formal Safety Assessment (FSA) for use in IMO rule making process*, established by the International Maritime Organization (IMO)[1].

FSA is a structured and systematic methodology that uses risk analysis and cost-benefit assessment to enhance maritime safety, encompassing the protection of life, health, marine environment, and property. It is a valuable tool for assessing new maritime safety and environmental protection regulations, comparing existing and proposed regulations to achieve optimal outcomes, and striking a balance between various technical and operational considerations, including human factors, and between safety/environmental protection and costs.

It is not intended that FSA should be applied in all circumstances, but its use is strongly recommended for proposals with potentially significant consequences. These consequences can be financial, impacting society or the maritime industry, or regulatory, creating new legislative or administrative burdens. Furthermore, FSA is valuable in situations where risk reduction is necessary, but the specific actions are unclear. By employing FSA, the true benefits of proposed changes can be demonstrably established. This provides member states with a clearer understanding of the proposal's scope and a more informed basis for decision-making.

A critical initial step in conducting an FSA is the meticulous definition of the problem. This necessitates a comprehensive examination of all relevant factors, including the characteristics of the vessel, its onboard systems, the operational activities, and the external influences it encounters during navigation. Additionally, the specific category of incident under investigation and the associated risks must be carefully considered. These risks encompass potential harm to crew and passenger, the vessel itself, the environment, port facilities, and commercial interests.

The guidelines therefore elucidate the purpose and applicability of the methodology, and meticulously outline its characteristics and the procedure to be followed, dividing it into five steps (Figure 6):

1. **Hazard identification**: identifying hazards and accident scenarios,

2. **Risk analysis**: analysing risks using both qualitative and quantitative methods,
3. **Risk control options**: identifying measures to reduce risks,
4. **Cost-benefit assessment**: evaluating the costs and benefits of risk control options,
5. **Recommendations for decision-making**: providing recommendations to IMO decision makers.

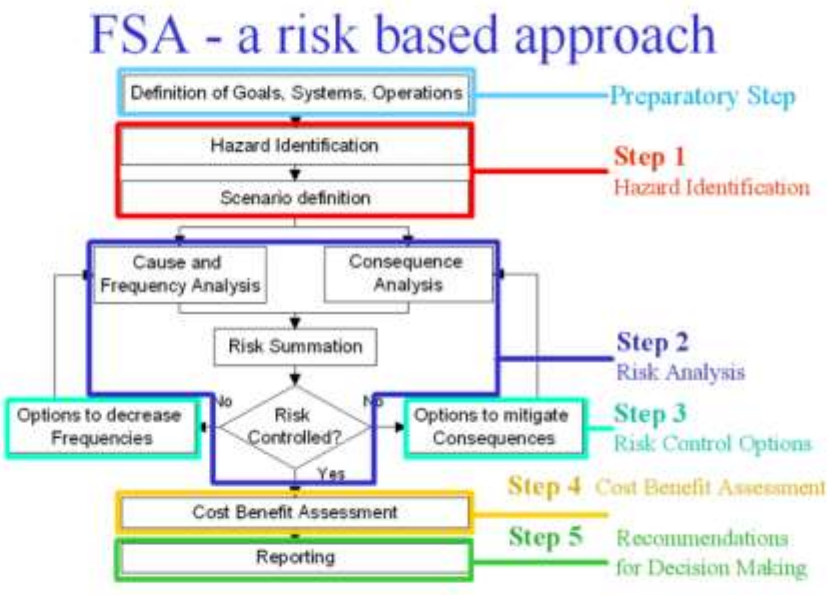


Figure 6. FSA Flowchart [2]

The above-mentioned steps are then accurately described within the guidelines indicating for each of them results to be achieved and methodology to be adopted.

4.1.1 Risk Analysis

The step 2 (risk analysis) delves into a detailed examination of the causes, initiating events, and potential consequences of the most significant accident scenarios identified in step 1 (Hazard identification). This *in-depth* investigation is facilitated by the employment of suitable risk modelling techniques. The primary objective of this analysis is to identify high-risk areas and comprehensively identify and evaluate the factors that influence risk levels.

The risk analysis should encompass different types of risk, including personnel safety, environmental impact, and property damage, as deemed relevant to the specific problem being addressed. The choice of risk analysis method or tool depend on several factors, including the scope of the Formal Safety Assessment (FSA), the types of hazards identified in step 1 and the availability of failure data.

The quantification of the risk makes use of accident and failure data and other sources of information as appropriate to the level of analysis [1]. In situations where data is unavailable, other methods, such as calculations, simulations or established expert judgment techniques can be used.

Both quantified and/or qualified risk models should incorporate sensitivity and uncertainty analyses suitable for the chosen risk analysis method and/or risk model. The results of these analyses, along with the quantitative data and an explanation of the employed models, should be reported.

The key output of the risk analysis process comprises two essential elements: identification of high-risk areas requiring mitigation efforts, and provision of a clear and comprehensive explanation of the utilized risk models.

To this end, appendix 3 lists and briefly describes the hazard identification and risk analysis techniques to be used in conducting the risk analysis [1].

The methods highlighted are:

- Fault Tree Analysis (FTA),
- Event Tree Analysis,
- Failure Mode and Effect Analysis (FMEA),
- Hazard and Operability Studies (HAZOP),
- *What-If* Analysis Technique
- Risk Contribution Tree (RCT),
- Influence Diagrams,
- Bayesian Network,
- Sensitivity Analysis and Uncertainty Analysis.

4.2 LITERATURE REVIEW METHODOLOGY

To determine the most prevalent risk analysis methodologies employed in the maritime sector dealing with operations, both onboard containers and port infrastructure, a comprehensive literature review is essential. This review aims to scrutinize the current State-of-the-Art in the field of interest.

A literature review is a systematic and critical examination of scholarly publications relevant to a specific research topic. Its primary objectives are to synthesize existing knowledge, identify pertinent theories and methodologies and potentially reveal gaps in current research. Within the context of the OVERHEAT project, the literature review will facilitate the identification of the most suitable risk analysis methodology for the operations dealing with containers stowed in the terminals and on board the vessels, thereby ensuring compliance with maritime industry standards, effectiveness in risk assessment and enhanced document quality.

To achieve this, the literature review has been conducted utilizing a methodology grounded in the *Preferred Reporting Items for Systematic Reviews and Meta-Analyses* (PRISMA) approach [7] (Figure 7). The main purpose of PRISMA is to help authors improve the quality of reporting of systematic reviews and meta-analyses by providing a minimum set of essential items.

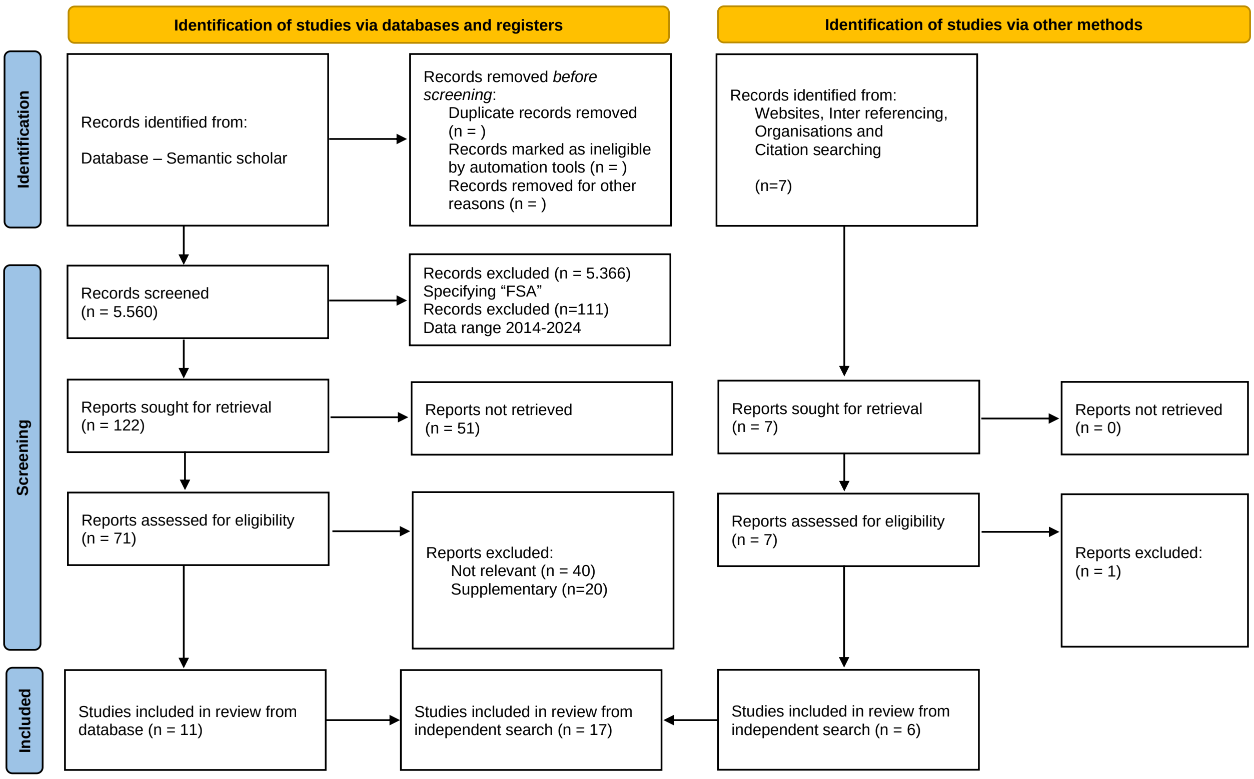


Figure 7. PRISMA flow diagram

During the implementation of the PRISMA methodology, the Semantic Scholar database was utilized, focusing the research on risk analysis within the maritime domain with a specific emphasis on containers. This approach led to the identification of 5560 documents. Subsequently, a further filtering process was conducted, specifying the use of FSA and selecting only documents published within the last 10 years (2014-2024) thus obtaining 122 documents.

Out of the initial 122 papers, 51 documents could not be retrieved, resulting in the analysis being narrowed down to 71 documents. These documents underwent scrutiny through the examination of titles, abstracts, keywords, and the content itself, leading to the exclusion of 40 deemed irrelevant and 20 considered supplementary to the selected documents.

The examined documents encompass various aspects related to methodologies for risk analysis applicable to containers onboard and in terminals. In addition to these 11 documents, 6 more were subsequently included through alternative methods such as websites, inter-referencing, organizations, and citation searching, bringing the total to 17 documents.

4.3 LITERATURE REVIEW RESULTS

In the execution of the literature review, several papers were identified that cover various aspects related to containers in the maritime domain, addressing both the risks associated with their presence onboard vessels [8] and those pertaining to containers within port terminals [9] [10] [11] [12] [13] [14] [15]. The aim of the literature review was therefore to investigate the risk analysis methodologies most widely used in the maritime and port sector to ensure safety during operations [16] [17], during emergencies and cargo management [18] [19].

The reviewed documents delve into a multitude of facets, providing a comprehensive understanding of the problem. These aspects include, but are not limited to, the human impact of container operations [20], the specific tasks involved in the movement and handling of containers and the critical issues of fire risk management [21] [22] [23]. By examining these elements, the literature review offers a holistic perspective on the challenges and considerations surrounding containers in the maritime industry.

The documents highlight the risk analysis methodologies based on those outlined in the IMO’s FSA [20] but are tailored to suit the current application. Among the papers reviewed, the most utilized methods are based on Failure Mode and Effects Analysis (FMEA) and Fault Tree Analysis (FTA) (Figure 8). However, there are cases in which Event Tree Analysis (ETA) has been employed for conducting the risk analysis of container ship accidents. Finally, these methods are often used at the same time, combining methodologies as in the case of FMEA and ETA or in the case of FTA and ETA. Sometimes these methodologies have also been combined with other methodologies, such as the Bayesian Network or a cause-consequence analysis [9].

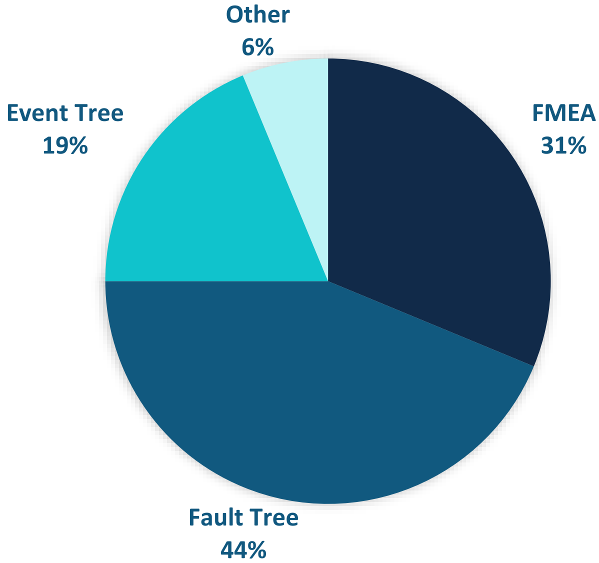


Figure 8. Literature review results

The obtained results encompass various types of risk, ensuring a comprehensive coverage of the existing literature. From the conducted analysis, it is evident that the most widely utilized methods are FMEA, ETA and FTA. Despite this, several cases were identified where authors have adopted ad-hoc, mixed, or undefined methodologies for the execution of risk analysis. The results of the literature review highlighted the above-mentioned three methodologies (specifically mentioned in the IMO guidelines for Formal Safety Assessment), thereby ensuring their applicability for the purposes of the project. These methodologies, recognized by the IMO as suitable for maritime risk analysis, provide a solid foundation for the project's objectives. The next chapter provides a detailed description for each of the three methodologies including advantages and disadvantages.

4.4 COMPARATIVE ANALYSIS

The comparative analysis among the identified methods will be presented by detailing each method individually, highlighting their distinctive characteristics and endeavouring to underscore the major differences between them.

4.4.1 FMEA

FMEA is a widely adopted and proven approach for failure analysis and risk assessment. Originating in the 1940s for use in the U.S. military, FMEA is now one of the most used techniques in engineering for failure analysis of products and processes. FMEA is organized, step-by-step process for comprehensively evaluating a system or process to identify potential failure modes and eliminate or mitigate those deemed most critical [1] [25].

The assessment starts with the definition of the subject of analysis, which may be a specific product, process, or system and establishes the boundaries and specifications of the project. Subsequently, an FMEA team comprising multidisciplinary experts is assembled to ensure a comprehensive and in-depth perspective [26].

The next step involves identifying failure modes. This requires a detailed examination of each component or stage of the process to identify all potential failure modes, utilizing brainstorming sessions, historical failure data, and other techniques. Once the failure modes are identified, their effects are described, and the severity of the impacts is assessed using a predefined scale.

The analysis further delves into determining the potential causes of each failure mode, considering factors such as design, materials, work methods, and environment. For each failure mode, scores for severity, occurrence probability, and detectability are assigned [27].

To effectively evaluate these parameters, the team must accurately assess and approve three distinct scales here below described:

- The severity scale evaluates the effects of a potential failure mode on a scale from 1 to 10, where 1 represents *no effect* and 10 indicates a severe effect,
- The occurrence scale evaluates the frequency with which the potential failure mode might occur, using a scale from 1 to 10, where 1 indicates a *remote probability* and 10 indicates a *high frequency*,
- The detection scale assesses the ability to detect the cause of the failure mode, using a scale from 1 to 10, where 1 indicates an *almost certain detection of the cause* of the failure mode and 10 indicates the *impossibility of detecting the cause*.

Figure 9 and Figure 10 show examples for severity, occurrence, and detection scales.

Severity Ranking

Rank	Description
Minor (1)	No or minor effect
Low (2-3)	Low effect
Moderate (4-6)	Loss of secondary function
High (7-8)	Loss of primary function
Very High (9-10)	Hazardous without warning

Occurrence Ranking

Rank	Description
Remote (1)	Failure unlikely
Very Low (2)	Isolated failures associated with this process or almost identical processes
Low (3-5)	Isolated failures associated with similar processes
Moderate (6-7)	Occasional failures, but not in major proportions
High (8-9)	Often failures
Very High (10)	Failure is almost inevitable

Detection Ranking

Rank	Description
Very High (1-2)	Controls certain to detect the failure mode
High (3-4)	Controls have a good chance to detect the failure mode
Moderate (5-6)	Controls may detect the existence of a failure mode
Low (7-8)	Controls have a poor chance of detecting the existence of a failure mode
Very Low (9)	Controls probably will not detect the existence of a failure mode
Absolutely no (10)	Controls will not or can not detect the existence of a failure mode. No known controls available to detect failure mode

Figure 9. Severity, Occurrence and Detection scales examples (source: https://sdh.global/blog/business/failure-mode-and-effects-analysis-an-overview/)

Rank	Severity class	Description
10	Catastrophic	Failure results in major injury or death of personnel.
7-9	Critical	Failure results in minor injury to personnel, personnel exposure to harmful chemicals or radiation, or fire or a release of chemical to the environment.
4-6	Major	Failure results in a low level of exposure to personnel, or activates facility alarm system.
1-3	Minor	Failure results in minor system damage but does not cause injury to personnel, allow any kind of exposure to operational or service personnel or allow any release of chemicals into the environment

Figure 10. Severity scale example [28]

These scores are used to calculate the Risk Priority Number (RPN), which is the product of these three factors. The RPN allows for prioritizing risks based on their severity and detectability. In case of high score, the team proposes corrective/mitigation actions to reduce the highest RPN scores, implementing changes in processes, improving controls or introducing new technologies. It is essential to monitor and evaluate the effectiveness of the corrective actions implemented, periodically reviewing and updating the FMEA to reflect new data or changes in the system. The illustrative Table 20 and Table 21 demonstrate the structure of the FMEA table [29].

ID	System, Component, Function	Potential Failure Mode	Potential Effects of Failure	Severity	Potential Causes of Failure	Occurrence	Current Process Controls	Detection
1	Example 1			6		6		9
2	Example 2			7		6		5
3	Example 3			8		2		3

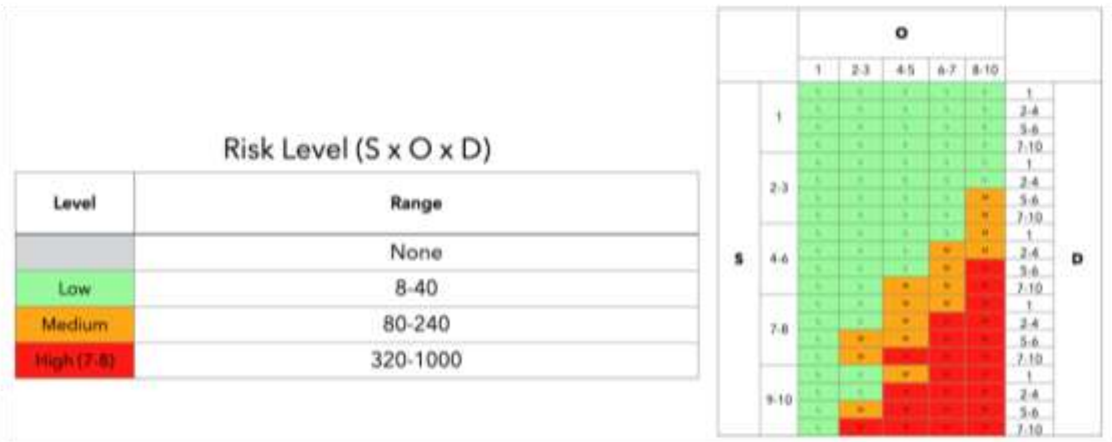
Table 20. FMEA table example

ID	Severity	Occurrence	Detection	RPN	Action Recommended
1	6	6	9	**324**	
2	7	6	5	**210**	
3	8	2	3	**48**	

Table 21. RPN example

To assess whether an RPN value is high, two threshold values must be established through which the failure mode can be assigned in three different categories (Figure 11):

- **Low risk** if the RPN value is below the first threshold,
- **Moderate risk** if the RPN value is between the values of the two thresholds,
- **High risk** if the RPN value is higher than the value of the higher threshold.


Risk Level (S x O x D)

Level	Range
	None
Low	8-40
Medium	80-240
High (7-8)	320-1000

Figure 11. Risk level example

A summary (Table 22) highlights advantages and weaknesses of the examined methodology [30] [28] [25].

Advantages	Weaknesses
▪ Performs a systematic review of the process. A detailed methodology is available to assess the plant item by item. ▪ Helps prioritize risks, allowing to focus on the most critical issues by evaluating and prioritizing risks based on severity, occurrence, and detection. ▪ Focuses on identifying failures before they occur to implement preventive measures. ▪ Concept and application are easy to learn. ▪ Detailed Documentation. ▪ Supports ongoing updates and improvements as new information arises. ▪ Is applicable across various industries and processes thanks to its versatility.	▪ Can be time consuming and expensive. For complex processes there will be many items to be investigated each with a complex series of failure modes to be examined. ▪ Difficulty identifying hazards due to more than one failure. It is hard to combine the effect of multiple failure modes of different items to identify combined hazards.

Table 22. FMEA advantages and weaknesses

4.4.2 Fault Tree Analysis

Fault Tree Analysis (FTA) is a method employed to evaluate the probability of a top event, which can be an accident or an unintended hazardous outcome. This graphical technique represents the combination of faults leading to a specified undesired event by creating a logic diagram (Figure 12) that illustrates the causal relationships among contributing events. FTA can account for common cause failures in systems with redundant or standby elements and include failure events or causes related to human factors [31] [32][1].

The development of a fault tree follows a top-down approach, beginning with the undesired top event and tracing back to the primary events that initiated the failure. This approach uses logic gates, such as AND/OR gates, to determine the addition or multiplication of probabilities (assuming independence) to evaluate the top event based on the probabilities of the lower-level events. These logic gates facilitate the flow of fault logic throughout the tree until further development is halted due to insufficient knowledge or the absence of identifiable causes [33].

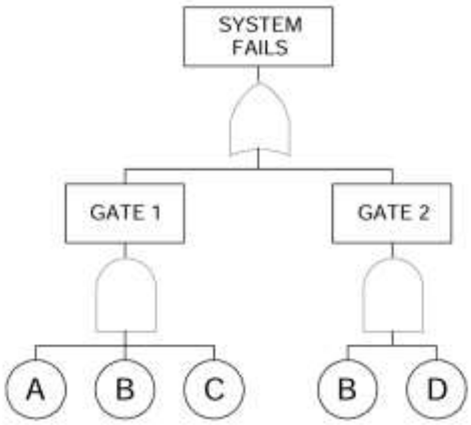


Figure 12. Example System Fault Tree Structure [29]

Once constructed, a fault tree can be translated into an equivalent set of Boolean equations using the rules of Boolean algebra. This translation allows for both qualitative and quantitative evaluation of the fault tree's characteristics.

The FTA process typically involves six stages [32]:

1. Definition of Scope: it outlines the purpose and scope of the assessment, along with foundational assumptions,
2. Familiarization with Process: it ensures that all assessment team members have a comprehensive understanding of the process,
3. Identification of Top Event: it involves selecting an event suitable for fault tree analysis, typically characterized by the emergence or presence of a hazardous condition or system failure,
4. Construction of Fault Tree: it deconstructs the top event to identify the primary contributing events,
5. Analysis of Fault Tree: it quantifies the risk associated with the top event by incorporating frequencies and probabilities for the primary events within the fault tree,
6. Documentation of Results: it involves thoroughly documenting all activities performed by the assessment team, the information utilized, and the outcomes achieved, including any pertinent conclusions.

The primary objectives of both qualitative (logical) and quantitative (numerical) safety evaluations of a system are multifaceted. They involve identifying and analysing the elementary events and minimal combinations that can lead to a system failure, as well as evaluating the associated safety measures. Additionally, these evaluations allow to assess the system's fault tolerance, determining its ability to continue functioning despite a specified number of lower-level failures or contributing events. This assessment includes verifying the degree of redundancy within the system and ensuring it is not compromised by common events or common cause events.

Furthermore, the evaluations verify the independence of failures across systems, subsystems or components. This also involve analysing data to locate critical components and failure mechanisms. Finally, these evaluations identify failure diagnostics for devices and provide essential inputs for repair and maintenance activities. Overall, these comprehensive assessments ensure the system's robustness and reliability by addressing potential vulnerabilities and enhancing safety measures. Table 23 highlights advantages and disadvantages of the examined methodology [25].

Advantages	Weaknesses
▪ Highly adept at analysing complex systems. ▪ Facilitates the evaluation of a diverse array of failures, encompassing hardware, software, human, and process failures, seamlessly integrated into the analytical framework. ▪ Present a coherent logical depiction of event sequences. ▪ Accommodates the consideration of multiple failures or their combinations. ▪ Outcomes offer the potential for both qualitative and quantitative data. ▪ Established and robust software tools are available to facilitate the editing and assessment of fault trees.	▪ Time consuming and expensive for complex systems. ▪ Requires detailed breakdown of events to initiating conditions, identification of values for those conditions, and logic for hazard quantification. ▪ Potential to miss top events (overall system failures). ▪ Potential to miss some failure paths. ▪ Cannot handle dependent failures caused by fault propagation (domino effects). ▪ Cannot handle stochastic dependencies (failures influencing each other's probability). ▪ Does not cover dynamic (behavioural) or temporal aspects.

Table 23. Fault Tree Analysis advantages and disadvantages

4.4.3 Event Tree Analysis

An Event Tree Analysis (ETA) is a logic diagram used to analyse the effects of an accident, failure, or unintended event. This inductive procedure, known as ETA, displays all possible outcomes resulting from an initiating event, considering the functionality of installed safety barriers and additional factors. The diagram illustrates the probability or frequency of the accident in conjunction with the required safeguard actions to mitigate or prevent escalation. The success or failure of these actions (barrier) leads to various consequences of differing severity or magnitude [1] [25] [31].

Each barrier should be described in a negative statement, such as *Barrier X does not function*, indicating the barrier's failure to perform its required function during the specified accidental event. Additional events and factors should be described using worst-case scenarios, such as *gas is ignited* or *wind blows toward the dwelling area*.

By examining relevant accidental events, identified through preliminary hazard analysis, HAZOP, or other techniques, ETA can identify all potential accident scenarios and sequences in a complex system. This analysis helps to detect design and procedural weaknesses and to determine the probabilities of different outcomes from an accidental event. Multiplying the likelihood of the accident by the probabilities of failure or success in each path provides the likelihood of each consequence.

ETA focuses on defining consequential events that result from the primary initiating event. Event trees are used to explore the consequences of loss-making events to find ways to mitigate, rather than prevent, losses. For this reason, it is possible to define the two methodologies as complementary, as they are positioned on opposite sides with respect to the undesirable event. (Figure 13).

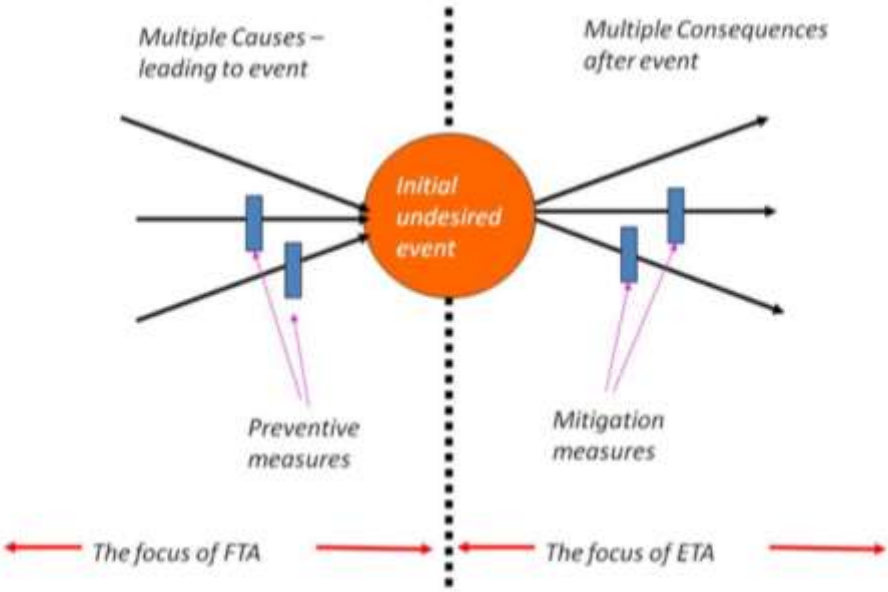


Figure 13. Difference between FTA and ETA

The stages in carrying out an ETA include [34]:

1. **Identify and Define the Accidental Event**: recognize a relevant accidental (initial) event that may lead to unwanted consequences,
2. **Identify Barriers**: identify the barriers designed to deal with the accidental event,

3. **Construct the Event Tree**: develop the event tree beginning with the initiating event,
4. **Describe Potential Accident Sequences**: outline the (potential) resulting accident sequences,
5. **Determine Frequencies and Probabilities**: establish the frequency of the accidental event and the (conditional) probabilities of the branches in the event tree,
6. **Calculate Probabilities/Frequencies for Outcomes**: compute the probabilities/frequencies for the identified consequences (outcomes),
7. **Compile and Present Results**: present the results from the analysis.

There are various methodologies for constructing an event tree (Figure 14). These typically employ Boolean (or binary) logic gates, which operate with two distinct options, such as success/failure, yes/no, or on/off. Event trees generally commence on the left with the initiating event and extend to the right, branching progressively. Each branching point is referred to as a node. Simple event trees are often presented at a system level, omitting intricate details. Table 24 highlights the advantages and the disadvantages of the examined methodology [25] [34].

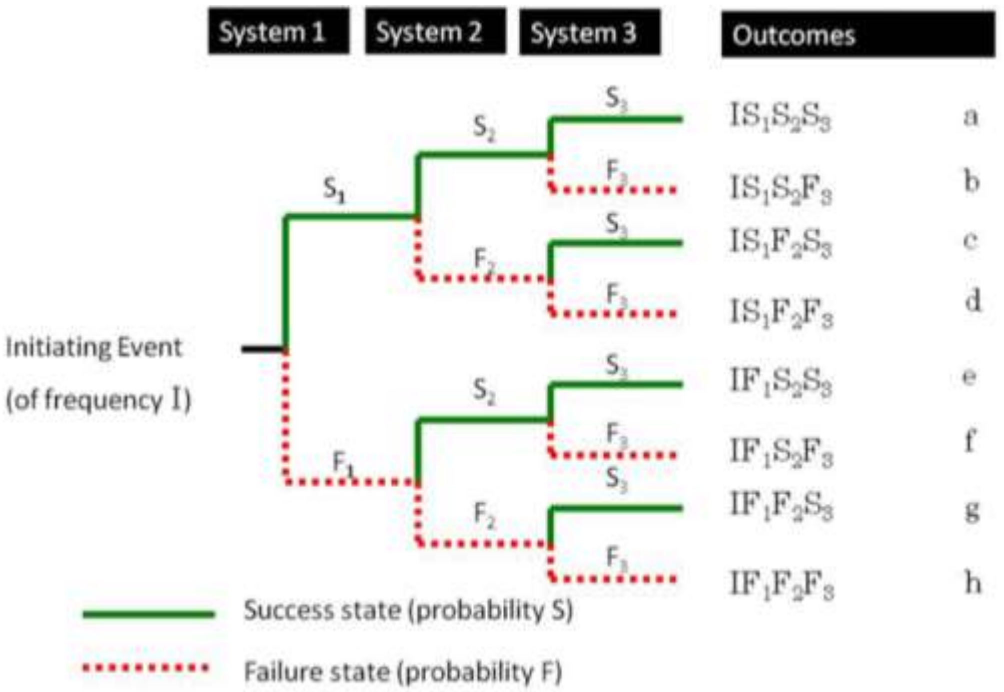


Figure 14. Event Tree Analysis - Stage System failure sequence [27]

Advantages	Weaknesses
• Illustrate the progression of events after an incidental occurrence. • Depict the barriers and their activation sequence. • Provide a solid foundation for assessing the necessity of new or enhanced procedures and safety functions. • General utilization and acknowledge all around and we can utilize it for cross-discipline framework investigation.	• Limited to examining a single initiating event. • Subtle dependencies within the system may be easily overlooked. • Not well-suited for addressing common cause failures in quantitative analyses. • Not illustrate acts of omission. • Not proficient where numerous occasions should happen in mix, as it brings about numerous repetitive branches.

Table 24. Event Tree Analysis advantages and disadvantages

4.5 CONCLUSIONS AND RECOMMENDATIONS

This study has identified the primary risk analysis methodologies utilized for containers onboard ships and in port terminals, specifically the FMEA, FTA and ETA. These methodologies are recognized within the IMO Formal Safety Assessment guidelines, ensuring their compliance with current regulations.

The three methodologies shown distinct structures and characteristics, leveraging complementary approaches that support their combined application. FMEA, with its focus on identifying potential failure modes and their effects, provides a detailed understanding of individual component risks. FTA, by mapping out the logical relationships leading to system failures, offers a comprehensive view of potential faults within a system. ETA, on the other hand, models the possible outcomes following an initiating event, highlighting the sequences of events that could lead to different consequences.

The integration of these methodologies facilitates a robust and multi-faceted approach to risk analysis, enabling a thorough assessment of risks from various perspectives. This comprehensive approach is crucial for enhancing the safety and reliability of container operations both onboard ships and within port terminals.

5 SAFETY AND RISK ANALYSIS METHODS SHIFTABLE FROM AVIATION TO SHIPPING

This section will address the potential of improving maritime container cargo transportation safety as inspired by best practices developed and implemented in the aviation sector considered one of the most safety-oriented industries.

In detail, the section will cover the following aspects:

- Introduction highlighting foundations for safety approaches in aviation and maritime transport,
- Description of risk analyses and safety methods used in aviation, with special on fire aboard aspects,
- Analysis of differences and indication on areas where aviation experience can result with improvement of container cargo transportation safety in maritime transport.

5.1. GENERAL DIFFERENCES IN TRANSPORT MODES SPECIFICATION LEADING TO SAFETY AND RISK MANAGEMENT IMPLICATIONS CONCERNING CONTAINER CARGO TRANSPORTATION

Both industries operate in real market conditions and are oriented on maximization of provided economic value. This implies the specific and historically optimized approaches resulted from trade-offs between economic, environmental, social and psychological aspects.

Therefore, it is reasonable to indicate first on some major differences which needs to be highlighted to properly understand strategies behind both aviation and maritime transport safety and risk management aspects. In aviation transport they are:

1. The most fundamental is the fact that in case of aviation, transportation takes place in the airspace, on altitude of several km and with speed of several hundred km/h; It entails the need of management of large potential portions of kinetic energy, what automatically generate relevant high risks,
2. Movement range limitations related to minimum and maximum possible speeds assuring controllability of the aircraft, as the fixed wing aircraft cannot stop in the air, combined with inertia resulted from manoeuvrability, lead to specific challenges in traffic management,
3. Operational conditions partially depend on state of atmosphere, which is often dynamic, variable and still of limited predictability.
4. When it comes to fire aboard, aircraft is considered as very vulnerable to propagating uncontrollable fire mostly due to structure made of composites, light alloys (*duraluminium*) or combination of both.

Therefore, the approach toward safety in aviation is predominantly determined by the fact that any factor or failure leading to loss of control over the aircraft (e.g. uncontrolled loss of speed or altitude) can be of catastrophic consequences as the time and means for recovery or significant risk mitigation are usually very limited and of reduced effectiveness. When it comes to the maritime transport, there some similarities as well as significant differences.

1. Maritime transport operates on water within two dimensions, therefore potential energy is usually not an issue, except in case of relevant wave motion; the operating speed are lower by two orders of magnitude, nevertheless the kinetic energy is somehow comparable due to accordingly higher mass,
2. In relation to the second point, the ship or vessel can stop which does not lead to compromising operational safety, however it does not affect the overall risk corresponding to sinking; there are also movement limitations concerning inertia, which can be seen as contributing to risk and safety related approach,
3. Operational conditions in maritime transport are more stable and predictable when compared to aviation; nevertheless, they still can significantly affect operational safety,
4. Despite the differences related to the structure of vessels risk concerning fire of container cargo is of critical meaning for the maritime transport safety since they are hard to extinguish and even to contain; therefore, in nature it directly corresponds to typical aviation safety problem mentioned above. Especially in case that [36]:
    a. Container cargo fire involve dangerous goods, which cannot always be ascertained when the fire starts since dangerous goods may be difficult to trace through cargo declarations; dangerous goods both entail an increased fire risk and lead to fires hard to suppress.,
    b. The container where the fire originates may be difficult to identify and to reach due to cargo hold or cargo deck area congestion; the options for firefighting are therefore quite limited since the only fixed fire-extinguishing system required by SOLAS in the cargo area is a CO_2 system in the cargo holds [37],
    c. The increasing size of the containerships means increased risk to the crew, cargo and ships.
5. Despite significantly lower risk of loss of life in maritime transport when compared to aviation, the vast risk of environmental and economic loss makes the crew evacuation as a scenario not considered as a reference solution.

In summary, generally maritime transport can be described as enabling more risk mitigation means, which can be considered as being of higher effectiveness when compared to aviation. It leads to possibility of more balanced and better distributed approaches to safety and risk management about corresponding. Nevertheless, the case of fire aboard should be considered as equally critical for both aviation and maritime sector, justifying the same considerations on looking for best practices and solutions in aviation sector to be shiftable to maritime transport domain.

Therefore, the next section focuses on identifying and analysing fire prevention and fighting methods applied in aviation transport, which could be successfully implemented in the maritime domain, contributing to the increase of fire related safety.

5.2 REVIEW OF THE MOST CRUCIAL SOLUTIONS APPLIED FOR AVIATION SAFETY AND RISK ANALYSIS PROMISING WITH REGARD TO APPLICATION IN THE MARITIME TRANSPORT DOMAIN

5.2.1 Regulations

The regulations play a crucial role in ensuring safety in aviation by establishing standards, monitoring compliance, and enforcing rules [38]. It especially relates to:

- Safety Management Systems (SMS), designed to manage safety risks in aviation operations. They integrate safety management into the daily operations of aviation organizations,
- Functions of Regulatory Authorities, such as the Civil Aviation Authorities (CAAs) and the European Union Aviation Safety Agency (EASA), responsible for identifying aviation safety risks, developing mitigations, drafting rules, issuing approvals, monitoring compliance, and taking enforcement actions [38],
- Certification and Standards by aviation safety authorities before allowance to fly, which ensures that the aircraft meets established safety standards.

5.2.2 Safety Management System

According to EASA (European Aviation Safety Agency) a Safety Management System (SMS) is a structured framework that helps organizations manage safety risks systematically and proactively. It involves identifying hazards, assessing risks, and implementing controls to prevent accidents and injuries [34]. It contains methodologies seeking to proactively identify hazards and to mitigate the related safety risks before they result in aviation accidents and incidents. SMS defines working environment for efficient safety management processes. Key Components of an SMS are [39]:

- Safety Policy and Objectives: establish the organization’s commitment to safety and outlines specific safety goals,
- Safety Risk Management: identifies hazards, assesses risks, and implements measures to mitigate them,
- Safety Assurance: monitors and evaluates the effectiveness of safety measures and ensures continuous improvement,
- Safety Promotion: fosters a safety culture through training, communication, and awareness programs.

SMS in aviation, as well as in other domains, is considered as providing foundations and framework for furthermore detailed actions. It plays a crucial role in ensuring safety by:

- Proactively Identifying Hazards: SMS Helps in recognizing potential safety issues before they result in accidents,
- Risk Management: assessing and mitigating risks to maintain safe operations.
- Continuous Improvement: regularly reviews and improves safety practices to adapt to new challenges,
- Promoting a Safety Culture: encourages a culture where safety is a priority, ensuring that all employees are aware of and committed to safety practices [38].

Implementation and maintaining of SMS in organisation is always first step in the process of improving safety in given area. All risk identified and measured within SMS need to be mitigated and controlled. Mitigation means can be set in 4 different areas:

- **Human Factor:** to reduce risk related to human error. Focusing on the physical, psychological, and social characteristics that influence human performance and behaviours; Effective safety management considers these factors to minimize human error and enhance safety (e.g. mainly education and training activities assuring appropriate level of competences) [40],
- **Technical Reliability:** solutions applied a various levels of system structure aimed at reducing the risk related with technical malfunction and failure; here it can be achieved with assuring technical quality through e.g. certification as well as redundancy, separation and isolation of key components of the system [41],
- **Organisation Level:** assuring the organisation operates in a way which does not lead to occurrences; here the activities like Jus Culture of Safety Culture policies are important as well as quality assurance standards (e.g. ISO) [42],
- **System of Organisation Level:** right regulation and operational environment assured by appropriate law (level of system of systems); Holistic Approach is viewing safety management as an interconnected system where human, technological, and organizational factors interact and influence each other, and Continuous Improvement is regularly assessing and improving safety practices based on feedback and new insights [41] [42].

Within these application areas the control and mitigation means can be divided into three following levels: predictive, proactive and reactive [43], according to the time of application of mitigation mean in relation to the time of expected hazards occurrence. All safety addressing solutions relate to one of the levels and as inscribed into SMS commonly contribute to achieving predefined safety objectives. In aviation, due to its mentioned earlier nature, most focus is set on proactive and predictive areas considered as preventing occurring of hazards according to:

- *Predictive Approach*, where future exposure to hazards is anticipated based on past performance data; directly, if already experienced or indirectly if given hazard and related risk are considered as sufficiently high; the analysis of current and historical operations to identify areas of potential concern in future, hypothetical situations is crucial; it can be performed following ASCOS project [44] approach through identification and specification of precursors which potentially can lead to specified set of risks or if focused on technical reliability FMEA [45] [46] based on ISO standards, e.g. ISO 9001, 31000 [47],

- *Proactive Approach*, where focus is set on the initialization of identified and known cause-effect chain starting with non-hazardous event recognized as control measure, triggering predefined mitigation measures; this approach usually is executed with proactive activities and by reviewing proactive approach related data; due to various nature of hazards proactive approach requires implementation of safety and just culture policies as often relies on voluntary reports,
- *Reactive Approach*, which concentrates on reaction to occurred hazard to mitigate related risk; it means effort allocated to reduce severity resulted with hazard occurred (e.g. to prevent an accident) and identification and application of measures significantly reducing probability of re-occurrence, by processing incident/accident reports elaborated after such events.

5.2.3 Solutions

When it comes to concrete methods and technologies the following key solutions can be identified as particularly assuring high level of safety in aviation in case of fire aboard:

- **Rigorous Inspections and Maintenance Routines**: regular inspections and maintenance of aircraft systems including the cargo compartment linings and fire safety systems; it is essential factor for high system reliability and helps identify and rectify potential fire hazards before they become an issue,
- **Use of Fire-Resistant Materials and Systems**: aircraft design incorporates materials that are flame-proof and air-tight e.g. cargo compartment linings; additionally, the design standards for cargo compartments, especially Class D compartments, rely on the principle of fire containment by restricting the supply of oxygen into the compartment,
- **Advanced Fire Detection and Suppression Systems**: specifically designed to monitor the cargo area for signs of fire, providing early warning to the crewhttps://www.aircraftsystemstech.com/2017/06/cargo-fire-detection.html and effectively extinguish or control a fire without the need for manual intervention; additionally, aircraft firefighting systems cover smoke removal strategies, among others, procedures allowing for removing smoke from the cabin to maintain visibility and prevent inhalation of toxic fumes and implementation and maintaining smoke barriers (e.g. keeping doors and other barriers closed to prevent smoke from spreading throughout the aircraft),
- **Flight Crew Procedures, Education and Training**: predefined procedures developed and tested towards prevention, reducing of propagation and fighting with fire are based on previous experiences, as well as specification of aircraft and cover prevention and firefighting techniques, including the use of emergency equipment and the execution of evacuation

procedures; crews receive extensive training on how to follow fire emergency procedures and handle fire emergencies, which includes the use of simulators and practical drills,

- **Design Improvements**: learning from aircraft operations, especially fire related occurrences are turned into appropriate changes in regulatory, relevant safety standards and practices; often it means improvements in materials and design, such as the use of composite linings and new more reliable fire suppression technologies, contributing to continuously enhanced fire safety in cargo holds.

The above areas of activity complementarily and comprehensively contribute to the container cargo fire safety in domain of aviation transport. They can be effective and reliable only if they are part of a SMS in deeply regulated environment assuring high quality of all related processes.

5.3 IMPLEMENTATION ASPECT STUDY. ANALYSIS AND EVALUATION OF IMPACT ON MARITIME SAFETY

SMS is fully implemented in maritime transport adopting the same all the crucial aviation best practices on level of systemic approach to safety and risk management. IMO has adopted the ISM Code, which provides an international standard for the safe management and operation of ships and for pollution prevention. The ISM Code requires ship owners and operators to develop and maintain an SMS that includes the following elements [48]:

- Safety and environmental protection policy,
- Defined levels of authority and lines of communication between shore and ship personnel,
- Procedures for reporting accidents and non-conformities,
- Procedures to prepare for and respond to emergency situations,
- Procedures for internal audits and management reviews.

The implementation of a SMS in maritime transport involves several steps, including:

- Assessment of Current Practices: understanding the current safety practices and identifying areas for improvement,
- Development of Policies and Procedures: establishing clear safety and environmental policies and developing procedures to implement these policies.
- Training and Competence: ensuring that all personnel are properly trained and competent to perform their duties safely,
- Risk Management: identifying potential risks and implementing measures to manage and reduce these risks,
- Emergency Preparedness: Developing and practicing emergency response procedures,
- Continuous Improvement: Regularly reviewing and improving the SMS to ensure its effectiveness.

Role and responsibility of organisation in the process of safety assuring, covering policies of safety culture addressing: Communication, Commitment, Competence and Continuous

Improvement and Jus Culture focusing on Accountability, Learning Environment and Balanced Approach are also implemented in the maritime transport guaranteeing continuous improvement of safety level both in overall maritime transport aspects as well as about container cargo fire occurrences [48] [49]. Process of implementation of Safety Management System in maritime transport domain entails the comprehensive approach to prevention and fighting with fire. There is a set of measures addressing this type of events [48]:

- **Prevention Measures:** covering proper stowage and segregation as reducing the risk of reactions leading to fire; regular Inspections of containers and cargo holds to identify and mitigate potential fire hazards; and comprehensive fire safety training for crew members, focusing on prevention, detection, and response,
- **Detection Systems:** heat detection systems in cargo holds to identify potential fires early as well as portable IR cameras to enhance manual detection of hot spots,
- **Fire Suppression Systems:** water spray systems to prevent reflash and control fires, fixed firefighting systems, such as CO_2 or foam systems, in cargo holds as well as advanced manual firefighting tools for individual container breaching and firefighting and remote closing arrangements for all openings to cargo holds to contain fires,
- **Operational Measures:** dedicated fire control stations to manage firefighting efforts effectively and additional firemen arrangements to ensure adequate water supply for firefighting,
- **Innovative Technologies:** based on digital solutions to provide situational awareness onboard and around the vessel, integrating these systems into the vessel’s IT infrastructure.

They are all can be considered as maritime representatives of systems and solutions developed for aircraft fire prevention. Further, more detailed comparison, aimed at identification of areas of potential improvement inspired by aviation related experiences would require detailed case study, being in fact one of the goals of the OVERHEAT project. Nevertheless, based on the overall comparison of fire safety situation in maritime and aviation the conclusions below can be derived.

Review of regulatory aspects. Proactive and predictive approach contained in aviation regulatory is commonly considered (beside SMS) as reason for safety performances in aviation transport. Every aspect of air transport is heavily regulated, supervised and often certified enabling the same high quality of all related processes. Maritime transport when compared to aviation allow for more economically balanced approach what resulted with development of primarily reactive solutions. Nevertheless, it is assumed that in maritime domain and corresponding processes the focus will be on avoiding hazards (risk mitigation means) as the most effective method for safety assuring. Besides SMS, Functions of Regulatory Authorities actively acting in the process of risk identification and mitigation and Certification and Standards should be introduced. Modelled on solutions in aviation sector. It is of crucial importance in case of container fire in maritime transport, very similar in nature to the classic aviation accidents. This can be seen as one of lessons learnt from aviation worth considering while working on improvement of fire safety in maritime transport.

Further implementation of SMS supported by more stringent and precise regulations. With special focus on level of organization (Safety and Jus Culture policies). SMS should be implemented in all organisations involved in value chain generation and contributing to the fire safety. Especially those responsible for design, manufacturing, maintenance and operation of vessels and critical systems and components.

Further detailed research. Implementation of effective control and mitigation means about identified risk (in SMS) require detailed research aiming at better understanding of fire occurrences aboard ships and vessels, on level of: Ship design, Container design, Fire detection methods, Firefighting means, Stowage & planning, Container inspection regime, Port state control, Crew training as well as definition of Regulations (IMO, Class). Rapid development of digital technologies seems to be in line with this need by providing additional solutions. Such approach will result with tailored and optimized solutions significantly contributing to increased compartment cargo fire safety.

6 SAFETY TARGETS AND PROCEDURES FOR PREVENTION AND MITIGATION OF FIRE IN CONTAINERS ONBOARD AND IN TERMINALS

This chapter provides a comprehensive overview of the safety targets and procedures designed to prevent and mitigate fires in containers, both onboard vessels and within port terminals. The information is organized into three sections to address each scenario's specific requirements and protocols.

Firstly, the procedures for fire situations onboard ships are detailed. This section includes two critical documents that serve as essential references for managing fire emergencies at sea. The first document is the *Intervention Manual for Firefighters on Ships*, developed by *Puertos del Estado*. This manual offers detailed guidance on the intervention strategies and safety measures necessary for firefighting operations aboard vessels. The second document is the *Operations Policy Manual* created by the Maritime Incident Response Groups (MIRG) of the European Union. This manual outlines the operational policies and best practices for maritime incident response, ensuring coordinated and effective actions in fire emergencies on ships.

Secondly, the chapter addresses procedures for fire incidents on the land side, specifically within port terminals. For this purpose, we refer to *Response Methods in Emergencies with Chemicals (*TOKEVA*)*. This document developed by the Emergency Services College with funding from the Ministry of the Interior and the Nordic Council of Ministers, provides essential tactical and technical instructions for responding to chemical accidents. It includes real-world-tested guidelines for identifying hazards, mitigating chemical releases, and using protective gear.

By separating the procedures into these three parts, the chapter ensures that both maritime and terrestrial fire scenarios are addressed with precision and clarity. This structured approach facilitates a thorough understanding of the preventive measures and response strategies required for effective fire management in different environments.

6.1 OPERATIONS POLICY MANUAL

The Operations Policy Manual is a crucial document for managing incidents involving fire or hazardous materials at sea. This Standard Operating Procedure (SOP) provides detailed guidelines and protocols that Maritime Incident Response Groups (MIRG) of the European Union should follow from the initial alert to the arrival of their personnel at the designated *Holding Area*. The manual is designed to ensure a coordinated, efficient, and effective response to maritime emergencies, with a focus on safety and operational effectiveness. The content of the document is structured in these chapters below.

Standard Operating Policy 1 – Tasking to Incidents at Sea

- Purpose: outlines the procedures for assigning MIRG EU teams to maritime incidents involving fire or hazardous materials.
- Details: describes the process for receiving and processing incident alerts, coordinating with the Coastguard, and dispatching teams to the scene.

Standard Operating Policy 2 – Fire Liaison Officer

- Purpose: defines the role and responsibilities of the Fire Liaison Officer within the response framework.
- Details: includes guidelines on how the Fire Liaison Officer should manage communications between different response teams and agencies, ensuring that all firefighting efforts are well-coordinated.

Standard Operating Policy 3 – Deployment & Transportation

- Purpose: provides protocols for the deployment and transportation of MIRG EU teams to the incident site.
- Details: covers logistical considerations such as transportation methods, equipment handling, and ensuring that teams arrive at the scene promptly and safely.

Standard Operating Policy 4 – Nominal Roll Procedures

- Purpose: Details the procedures for maintaining an accurate list of personnel involved in the response.
- Details: Describes how to track team members, manage their assignments, and ensure that all personnel are accounted for during the incident.

Standard Operating Policy 5 – Communications

- Purpose: Establishes guidelines for maintaining effective communication throughout the incident response.
- Details: Includes protocols for radio communication, information sharing between teams, and updates to command centres, ensuring that all parties involved are informed and coordinated.

Standard Operating Policy 6 – Incident Command

- Purpose: Defines the structure and procedures for establishing and maintaining command during the incident.
- Details: Outlines the hierarchy of command, responsibilities of command staff, and procedures for decision-making and strategic planning during the response.

The Operations Policy Manual is a comprehensive guide that ensures that teams are well-prepared and equipped to handle complex maritime incidents effectively. By adhering to these standardized procedures, the manual helps facilitate a structured response, enhances coordination among different agencies, and improves overall safety and efficiency during maritime fire and hazardous materials emergencies.

6.2 INTERVENTION FIREFIGHTER MANUAL FOR SHIPS

The Intervention Firefighter Manual for Ships serves as a critical guide for local firefighters, offering a comprehensive introduction to maritime firefighting and equipping them with the necessary tools and knowledge to handle various fire scenarios aboard vessels. This manual is designed to help firefighters understand the unique challenges of maritime environments and develop effective action procedures tailored to these settings. The content of the document is structured in these chapters below.

Basic Concepts of the Ship and Familiarization with the Environment

- Purpose: to provide firefighters with essential knowledge about ship structures and maritime environments.
- Details: this section introduces fundamental ship components, such as the hull, decks, and compartments, and explains how these elements impact firefighting operations. It also covers the importance of understanding the ship's layout and the maritime context in which firefighting occurs.

Rescue Devices and Means. Survival at Sea

- Purpose: to ensure that firefighters are well-prepared for rescue operations and survival situations at sea.
- Details: this chapter outlines various rescue devices, such as lifeboats, life vests, and emergency signalling equipment. It provides guidelines for their use and emphasizes the critical survival techniques required for ensuring safety in maritime rescue operations.

Ship's Firefighting Systems

- Purpose: to familiarize firefighters with the onboard firefighting systems and their operation.
- Details: covers the different types of firefighting systems installed on ships, including sprinklers, foam systems, and water mist systems. This section explains how these systems work and how to operate them effectively during a fire emergency.

Interventions on Board

- Purpose: to provide actionable procedures for firefighting interventions on ships.
- Details: offers practical guidelines and strategies for responding to various fire scenarios onboard, such as fires in cargo holds, engine rooms, and living quarters. This chapter emphasizes

tactical approaches, coordination with ship's crew, and safety measures specific to onboard firefighting.

The Intervention Firefighter Manual for Ships is an invaluable resource for preparing local firefighting teams to address the complexities of maritime fire emergencies. By combining detailed knowledge of ship environments with practical firefighting techniques, the manual supports the development of tailored action procedures, ensuring that firefighters are equipped to manage fire incidents effectively and safely aboard vessels.

6.3 TOKEVA (Response Methods in Emergencies with Chemicals)

The manual was developed through the TOKEVA project by the Emergency Services College between 1993 and 1996, provides comprehensive tactical and technical instructions for responding to chemical accidents. Funded by the Ministry of the Interior and the Nordic Council of Ministers, this manual is designed to enhance response strategies and methods specifically tailored to the hazardous properties of chemicals. It aims to build on previous guidelines by integrating new tactics, materials, and mitigation methods. The content of the document is structured in chapters below.

User's Guide

- Purpose: to provide an overview and orientation for users of the manual.
- Details: offers guidance on how to navigate the manual, including how to utilize the various sections effectively for different types of chemical emergencies.

Index of Tactical Guides

- Purpose: to facilitate easy access to specific tactical information.
- Details: an organized list of tactical guides included in the manual, allowing users to quickly locate relevant instructions based on the nature of the chemical incident.

Tactical Guides

- Purpose: to provide detailed tactical instructions for responding to chemical emergencies.
- Details: includes strategies for various scenarios, such as containment, neutralization, and evacuation, tailored to different types of chemical releases and environments.

Method Guides

- Purpose: to outline methods for mitigating the impact of chemical incidents.
- Details: offers practical methods for managing chemical spills, leaks, and exposures, including techniques for effective cleanup and decontamination.

Spreading, Dispersion, and Mitigation of Releases

- Purpose: to address the dynamics of chemical releases and their impact.
- Details: provides information on how chemicals spread and disperse, and methods for mitigating these effects to minimize harm to people and the environment.

Response Using Chemical Protective Clothing

- Purpose: to guide the use of protective clothing during chemical emergencies.
- Details: includes instructions on selecting, donning, and using chemical protective clothing to ensure the safety of responders.

Training Instructions

- Purpose: to support the development of training programs for emergency responders.
- Details: provides protocols and training modules to enhance responders' skills and preparedness for handling chemical emergencies effectively.

The TOKEVA manual features several important aspects that enhance its utility and effectiveness. The instructions have been rigorously tested in real-world scenarios across fire brigades, industries, and transportation sectors, ensuring their practical applicability and effectiveness. The manual provides comprehensive tactical and method guides that assist users in identifying hazards, taking appropriate actions, and applying methods tailored to various chemical incident scenarios. It also details the specific types of materials and equipment required for effective response and mitigation. Additionally, the manual includes specialized modules for chemical diving and training, which are essential for establishing protocols and developing training programs for responders dealing with complex chemical incidents.

7 RISK ANALYSIS BUILDING SCENARIOUS AND RISK EVALUATION

The International Maritime Organization (IMO) defines the risk assessment as “a rational and systematic process for assessing the risks associated with shipping activity and for evaluating the costs and benefits of IMO's options for reducing these risks”. It can be used as a tool to help ensure that actions are taken before a disaster occurs.

The maritime is a critical safety field that uses a predictive approach and, for this reason, requires assessing risks to minimize the probability and severity of hazards. Moreover, the OVERHEAT project aims to detect, prevent, and mitigate fire on board containership. For this reason, the risk analysis for the OVERHEAT project requires a dedicated model to reach the main objectives.

The OVERHEAT risk assessment model is based on both qualitative and quantitative appraisal. The models detailing the methodology used are presented below.

Qualitative assessment methodology

The OVERHEAT qualitative assessment relies on the qualification, prevention and mitigation of hazards previously defined. Specifically, the model follows three steps:

1. Classifies and help to prioritize the hazards,
2. Provides a detailed description of each hazard,
3. Tailors preventive and mitigation measures to each specific risk.

Quantitative assessment methodology

The OVERHEAT quantitative assessment relies on the creation of a risk matrix. Particularly this process consists of the following steps:

- Identifying hazards and risk factors that potentially cause harm (hazard identification);
- Analysing and evaluating the risk associated with that hazard (risk evaluation);
- Determining appropriate ways to mitigate the hazards (mitigation).

A risk assessment is conducted based on a high-level descriptive terms (Figure 15) as below.

- A detailed description of the operational environment: all the elements of the operational environment have a vital role in ensuring the successful detection of a fire accident. The OVERHEAT project is targeting to develop Digital Solution (DS) capable to provide a complete operational picture to the seafarers. The DS is equipped with tools, such as Internet-of-Things (IoT) sensors and Unmanned Aerial System (UAS) to detect fire on board containerships early.

Figure 15. High-level risk assessment approach

- A detailed description of procedures: this block refers to procedures to be executed in case of a fire accident and standard operational procedures followed by the seafarers. One of the project's outcomes will be to enhance the training courses foreseen by the STCW convention related to fire management.
- Identification of contingency situations: important to assess the ability of the new operational concept to work through (robustness), or at least recover from (resilience) any contingency situation external to the Concept and not under control, that might be encountered relatively infrequently. In the OVERHEAT project, contingency situations will be validated through simulations and demonstration activities.
- Identification of hazards: before the assessment of the risks associated with the introduction of a change in a given operational environment, a systematic identification of the hazards shall be conducted. In fact, a pre-condition for performing the risk assessment for introducing a new concept is to understand the impact it would have on the overall maritime risk picture. In the following sections the hazards related to the fire on containerships and their mitigation are detailed.
- External factors identification (e.g., bad weather conditions).

Risk assessment based on a risk matrix allows to determine the tolerability of the risks. Table 25 presents a typical risk probability classification. It includes five categories to denote the probability related to an unsafe event or condition, the description of each category, and an assignment of a value to each category.

Likelihood Class	Qualitative
Frequent (5)	Likely to occur many times (has occurred frequently)
Occasional (4)	Likely to occur sometimes (has occurred infrequently)
Remote (3)	Unlikely to occur, but possible (has occurred rarely)
Improbable (2)	Very unlikely to occur (not known to have occurred)
Extremely Improbable (1)	Almost inconceivable that the event will occur

Table 25. Probability classes used in the operational risk assessment

In terms of severity categories (Table 26), catastrophic hazards effect involve multiple fatalities, loss of the ship or incapacitation of the seafarers. A hazardous event involves a large reduction in safety margins, physical distressor a workload, such that operational personnel cannot be relied upon to perform their tasks accurately or completely, such as a serious injury and/or a major equipment damage. A major hazard involves significant reduction of safety and a significant increase of workload for the crew to perform their task. A minor hazard involves no injuries for the people, a slight decrease of safety and a slight increase of workload for the crew to perform their task. Finally, a "no effect" hazard do not affect people, safety and crew workload.

Severity Category	Injuries	Effect on safety	Crew workload
Catastrophic (A)	ship or equipment destroyed / Multiple Fatalities		
Hazardous (B)	Single Fatality and/or Multiple serious injuries / Major equipment damage	Large decrease	Compromises safety
Major (C)	Non serious injuries / Serious incident	Significant decrease	Significant increase
Minor (D)	None	Slight decrease	Slight increase
Negligible (E)	None	No effect	No effect

Table 26. Proposed hazard severity categories

The combination of Likelihood and severity generates the risk matrix (Table 27), used to assign a risk level for each identified hazard.

Probability	Severity				
	Catastrophic (A)	Hazardous (B)	Major (C)	Minor (D)	Negligible (E)
Frequent (5)	5A	5B	5C	5D	5E
Occasional (4)	4A	4B	4C	4D	4E
Remote (3)	3A	3B	3C	3D	3E
Improbable (2)	2A	2B	2C	2D	2E
Extremely improbable (1)	1A	1B	1C	1D	1E

Table 27. Risk Matrix

The index obtained shall be exported to a risk tolerability table (Table 28) that describes the tolerability criteria. Risks are assessed as acceptable, tolerable or intolerable.

Safety Risk Description	Recommended Action
Intolerable	Immediate actions to mitigate the risk or stop the activity are necessary: perform priority risk mitigation to ensure additional or enhanced preventative controls are in place to reduce the risk index to tolerable.
Tolerable	It can be tolerated based on the safety risk mitigation: management's decision to accept the risk could be ncessary.
Acceptable	Acceptable as is: no further risk mitigation is required.

Table 28. Tolerability index

8 IDENTIFICATION AND CLASSIFICATION OF HAZARDS

This section consolidates key hazards relevant to fire safety in container transport, classifying them according to the taxonomy introduced in Section 2. It provides the hazard baseline used for the scenario-based risk assessments in the OVERHEAT use cases.

8.1 HAZARD'S IDENTIFICATION

The operation of container ships and port areas is a complex and multifaceted process, involving a wide range of activities that can present significant risks. These risks, if not effectively identified, assessed, and managed, have the potential to lead to severe consequences that can affect not only human safety but also the integrity of valuable assets, infrastructure, and the surrounding environment. Given the complexity of modern shipping and port operations, it is crucial to adopt a comprehensive approach to risk management that accounts for all possible hazards.

To handle these risks in an organized and systematic manner, it is helpful to categorize them based on their origin and nature. This allows a more targeted approach to mitigation strategies and ensures that all potential dangers, related to human error, equipment failure, environmental factors, or operational processes, are properly addressed. By understanding the specific nature of each risk, stakeholders can implement the necessary safety protocols, technological solutions, and contingency plans to reduce the likelihood of accidents, minimize damage, and ensure the long-term sustainability of both maritime operations and port facilities. This holistic risk management approach makes it possible to navigate the inherent challenges of container shipping while safeguarding people, assets, and the natural environment from harm.

Hazards identification is the first critical step in the risk management process for container shipping and port operations. It involves systematically recognizing potential sources of harm that could lead to incidents, operational disruptions, or environmental damages. Given maritime logistics' diverse and dynamic nature, hazard identification must be an ongoing process, incorporating insights from historical data, real-time monitoring, and predictive risk assessments.

Methods for Hazard Identification

To effectively identify and address hazards, various methodologies can be employed:

- Safety audits and inspections: regular assessments of port facilities, cargo handling equipment, and onboard operations to detect potential risks,
- Incident and near-miss reporting: encouraging a culture of safety where workers report unsafe conditions and close calls,
- Risk assessment tools: using frameworks, such as Hazard and Operability Study (HAZOP), Failure Mode and Effects Analysis (FMEA), and Fault Tree Analysis (FTA) to evaluate risks systematically,
- Technological monitoring: implementing sensor-based systems, automated tracking, and predictive analytics to identify hazards in real-time.

By systematically identifying hazards, port authorities, shipping companies, and logistics providers can develop effective control measures, enhance operational resilience, and improve overall safety in container shipping and port environments. This proactive approach is essential to minimizing disruptions, protecting personnel, and ensuring the sustainable development of maritime transport systems.

List of the identified hazards

- **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.
- **Declared dangerous goods:** continuous heating may be the reason for self-ignition of batteries, particularly lithium-ion batteries.
- **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 appropriate safety procedures, 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 include collisions and stranding, 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 heating and electrical shortcut.
- **Human errors and Inadequate training:** mistakes regarding stowage of containers due to human errors, inadequate training and false declared cargo, such as containers with low flashpoint goods accidentally stowed on the top row on deck might cause a fire since temperature inside a container in direct sunlight might rise up to 55°C.

8.2 CLASSIFICATION OF IDENTIFIED RISKS

The operation of container ships and port areas involves numerous risks that, if not properly managed, can result in significant consequences for people, assets, and the environment. To effectively address these challenges, risks can be categorized based on their origin and nature. This classification not only provides clarity but also helps prioritize preventive and mitigating measures tailored to each specific type of risk. Below is an extended overview of the key categories.

Dangerous Goods and Hazardous Products (and/or Contaminants)

This category encompasses risks associated with hazardous goods, such as chemicals, batteries, and flammable materials. If these goods are not properly declared, packaged, or handled, they can lead to fires, chemical spills, or even explosions, especially when stored in confined spaces like cargo holds. Examples include misdeclared dangerous goods, which may go unnoticed, and declared goods, such as lithium-ion batteries, which can self-ignite under certain conditions. Proper management of these risks requires strict compliance with regulations, robust inspection processes, and specialized training for those handling such materials.

Other General Risks in the Land Service Area of the Port

Risks in this category are specific to the port's landside operations. These include electrical failures in refrigerated containers (reefer containers), mishandling of cargo, or poor stowage practices within the service area. Such incidents can disrupt operations, cause property damage, or even escalate into larger emergencies. Preventive measures such as routine equipment maintenance and proper cargo handling protocols are essential to mitigating these risks.

Nautical Accidents

Maritime incidents, such as collisions, groundings, and cargo shifting during transit, fall into this category. These events can lead to severe structural damage to ships, fires, and in extreme cases, the loss of cargo overboard. The dynamic and often unpredictable nature of the maritime environment makes these risks particularly challenging to manage. Implementing advanced navigation systems, proper cargo-securing methods, and adherence to maritime traffic rules are critical to reducing these hazards.

Marine Contamination

Marine pollution caused by hazardous spills, container losses, or inadequate containment of dangerous goods poses significant environmental threats. This includes the release of chemicals or fuel into the sea, which can harm marine ecosystems and protected coastal zones. Preventing such contamination requires stringent regulations, emergency containment measures, and technologies to track and secure containers during transit.

Human Errors

Human factors remain one of the leading causes of incidents in both maritime and port environments. Mistakes in stowage, non-compliance with safety procedures, and inadequate training increase the likelihood of accidents. Errors may also exacerbate emergencies, as untrained personnel might not respond appropriately. Continuous training, periodic drills, and strict adherence to operational protocols are essential to minimizing these risks.

Technical and Mechanical Failures

This category includes risks arising from equipment failures, such as engine room malfunctions, electrical short circuits, or breakdowns in fire suppression systems. These failures can lead to significant incidents, such as fires spreading rapidly through cargo areas. Implementing real-time monitoring systems, regular maintenance schedules, and ensuring the proper functionality of safety equipment are crucial to addressing these risks.

This comprehensive classification provides a structured approach to understanding the diverse range of risks associated with container ships and port operations. By identifying the unique characteristics of each category, stakeholders can implement targeted strategies to manage these risks, ultimately ensuring safer, more efficient, and environmentally sustainable operations.

9 RISK ANALYSIS

Safety on container ships relies on effective management of risks associated with the operation and transportation of hazardous and non-hazardous goods. Identifying risks, analysing and developing preventive and mitigating actions are essential to reduce the consequences of incidents, such as fires, mechanical failures, human errors, and external factors. This section addresses a list of identified risks and outlines the measures designed to either prevent their occurrence or minimize their impact if they materialize.

Each identified risk has been analysed in detail to determine its root causes, assess its potential impact, and establish specific strategies for its management. These measures are divided into **preventive actions**, aimed at avoiding risks from becoming incidents and **mitigating actions**, designed to reduce the effects of incidents once they occur.

Below, the identified risks are presented, organized by their nature, along with the corresponding actions to address each one. These measures aim to enhance operational safety, protect the integrity of people, the environment, and facilities, and ensure the continuity of maritime and port operations.

9.1 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.

Sources

The root causes of misdeclared or undeclared dangerous goods can be attributed to several factors:

- **Human Errors:** Shippers may incorrectly classify or label goods due to a lack of training, negligence, or misunderstanding of regulations,
- **Frauds:** Intentional misdeclaration by shippers to avoid higher freight costs or regulatory restrictions,
- **Complex Supply Chains:** Inadequate oversight or miscommunication among multiple parties involved in shipping,
- **Regulatory Gaps:** Variations in international shipping standards and enforcement levels create opportunities for misdeclarations.

Likelihood

The occurrence of misdeclared or undeclared dangerous goods is relatively high due to the following reasons:

- **Volume of Trade:** the sheer number of containers processed globally increases the likelihood of errors or fraudulent declarations,
- **Limited Inspection:** only a small percentage of containers are physically inspected due to logistical constraints, leaving room for undetected hazards,
- **Growing Use of Lithium-Ion Batteries:** increased demand for goods containing these batteries (e.g., electronics) has raised the likelihood of improperly declared shipments.

Uncertainties

Key uncertainties complicating the assessment of likelihood include:

- **Quality of Data:** limited reliable data on the frequency of misdeclared shipments due to underreporting and inconsistent record-keeping,
- **Technological Variability:** differences in packaging and safety practices across industries affect the probability of incidents,
- **Evolving Regulations:** changes in international dangerous goods regulations can introduce variability in compliance rates.

Consequences

The consequences of misdeclared or undeclared dangerous goods are severe and multifaceted.

Direct Consequences:

- **Fires and Explosions:** hazardous materials, such as flammable liquids, gases, and batteries can ignite or explode under specific conditions.
- **Loss of Life and Property:** fires on container ships often result in crew fatalities, loss of cargo, and damage to vessels.

Indirect Consequences:

- **Environmental Impact:** spills and fires involving hazardous chemicals lead to pollution of marine ecosystems.
- **Economic Losses:** delays, insurance claims, and damage to shipping companies' reputations.
- **Disruption to Global Trade:** incidents at key ports or along major shipping routes can disrupt global supply chains.

Effectiveness of Preventing Actions

Stricter Regulations:

- Adoption of international standards such as the International Maritime Dangerous Goods (IMDG) Code ensures safer packaging, labelling, and declaration practices,
- Effectiveness: moderate; regulatory compliance depends on proper enforcement and global alignment.

Enhanced Training and Awareness:

- Educating shippers, freight forwarders, and shipping personnel on the proper handling and documentation of dangerous goods,
- Effectiveness: high, as it addresses human error and improves compliance with safety protocols.

Advanced Screening Technologies:

- Using AI and data analytics to identify patterns or discrepancies in cargo declarations,
- Effectiveness: high, though implementation costs may be prohibitive for smaller operators.

Random Physical Inspections:

- Increasing the frequency and randomness of inspections to deter intentional misdeclarations,
- Effectiveness: low to moderate, limited by resource and time constraints.

Effectiveness of Mitigating Actions

Fire Detection and Suppression Systems:

- Installing advanced sensors and automated fire suppression technologies in cargo holds,
- Effectiveness: high, though the risk of containment failure still exists in extreme cases.

Segregation of Cargo:

- Separating hazardous goods from general cargo to minimize the spread of fires,
- Effectiveness: Moderate to High, depending on proper identification of dangerous goods.

Emergency Response Plans:

- Ensuring vessels have well-trained crews and clear protocols for handling fires and chemical spills.
- Effectiveness: High, particularly when coupled with adequate equipment and communication tools.

Summary

The issue of misdeclared or undeclared dangerous goods represents a significant risk to container ship safety. Prevention strategies, such as improved regulations, training, and technology, can reduce the likelihood of incidents. At the same time, robust mitigation measures are critical to limiting their consequences. Addressing this challenge requires coordinated international efforts, substantial investment in safety systems, and ongoing monitoring of emerging threats.

9.2 DECLARED DANGEROUS GOODS

Such as lithium-ion batteries, continuous heating may be the reason for the self-ignition of a battery.

Sources

The primary sources of the problem are related to the properties of lithium-ion batteries and their handling during transport:

- **Thermal Runaway:** lithium-ion batteries are susceptible to thermal runaway, a condition where internal heat triggers a chain reaction, leading to fire or explosion,
- **Environmental Factors:** continuous heating due to high ambient temperatures, prolonged exposure to sunlight, or inadequate ventilation in cargo holds
- **Mechanical Damage:** vibration, puncture, or compression during transit can compromise battery integrity,
- **Defective Batteries:** manufacturing defects or improper assembly increase the likelihood of self-ignition,
- **Battery Overpacking:** large volumes of batteries packed together amplify the risk by creating localized heat build-up.

Likelihood

The likelihood of fires involving declared lithium-ion batteries is influenced by several factors:

- **Proliferation of Lithium-Ion Batteries:** growing demand for electronics and electric vehicles has led to a significant increase in the volume of batteries shipped,
- **Regulatory Compliance:** while declared goods are subject to safety standards, variations in compliance and enforcement create vulnerabilities,
- **Packaging Standards:** improper or substandard packaging increases the chances of heat accumulation and ignition,
- **Cargo Hold Conditions:** lack of temperature control or poor air circulation exacerbates the risk.
- **Temperature Fluctuations:** carrier hold conditions vary across different shipping routes and seasons,
- **Battery Design:** differences in quality and safety features among manufacturers,

- **Detection of Defects:** limited ability to identify defective or damaged batteries before shipment.

Consequences

The consequences of fires caused by declared dangerous goods like lithium-ion batteries are significant:

Direct Consequences:

- **Fires and Explosions:** rapid escalation of thermal runaway can ignite nearby materials, leading to catastrophic fires,
- **Crew Safety Risks:** smoke and toxic gases from burning batteries pose serious health hazards to crew members,

Indirect Consequences:

- **Economic Losses:** damage to vessels, loss of cargo, and increased insurance premiums.
- **Reputational Damage:** shipping companies may face public scrutiny and loss of customer trust.
- **Environmental Impact:** fires involving lithium-ion batteries release hazardous chemicals into the environment.

Effectiveness of Preventing Actions

- **Improved Packaging Standards:**
  - Use fire-resistant and thermally insulating packaging materials to minimize the risk of ignition.
  - Effectiveness: high, especially for bulk shipments of batteries.
- **Temperature-Controlled Containers:**
  - Deploying specialized containers with active cooling systems or temperature monitoring capabilities,
  - Effectiveness: high, though cost implications may limit widespread adoption.
- **Battery State of Charge (SoC):**
  - Shipping batteries at a reduced state of charge (e.g. 30%) to lower heat generation during transit,
  - Effectiveness: moderate to High, dependent on enforcement.
- **Enhanced Regulations:**

- Stricter enforcement of International Maritime Dangerous Goods (IMDG) Code provisions specific to lithium-ion batteries,
- Effectiveness: Moderate, as compliance varies across jurisdictions.

- **Training and Awareness:**
  - Educating supply chain stakeholders on proper handling, packaging, and storage of lithium-ion batteries,
  - Effectiveness: High, as it addresses human error and negligence.

Effectiveness of Mitigating Actions

- **Fire Suppression Systems:**
  - Deploying fire detection and suppression systems specifically designed for lithium-ion battery fires, such as aerosol extinguishers or dry powder agents,
  - Effectiveness: High, though suppression methods for battery fires are still evolving.

- **Thermal Management:**
  - Ensuring adequate ventilation and air circulation in cargo holds to prevent localized heating,
  - Effectiveness: High, provided that ventilation systems are maintained and monitored.

- **Emergency Protocols:**
  - Developing and practicing emergency response procedures for battery fires, including isolation of affected cargo.
  - Effectiveness: High, though dependent on crew training and readiness.

Summary

Fires caused by declared lithium-ion batteries are a growing concern in maritime shipping. The risks are driven by batteries' chemical and physical properties and the challenges in managing environmental conditions during transit. Prevention strategies, such as improved packaging, temperature-controlled shipping, and regulatory compliance are critical to reducing the likelihood of incidents. Mitigation measures, including advanced fire suppression systems and robust emergency protocols, are essential to minimize the consequences of such fires.

Addressing this issue requires collaboration among regulators, manufacturers, and shipping companies to ensure safer transport of lithium-ion batteries.

9.3 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.

Sources

The primary sources of electrical failures in reefer containers include:

- **Aging Equipment:** older reefer units with deteriorated insulation, corroded components, or worn-out wiring are prone to electrical malfunctions.
- **Faulty Maintenance:** improper inspection, inadequate repairs, or lack of preventive maintenance can leave wiring issues unresolved.
- **Overloading Circuits:** plugging multiple reefer units into the same power supply can lead to electrical overloads and overheating.
- **Environmental Factors:** exposure to saltwater, humidity, and vibration during transit can degrade electrical connections over time.
- **Installation Errors:** incorrect connection of power cables during loading can cause short circuits or sparks.

Likelihood

The likelihood of electrical failures in reefer containers leading to fires depends on several factors:

- **High Demand for Reefer Containers:** the growing need for refrigerated transport increases the number of reefer units in use, raising the probability of incidents,
- **Complexity of Electrical Systems:** each reefer unit has an independent electrical system, increasing the chances of malfunctions,
- **Limited Inspection Access:** the placement of reefers in cargo holds makes frequent inspection and early fault detection challenging,
- **Variability in Maintenance Standards:** differing maintenance practices among operators and shipping companies introduce variability in equipment reliability,
- **Undetected Pre-Existing Faults:** electrical issues might remain hidden until they escalate into fires,
- **Cargo Placement:** the positioning of reefer containers in the ship can affect the likelihood and severity of electrical incidents.

Consequences

The consequences of electrical failures in reefer containers can be severe and far-reaching:

Direct Consequences:

- **Fires in Cargo Holds:** electrical faults can ignite nearby flammable materials, potentially spreading to adjacent containers,
- **Loss of Refrigerated Goods:** fires or power failures result in spoilage of perishable goods, leading to economic losses.

Indirect Consequences:

- **Damage to the Ship:** fires can compromise the structural integrity of the vessel and its electrical systems,
- **Crew Safety Risks:** smoke and toxic fumes from burning wiring or cargo can endanger crew members,
- **Disruption of Operations:** firefighting efforts and damage control can delay the vessel's schedule and disrupt global supply chains.

Effectiveness of Preventing Actions

Regular Maintenance and Inspection:

- Conduct routine checks of reefer units, power connections, and electrical components to identify faults early,
- Effectiveness: high, though it requires consistent implementation and skilled personnel.

Use of Modern Equipment:

- Replacing aging reefers with newer models equipped with advanced safety features, such as circuit breakers and fault detection systems,
- Effectiveness: high, though initial investment costs can be significant.

Enhanced Crew Training:

- Providing specialized training for crew members on safe reefer operations, including proper electrical connections and fault identification,
- Effectiveness: moderate to High, as it addresses human error.

Centralized Monitoring Systems:

- Deploying monitoring systems that provide real-time data on reefer performance and alert operators to electrical anomalies,
- Effectiveness: high, especially for early detection of faults.

Effectiveness of Mitigating Actions

Fire Detection and Suppression Systems in Cargo Holds:

- Installing heat and smoke detectors alongside automated suppression systems to contain fires involving reefers,
- Effectiveness: high, though detection may be delayed due to container placement.

Improved Reefer Placement Strategies:

- Positioning reefers in accessible areas of the vessel to facilitate monitoring and firefighting efforts,
- Effectiveness: moderate, as space constraints may limit flexibility.

Emergency Response Protocols:

- Developing clear procedures for isolating faulty units and managing fires in cargo holds,
- Effectiveness: high, provided the crew is well-trained and equipped.

Summary

Electrical failures in reefer containers represent a significant fire hazard due to the complexity and location of their systems. Preventing such incidents requires rigorous maintenance, regular inspections, and the use of modern technology. Mitigation strategies, such as advanced fire suppression systems and well-trained crews, are crucial to minimizing the impact of these fires.

A combination of preventive and reactive measures, supported by enhanced crew training and improved reefer placement, is essential to reduce risks associated with reefer container electrical failures.

9.4 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.

Sources

The problem of cargo shifting and poor stowage arises from multiple causes:

- **Improper Lashing and Securing:** cargo is not adequately lashed or restrained and is prone to movement during transit,
- **Inadequate Weight Distribution:** overloading or improper balancing of containers can lead to instability during rough seas,
- **Stowage Planning Errors:** incorrect placement of hazardous materials, incompatible substances, or overweight containers.
- **Human Error:** lack of training or negligence during cargo securing or stowage planning,

- **Dynamic Forces:** environmental factors such as high winds, rough seas, and ship roll amplify the likelihood of cargo shifting.

Likelihood

The likelihood of cargo shifting and poor stowage contributing to fire hazards is moderate to high due to the following factors:

- **Volume and Complexity:** the global shipping industry transports millions of containers annually, increasing the chances of stowage errors,
- **High Risk in Hazardous Goods:** when dangerous goods are improperly stowed, the consequences of shifting cargo can escalate into fire or explosions,
- **Crew Expertise:** limited training or experience in stowage practices among crew members heightens the risk,
- **Variability in Ship Design:** differences in vessel structure, container stacking limits, and lashing systems affect the stability of cargo,
- **Weather Conditions:** unpredictable storms or heavy seas increase dynamic forces acting on the cargo,
- **Inspection Rates:** the actual prevalence of poor stowage is difficult to determine due to limited on-board inspections.

Consequences

The consequences of cargo shifting and poor stowage can be severe, especially when hazardous materials are involved.

Direct Consequences:

- **Damage to Containers:** collisions or tipping of containers can rupture hazardous goods, leading to fire or chemical spills.
- **Ignition Sources:** shifting cargo can spark fires by damaging electrical connections or exposing flammable materials to heat sources.

Indirect Consequences:

- **Loss of Stability:** cargo shifting can compromise the vessel's balance, increasing the risk of capsizing,
- **Crew Safety Risks:** fire or toxic exposure endangers crew members, particularly during rough seas,
- **Environmental Hazards:** fires or spills from hazardous cargo can contaminate marine ecosystems.

Effectiveness of Preventing Actions

Improved Lashing and Securing Practices:

- Using standardized and certified securing equipment, such as lashing bars and twist-locks, to stabilize cargo,
- Effectiveness: high, as it directly addresses the mechanical causes of cargo shifting.

Advanced Stowage Planning Software:

- Leveraging digital tools for optimal weight distribution, container placement, and segregation of hazardous materials,
- Effectiveness: high, though implementation requires investment and training.

Compliance with International Guidelines:

- Adhering to standards like the International Maritime Organization's (IMO) Cargo Securing Manual (CSM) and International Maritime Dangerous Goods (IMDG) Code,
- Effectiveness: moderate to High, dependent on enforcement and adherence by shipping operators.

Enhanced Crew Training:

- Providing training on proper lashing techniques, stowage planning, and the handling of hazardous materials,
- Effectiveness: high, addressing human error as a root cause.

Pre-Voyage Inspections:

- Conducting thorough inspections of cargo lashing and stowage before departure,
- Effectiveness: moderate, as inspections may miss hidden faults or be constrained by time pressures.

Effectiveness of Mitigating Actions

Damage Control Plans:

- Establishing protocols for detecting and securing shifted cargo mid-voyage to prevent escalation,
- Effectiveness: moderate, depending on crew readiness and available equipment.

Fire Suppression Systems:

- Equipping cargo holds with advanced fire detection and suppression technologies to mitigate incidents involving hazardous materials,
- Effectiveness: high, though detection can be delayed in deep cargo holds.

Monitoring Systems:

- Using sensors or cameras to track cargo movement in real time during transit enables early intervention,
- Effectiveness: high, but dependent on technology adoption.

Summary

Cargo shifting and poor stowage present a significant fire risk on container ships, particularly when hazardous materials are involved. Preventing such incidents requires a combination of improved lashing practices, advanced stowage planning, and adherence to international regulations. Mitigation measures like fire suppression systems and real-time monitoring can limit the impact of shifting cargo.

Addressing this issue necessitates collaboration between ship operators, regulatory bodies, and technology providers to enhance safety practices and reduce the frequency of stowage-related fires.

9.5 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.

Sources

The sources of human error and inadequate training that contribute to fires can be traced to several factors:

- **Lack of Fire Safety Training:** crew members may not have received adequate training in fire prevention, detection, or firefighting techniques, especially in emergency situations.
- **Operational Mistakes:** crew may fail to follow established safety protocols, either due to oversight, fatigue, or lack of attention.
- **Inadequate Knowledge of Cargo:** crew members may not fully understand the properties of hazardous or dangerous goods, leading to improper handling, storage, or emergency response.
- **Communication Failures:** poor communication between crew members, between the crew and shore-based staff, or within different teams on the ship can result in delayed or incorrect responses to fire-related incidents.
- **Time Pressure:** the need to meet tight shipping schedules may lead to shortcuts being taken in safety procedures, such as skipping checks or not fully securing dangerous goods.

Likelihood

The likelihood of human error or inadequate training contributing to fire hazards is high due to the following reasons:

- **High-Stress Environment:** the high-pressure and fast-paced environment of container shipping increases the chances of mistakes.
- **Training Gaps:** there may be inconsistencies in training quality, with some crew members lacking exposure to specific safety procedures or new firefighting techniques.
- **Human Fatigue:** long working hours and insufficient rest can contribute to lapses in judgment and failure to follow safety protocols.
- **Insufficient Experience:** inexperienced crew members may be more prone to errors, particularly in managing complex cargo or unfamiliar fire scenarios.

Uncertainties

- **Training Gaps Across Fleets:** there may be variability in the quality and consistency of fire safety training across different shipping companies or vessels.
- **Complexity of New Cargo Types:** as shipping methods evolve, the introduction of new or more complex cargo (e.g., lithium-ion batteries and hazardous chemicals) may lead to misunderstandings about how to handle them safely.
- **Stress and Fatigue Impact:** the actual impact of fatigue and stress on crew performance may be difficult to quantify.

Consequences

The consequences of human error and inadequate training are potentially catastrophic, as they directly impact the ability of crew members to prevent, detect, and fight fires.

Direct Consequences:

- **Failure to Prevent Fires:** Iif fire prevention protocols are not followed, the likelihood of fire initiation increases.
- **Delayed Fire Detection:** without proper training, crew may fail to recognize early warning signs of fire (e.g., unusual heat, smoke), leading to delayed action.
- **Inadequate Firefighting:** crew members may not respond effectively to a fire emergency due to insufficient training on firefighting equipment or techniques, potentially escalating a fire.

Indirect Consequences:

- **Loss of Life and Injury:** fire and smoke inhalation can lead to injuries or fatalities among the crew.
- **Environmental Damage:** fires involving hazardous materials may result in chemical spills, which can cause significant environmental harm.

- **Financial Loss:** the ship, cargo, and goods can be severely damaged or destroyed, leading to substantial financial losses.
- **Reputational Damage:** shipping companies may face reputational harm and regulatory scrutiny following incidents attributed to human error or lack of training.

Effectiveness of Preventing Actions

Enhanced Training Programs:

- Providing comprehensive and continuous training in fire prevention, detection, and firefighting procedures, including specific scenarios involving hazardous cargo.
- Effectiveness: high, as it directly addresses gaps in crew knowledge and skills, improving overall safety.

Regular Drills and Simulations:

- Conducting frequent fire drills and emergency response simulations, which simulate realistic fire scenarios and ensure the crew is prepared to act quickly and effectively.
- Effectiveness: high, as this helps crews develop muscle memory and familiarity with emergency protocols.

Standardized Safety Protocols:

- Standardizing and ensuring that all crew members are familiar with the company's fire safety procedures, particularly when dealing with hazardous materials.
- Effectiveness: high, as consistency in procedures across the ship reduces the chance of errors.

Fatigue Management:

- Implementing measures to monitor and manage crew fatigue, such as regulated rest periods and limiting work hours, to maintain alertness and reduce human error.
- Effectiveness: moderate to High, as it helps minimize lapses in judgment due to tiredness.

Use of Technology:

- Introducing automated monitoring and detection systems for fire hazards, reducing reliance on human detection alone.
- Effectiveness: moderate, as it augments human efforts but cannot fully replace crew intervention.

Effectiveness of Mitigating Actions

Emergency Response Teams:

- Training designated emergency response teams on specialized firefighting techniques and equipping them with state-of-the-art firefighting equipment, such as advanced fire extinguishers and thermal imaging cameras.
- Effectiveness: high, particularly if teams are well-practiced and equipped to respond rapidly.

Clear Communication Protocols:

- Establishing clear communication channels between the crew and command centre to ensure a coordinated and efficient firefighting effort.
- Effectiveness: high, as communication breakdowns can lead to delays or confusion during an emergency.

Real-Time Monitoring Systems:

- Implementing real-time monitoring systems that detect unusual temperature rises or smoke in cargo holds, alerts the crew early to potential fire hazards.
- Effectiveness: high, as it provides early warning and supports rapid intervention before a fire escalates.

Summary

Human error and inadequate training are key contributors to fire risks on container ships, especially when crew members fail to follow established protocols or lack knowledge of emergency procedures. Preventing such incidents requires comprehensive training, continuous drills, and standardized safety practices. Mitigation measures, such as clear communication, specialized response teams, and real-time monitoring systems, are essential to reducing the impact of human error in fire emergencies.

Addressing these challenges requires a cultural shift toward prioritizing safety and ensuring that all crew members are well-equipped to handle fire-related emergencies effectively.

9.6 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.

Sources

Mechanical failures in ship systems that lead to fires typically stem from a variety of issues:

- **Engine Room Overheating:** the engine room houses high-power machinery and engines that generate significant heat; poor maintenance or malfunctioning cooling systems can lead to overheating and fires,
- **Fuel Leaks:** leaking fuel, oil, or other flammable liquids from the engine room or machinery spaces can ignite if exposed to hot surfaces or sparks,
- **Electrical Failures:** shortcuts, faulty wiring, or damaged electrical panels in the engine room can trigger fires,
- **Exhaust System Failures:** malfunctions in exhaust systems can lead to the buildup of combustible materials that, when ignited, spread quickly throughout the engine room.
- **Corrosion and Wear:** over time, the wear and tear of machinery and components, particularly in older ships, can increase the risk of malfunctions.
- **Improper Maintenance:** inadequate servicing, failure to replace worn-out components, or neglecting routine inspections can result in mechanical failure.

Likelihood

The likelihood of mechanical failures leading to fires in machinery spaces is significant due to the following factors:

- **Complex Machinery Systems:** the intricate and high-energy systems in the engine room create multiple potential points of failure, particularly if equipment is old or inadequately maintained.
- **Environmental Stressors:** exposure to saltwater, humidity, and high temperatures accelerates the wear and tear of ship systems.
- **Increased Operational Demands:** continuous operations in harsh conditions can stress mechanical systems, increasing the chances of failure.
- **Lack of Regular Maintenance:** inconsistent or incomplete maintenance schedules on some ships increase the likelihood of mechanical failures.

Uncertainties

- **Condition of Machinery:** the actual state of mechanical systems and their components can vary widely across different ships and operators, making it difficult to predict failure rates.
- **Fire Suppression System Effectiveness:** the reliability of fire suppression systems in machinery spaces is difficult to assess without real-time monitoring of their functionality.
- **Age of the Vessel:** older ships are more prone to mechanical failures, but newer ships may still experience faults if equipment is defective or poorly maintained.

Consequences

Fires originating from machinery spaces can have devastating consequences, both for the vessel and the crew.

Direct Consequences:

- **Fire Spread to Cargo Holds:** fires in machinery spaces can spread quickly through the ship, especially if fire suppression systems are inadequate; this can ignite hazardous materials stored in cargo holds.
- **Engine Room Damage:** a fire in the engine room can result in the destruction of critical machinery, crippling the vessel's operational capacity and potentially causing it to lose power or steerage.
- **Explosion Risk:** leaking fuel, gas, or chemicals in the engine room can lead to explosions, further intensifying the fire.

INDIRECT CONSEQUENCES:

- **Crew Safety Risks:** fires in the engine room or machinery spaces pose significant risks to crew members, including burns, smoke inhalation, and exposure to toxic gases.
- **Loss of Cargo:** fire damage to cargo, particularly hazardous materials, can result in contamination, economic losses, and environmental damage.
- **Environmental Pollution:** explosions or fires resulting from fuel spills can pollute the surrounding marine environment.
- **Extended Operational Delays:** the vessel may require significant repairs, leading to long periods out of service and disruption to the shipping schedule.

Effectiveness of Preventing Actions

ROUTINE MAINTENANCE AND INSPECTIONS:

- Regular servicing of engine room machinery and systems to prevent wear and tear. This includes checking cooling systems, fuel lines, electrical components, and exhaust systems for potential failures.
- Effectiveness: high, as consistent maintenance directly addresses the primary causes of mechanical failures.

MONITORING AND EARLY DETECTION SYSTEMS:

- Implementing real-time monitoring systems to detect overheating, fuel leaks, and electrical faults before they escalate into fires.
- Effectiveness: high, especially when integrated with automated shutdown or warning systems.

FIRE-RESISTANT MATERIALS:

- Using fire-resistant materials for components in the engine room, including fuel lines, electrical wiring, and insulation, to minimize the risk of ignition.
- Effectiveness: moderate to high, as it helps contain fires and prevent rapid spread.

PREVENTIVE TRAINING FOR CREW:

- Ensuring the crew is trained in identifying early warning signs of mechanical failure and how to prevent such failures from escalating into fires.
- Effectiveness: moderate to high, as well-trained crews can take early **action to** mitigate risks.

Improved Ventilation Systems:

- Installing and maintaining proper ventilation systems in the engine room to dissipate heat and prevent the buildup of combustible gases.
- Effectiveness: high, as overheating is one of the leading causes of fires in machinery spaces.

Effectiveness of Mitigating Actions

Fire Suppression Systems:

- Installing and maintaining robust fire suppression systems, such as CO2 or foam systems, in the engine room to quickly extinguish fires and prevent spread.
- Effectiveness: high, especially if regularly tested and maintained.

Fire Containment Barriers:

- Implementing fire-resistant barriers within the engine room and machinery spaces to prevent fires from spreading to other areas of the ship.
- Effectiveness: High, as it isolates the source of fire and buys time for firefighting efforts.

Emergency Response Protocols:

- Establishing clear, efficient emergency procedures to be followed in the event of a fire in machinery spaces, including evacuation routes, use of firefighting equipment, and communication protocols.
- Effectiveness: high, provided the crew is well-drilled in responding quickly to emergencies.

Automated Shutoff Systems:

- Installing automatic shutoff systems for fuel lines, ventilation fans, and electrical circuits in case of fire, to minimize fire spread and control the ignition source.
- Effectiveness: high, as this can prevent the escalation of a fire by removing the fuel or ignition source.

Summary

Mechanical failures in ship systems, especially in engine rooms, represent a major fire hazard, with the potential to cause extensive damage to the vessel, cargo, and the environment. Preventive measures, such as regular maintenance, early detection systems, and fire-resistant materials, are essential for reducing the likelihood of these failures. Mitigation actions, including effective fire suppression systems, fire containment barriers, and crew training, are critical for minimizing the impact of fires that do occur.

A proactive approach that emphasizes regular maintenance, continuous monitoring, and comprehensive emergency preparedness is essential to preventing fires and ensuring the safety of both the crew and the vessel.

9.7 EXTERNAL FACTORS SUCH AS COLLISIONS AND STRANDLINGS, 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 short circuits in electrical systems.

Sources

External factors that can contribute to fires on container ships are typically related to unforeseen events or malicious acts:

- **Collisions:** crashes with other ships, floating objects, or structures like docks can cause damage to the hull, cargo holds, or engine rooms. This damage can result in heat development, electrical short circuits, or fuel leaks, leading to fire.
- **Strandings:** a ship running aground or getting stranded in shallow waters can result in structural damage. The impact or prolonged strain may cause fuel lines to rupture or electrical systems to fail, potentially igniting a fire.
- **Piracy and Armed Attacks:** various forms of armed attacks, such as hijacking or sabotage, can cause physical damage to the ship, cargo, or critical systems; deliberate acts like setting fire to the vessel or cargo could cause catastrophic damage.
- **Deliberate Arson:** intentional setting of fires, either as part of an attack or for malicious purposes, can cause serious incidents that could involve arson in cargo holds or engine rooms, especially when dangerous materials are involved.

Likelihood

The likelihood of fires due to external factors such as collisions, piracy, and arson is relatively low but significant due to the following reasons:

- **Collisions and Strandings:** while collisions and strandings are uncommon, they still occur, especially in busy shipping routes or bad weather conditions. Shipping accidents can damage critical infrastructure, increasing the chances of fires.
- **Piracy:** though relatively rare, it remains a threat in certain regions, such as the Gulf of Aden or Southeast Asia; attacks on ships can lead to fires, especially if the assailants target vulnerable areas like the engine room or cargo holds.
- **Deliberate Arson:** the likelihood of deliberate arson is lower but still a concern, particularly in high-risk regions or for ships carrying high-value cargo; criminals may target ships for insurance fraud or as part of an ideological or political attack.

Uncertainties

- **Piracy Trends:** the frequency and impact of piracy attacks are difficult to predict, as they fluctuate based on geopolitical factors, shipping routes, and regional security conditions.
- **Collision Severity:** the severity of a collision and its potential to cause a fire depends on many factors, including the size of the ships involved, the location of the collision, and the ship's cargo.
- **Arson Motivation:** the likelihood of deliberate arson may fluctuate based on criminal activity trends and the specific cargo transported.

Consequences

The consequences of fires resulting from external factors can be severe, especially if the fire spreads to critical systems or hazardous cargo:

DIRECT CONSEQUENCES:

- **Damage to Ship Infrastructure:** collisions or armed attacks can cause hull breaches, ruptured fuel lines, or electrical short circuits, leading to fire outbreaks.
- **Explosion Risks:** fuel leaks or the ignition of flammable cargo after a collision or attack can lead to explosions, causing rapid escalation of fires.
- **Loss of Cargo:** damaged or destroyed cargo, particularly hazardous goods, can lead to environmental contamination or a loss of value.
- **Crew Injury or Fatalities:** collisions, strandings, or attacks may cause injuries or fatalities among the crew due to fire, explosion, or physical trauma.
- **Ship Loss or Severe Damage:** in extreme cases, a fire triggered by external factors could lead to the total loss of the ship, especially if the fire spreads uncontrollably and the crew cannot extinguish it.

INDIRECT CONSEQUENCES:

- **Environmental Pollution:** Fires involving hazardous materials, such as chemicals or fuel, can result in environmental damage from spills and smoke.

- **Disruption to Trade Routes:** A ship accident or fire can block key trade routes, causing delays in global supply chains.
- **Reputation Damage:** Shipping companies involved in such incidents may face reputational damage, impacting their market share and future contracts.
- **Legal and Financial Consequences:** Legal action or penalties may result from the failure to prevent or respond to external threats, including claims for environmental damages or compensation for cargo loss.

Effectiveness of Preventing Actions

Navigational Risk Management:

- Implementing advanced navigational systems (e.g., GPS, radar, and AIS) to avoid collisions and identify potential hazards early.
- Effectiveness: high, as modern navigation systems can provide real-time data to help avoid dangerous situations.

Piracy Risk Management:

- Employing security teams, employing maritime escorts, and using anti-piracy technologies (e.g., water cannons, barbed wire) in high-risk regions.
- Effectiveness: moderate to High, depending on the region and the ship's security measures.

Ship Design and Maintenance:

- Designing ships with collision-resistant features, including reinforced hulls and compartmentalized sections, and regularly inspecting for vulnerabilities.
- Effectiveness: moderate, as stronger and well-maintained ships are less likely to suffer catastrophic damage in collisions.

Arson Prevention Measures:

- Installing fireproof doors, locks, and access control systems in sensitive areas like cargo holds, engine rooms, and storage spaces.
- Effectiveness: moderate, as physical security and restricted access can reduce the risk of intentional fire setting.

Effectiveness of Mitigating Actions

Fire Suppression Systems:

- Ensuring ships are equipped with advanced fire suppression systems (e.g., CO_2, foam, or water mist) in all high-risk areas, such as engine rooms and cargo holds.

- Effectiveness: High, especially when the systems are regularly maintained and tested.

EMERGENCY RESPONSE PROTOCOLS:

- Developing comprehensive emergency response plans for collision or attack scenarios, including clear evacuation procedures and crew training in firefighting.
- Effectiveness: High, provided the crew is well-prepared for such events.

INSURANCE AND CRISIS MANAGEMENT PLANS:

- Ensuring the ship is fully insured for risks related to piracy, arson, or collision and that a crisis management plan is in place for quick response and recovery.
- Effectiveness: Moderate to High, as this helps ensure financial recovery and quick incident resolution.

REAL-TIME MONITORING AND COMMUNICATION:

- Installing real-time tracking and communication systems allow the ship to alert authorities or nearby vessels in the event of a collision, attack, or fire.
- Effectiveness: High, as timely communication can facilitate faster emergency response.

Summary

External factors, such as collisions, strandings, piracy, and deliberate arson, present significant fire risks to container ships. Although these events are less frequent, their consequences can be catastrophic, especially when fires spread to critical systems or hazardous cargo. Preventive actions like advanced navigation, anti-piracy measures, and ship design improvements can help reduce the likelihood of these external factors leading to fires. Mitigation strategies, including robust fire suppression systems, emergency procedures, and real-time communication, are crucial to minimizing the impact of such incidents.

By addressing these external threats proactively, shipping companies can enhance the safety of their vessels and minimize the risk of fire-related incidents caused by unforeseen or malicious events.

9.8 REGARDING HUMAN ERROR AND INADEQUATE TRAINING

Mistakes regarding the stowage of containers are due to human errors, inadequate training and falsely declared cargo. Containers having goods with a low flashpoint accidentally stowed on the top row on deck might cause a fire since temperatures inside a container in direct sunlight might rise up to 55°C.

Sources

Human errors in the stowage of containers can significantly increase the risk of fire, especially when coupled with inadequate training and misdeclared cargo:

- **Incorrect Stowage of Containers:** If containers with hazardous materials (such as goods with low flashpoints) are stowed improperly, especially in top-tier positions on deck, they can become vulnerable to heat buildup; the temperature inside these containers can rise rapidly, particularly under direct sunlight, potentially reaching up to 55°C or more and this heat can cause self-ignition or worsen existing fires,
- **Misdeclared or Undeclared Cargo:** Incorrect cargo declarations, where dangerous goods are not properly disclosed or classified, can lead to improper stowage or inadequate safety precautions; this increases the chances of hazardous cargo being placed in inappropriate locations,
- **Inadequate Crew Training:** If crew members are not sufficiently trained in the handling and storage of hazardous materials or the identification of risky cargo, they may unknowingly make errors that could lead to fire risks,
- **Failure to Follow Safety Protocols:** without proper training, crew members may fail to follow established safety procedures for securing containers or properly assessing the potential risks associated with certain cargo types,

Likelihood

The likelihood of fires resulting from human error and inadequate training is significant, as several factors contribute to it:

- **Human Error:** despite technological advancements, human errors remain a key cause of incidents in the maritime industry. Inexperienced or poorly trained crew members may make critical mistakes during stowage, especially when under pressure or when working with hazardous materials.
- **Inadequate Training:** if training programs are insufficient or not regularly updated, crew members may lack knowledge of best practices for fire prevention and cargo handling; this can lead to errors in stowage or failure to recognize hazardous cargo.
- **Misdeclared Cargo:** the frequency of misdeclared cargo is higher than often realized. Incorrect declarations, whether intentional or accidental, can lead to improperly managed hazardous materials, increasing fire risk.
- **Lack of Clear Guidelines or Procedures:** the absence of clear stowage guidelines, particularly for hazardous goods, can result in improperly secured containers or improper placement in the cargo hold.

UNCERTAINTIES

- **Training Quality:** the effectiveness of crew training programs can vary significantly between shipping companies, making it difficult to estimate the actual risk.

- **Cargo Declaration Accuracy:** while cargo declarations are generally regulated, the possibility of misdeclarations or deliberate falsification can still occur, leading to uncertainty in the actual nature of the cargo being carried.
- **Stowage Procedures:** the complexity of modern container ships, with different levels of storage and various cargo types, can make the correct stowage challenging, especially in emergency or high-stress situations.

Consequences

Fires resulting from human error or inadequate training can have serious consequences:

Direct Consequences:

- **Container Ignition:** if a container with low flashpoint materials is improperly stowed on top of the deck and exposed to high temperatures, the risk of ignition becomes significant; this could lead to a fire in the container that might spread to others, especially if they are stacked near hazardous goods.
- **Spread of Fire to Cargo Holds:** a fire caused by incorrect stowage can quickly spread to adjacent containers or even to cargo holds, depending on the nature of the goods involved.
- **Ship Infrastructure Damage:** the damage caused by fire to ship infrastructure can be severe, especially if critical systems (like ventilation or fire suppression) are affected.
- **Loss of Cargo:** the goods in the affected containers may be destroyed, and hazardous materials may pose risks of contamination or environmental damage.

Indirect Consequences:

- **Environmental Contamination:** if hazardous materials like chemicals or oils are involved in the fire, they could leak and pollute the surrounding marine environment.
- **Injuries to Crew:** the risk of injury or death among the crew is heightened if they are not adequately trained to handle fire emergencies or recognize the signs of an impending fire.
- **Operational Delays:** fire-related damage can result in significant delays as the ship may need to be diverted for repairs, investigation, or to deal with cargo loss.
- **Legal and Financial Repercussions:** shipping companies may face legal actions and financial penalties due to improper stowage or misdeclared cargo.

Effectiveness of Preventing Actions

Comprehensive Crew Training:

- Regular and thorough training is needed to identify hazardous materials, proper stowage practices, and the importance of accurate cargo declarations. Crew should also be educated on the risks associated with temperature-sensitive cargo.
- Effectiveness: high, as well-trained crew members are more likely to follow safety procedures and recognize hazardous situations before they escalate.

Cargo Declaration Verification:

- Implement stricter checks and verification systems to ensure that all cargo is accurately declared and classified according to international regulations. This can be done through technology (such as scanning systems) or by having dedicated personnel responsible for verifying cargo details.
- Effectiveness: high, as correct declarations are essential for proper handling and stowage.

Clear Stowage Guidelines:

- Developing and enforcing clear guidelines and regulations for stowing hazardous materials, particularly those that may be heat-sensitive, to ensure they are placed in safe locations.
- Effectiveness: moderate to High, as precise guidelines help minimize the risk of human error and improper stowage.

Regular Audits and Inspections:

- Conducting regular audits and inspections to ensure compliance with stowage procedures and the proper handling of hazardous materials.
- Effectiveness: mModerate, as audits help identify potential gaps in procedures or training before they lead o an incident.

Effectiveness of Mitigating Actions

Fire Detection and Suppression Systems:

- Installing robust fire detection and suppression systems in high-risk areas, such as cargo holds and deck storage, to identify and control fires quickly.
- Effectiveness: high, as early detection and suppression can prevent fires from spreading and causing extensive damage.

Cargo Temperature Monitoring:

- Implementing temperature sensors and alarms in containers that are carrying sensitive or low flashpoint cargo, particularly those on deck exposed to sunlight.
- Effectiveness: high, as it allows for proactive intervention if temperatures reach dangerous levels.

Emergency Response Drills:

- Ensuring that the crew regularly participates in fire emergency drills to improve reaction times and ensure they are familiar with fire safety protocols.

- Effectiveness: high, as regular drills can prepare the crew to respond effectively to a fire emergency.

Access Control and Container Inspection:

- Limiting access to stowage areas and ensuring that containers are checked for compliance with safety standards, especially for hazardous materials.
- Effectiveness: moderate to High, as regular inspections can identify potential issues before they result in a fire.

Summary

Human errors and inadequate training are key contributors to the risk of fires on container ships, particularly when it comes to improper stowage and misdeclared cargo. These factors increase the likelihood of hazardous materials being exposed to unsafe conditions, such as excessive heat, which can lead to self-ignition or the rapid spread of fire. Preventive measures, such as comprehensive crew training, accurate cargo declaration verification, and clear stowage guidelines, can significantly reduce the risk of such incidents.

In addition, effective mitigation measures, including fire detection systems, temperature monitoring, and emergency response drills, are crucial to minimizing the impact of fires when they occur. By proactively addressing these risks, shipping companies can ensure safer operations and protect both the crew and cargo from fire-related hazards.

10 RISK TREATMENT STRATEGIES AND METHODS IMPORTABLE FROM AVIATION SAFETY MANAGEMENT

The aviation sector is commonly considered to ensure the highest safety level compared to other transport branches. Therefore, it has been considered useful to review existing safety strategies and methods applied in aviation regarding their applicability and relevancy to the maritime sector.

Misdeclared or undeclared dangerous goods

Both sectors have similar measures aimed at reducing the hazard of misdeclared or undeclared dangerous goods. They can be classified as follows:

- **Training and Education**. To ensure that personnel involved in the shipping processes are properly trained and aware of the regulations for handling dangerous goods. This includes recognizing hazardous materials and understanding the proper documentation and labelling requirements [49]. In aviation, the rules are set by Aviation Authorities and safety organizations (e.g., European Union Aviation Safety Agency (EASA), Federal Aviation Administration (FAA), International Civil Aviation Organization (ICAO)). In maritime transport, it is covered by the International Maritime Dangerous Goods (IMDG) Code [50].
- **Strict Regulations and Compliance.** Adhering to international regulations, such as the International Air Transport Association (IATA), Dangerous Goods Regulations (DGR) and the International Civil Aviation Organization (ICAO), Technical Instructions in aviation and the IMDG Code. These are part of the International Convention for the Safety of Life at Sea (SOLAS) and the International Convention for the Prevention of Pollution from Ships (MARPOL) in maritime sector. Both regulations provide detailed guidelines on the classification, packaging, marking, labelling, and documentation of dangerous goods [51].
- **Inspection and Enforcement.** Regular inspections and audits by regulatory authorities to ensure compliance with dangerous goods regulations. This includes checking for proper documentation, labelling, and packaging of shipments [52] (FAA/ICAO),
- **Use of Technology.** Implementing advanced screening technologies and automated systems to detect undeclared or misdeclared dangerous goods. This can include X-ray machines, chemical sniffers, and other detection tools in both sectors.
- **Accurate and complete information** in shipping documents in both domains.
- **Penalties and Consequences** for non-compliance with dangerous goods regulations (e.g., loss of privileges/licence to transport dangerous goods).

Superficial comparative analysis indicates on lack of differences in approach to measures addressing hazards related to misdeclared or undeclared dangerous goods in aviation and maritime transport sectors.

Therefore, possible conclusions based on aviation best practices can be the following: Inadequate measures in terms of their effectiveness. Possible strategies to mitigate the risk should focus on strengthening and sealing the barriers set by established measures. Nevertheless, identification of the best strategy (from economic and organizational points of view) to mitigate the risk requires looking into severity (partially) addressed in the next point.

Declared dangerous goods: self-ignition of batteries

Self-ignition of batteries is very dangerous and demanding phenomenon and can occur in various conditions and situations, which are not limited to shipping processes. Therefore, it can be expected to be addressed primarily by producers and technology providers. The situation slightly changes when conditions specific to transportation (e.g., changing pressure, temperature, humidity) can be identified as factors contributing to ignition-related risk.

Equally, aviation and maritime transport measures applied with regard to the risk of self-ignition of batteries are distributed throughout the whole possible event sequence addressing both preventing and reactive mitigations. Nevertheless, differences exist and are hereby highlighted.

- **Regulations and Guidelines.** IATA and ICAO provides regulations in aviation. In maritime there are IMDG Code covering the transport requirements and SOLAS and MARPOL addressing accordingly safety of life at sea and prevention of pollution from ships. In both industries regulations cover classifications, packaging, labelling, and documentation requirements to ensure safety. Additionally, according to the new regulations in aviation, batteries must undergo rigorous performance testing to verify their safety before being transported by air [53].
- **Packaging and Handling**. In Aviation transport, lithium batteries must be packaged to prevent short cuts and protect them from physical damage, as well as to reduce the risk of causing a post-crash fire. This includes strong outer packaging and insulating materials. Additionally, there is often limit the state of charge of lithium-ion batteries to reduce the risk of thermal runaway. Maritime transport regulators implemented similar requirements concerning protection against physical damage and short circuits [54] extended with segregation and stowage of lithium batteries, often stored in designated areas with appropriate fire suppression systems. The requirements can significantly differ due to the character of transport mode. In maritime transport, batteries often means electric cars, big devices, or large quantities of small lithium batteries, while in aviation, the focus is more on portable devices like laptops, smartphones, and drones. Although the risks can be critical in both sectors, the energy stored in maritime transport containers is often incomparable higher. This difference as well as the fact that ships usually can offer much more space and resources to manage this risk, make the high level comparative analysis pointless. Thorough, insightful and detailed analysis is necessary to identify specified conditions of these events and then design dedicated and tailored safety barriers to them.

- **Fire Suppression Systems**. Aircraft cargo holds are equipped with advanced fire suppression systems designed to handle fires involving lithium batteries. These systems can detect and suppress fires quickly to prevent them from spreading (e.g. sensitive smoke and heat detectors, effective agents, Halon 1301, automated response) [55]. Limited space in aircraft as well as immediate catastrophic results of fire inflight are main determinants behind the application of such means and methods. Vessels and container ships represent far more possibilities about using high-efficiency suppression methods like fixed fire suppression systems, such as CO_2, foam, Halon, or water mist systems, to handle fires involving lithium batteries [55]. Additionally, crew members are trained to use portable firefighting equipment specifically designed for lithium battery fires. Nevertheless, despite the more resources available, the self-ignition of batteries on ships is still a challenge due to demanding and complex process of extinguishing such fire. The methods and the strategies used in aviation with regard to fire suppression are seen inadequate or at least not optimal for specific of maritime transportation. Mostly due to difference in size of aircraft and ship as well as time for reaction, often shorter in aviation, but also due to the size of object in fire which in case of maritime transport is of container size rather than laptop battery. Possible strategies to mitigate the risk should focus on strengthening and sealing the barriers set by established measures.
- **Training and Awareness.** They can be considered as additional safety barriers or measures. Equally important in both sectors. In aviation personnel involved in the transport of lithium batteries receive specialized training on handling and emergency procedures, which follows guidelines about the latest safety practices and risks issued by regulatory bodies [54]. In maritime transport, besides trainings on the risks associated with lithium batteries and the procedures for handling and responding to fires, regular safety drills are conducted to ensure that crew members are prepared to respond to emergencies involving lithium batteries. In contrast to the aviation, vessels enable much more opportunities regarding reactive activities, which seems to be explored with shifting effort towards safety drills.

Electrical failures in reefer containers

Aviation and maritime transport mode are different therefore it must be kept in mind that in both safety measures address unique challenges and requirements contributing to equally the safe and efficient operation of reefer containers. Despite the differences, the criticality of the new identified risks may lead to an expansion of the set of similarities, thus contributing to the increased potential of using aviation solutions in maritime transport.

- First of all, aviation systems are designed for pressure and temperature changes, while maritime systems are built to withstand moisture, saltwater, and constant motion.
- One of the aviation sector's key specifics is that main effort needs to be allocated to prevention and addressing risks before they occur. Especially when it comes to fire. Maritime transportation

enables a more flexible approach leading to a more balanced distribution of effort among both preventive and reactive measures. As result, the required quality of components and related processes in aviation is higher than in maritime transport. It concerns pre-flight Inspections, scheduled maintenance as well as high-quality components (use of aviation-grade electrical components) and supplier audits ensuring compliance with standards. This area can be considered as having some room for improvements, nevertheless requiring long-term implementation of all necessary sector-wide regulations.

- Focus on prevention result from very limited means to react in case of fire aboard. Potentially catastrophic and immediate effects of fire imply the needs for efficient monitoring and diagnostics. Aviation relies on advanced real-time monitoring and remote diagnostics, while maritime focuses on robust, redundant systems and environmental protection. Real-time tracking of electrical parameters and especially remote diagnostics solutions enabling Immediate detection and resolution of issues represents some potential to mitigate reefer containers risks in maritime sector.
- Both sectors emphasize training, but aviation includes specific pre-flight inspections and emergency procedures, while maritime includes safety drills and protocols for harsh environments. Here the differences seem to reflect the nature of both modes including effective exploitation of unique opportunities and mitigation of specific constraints.

Cargo shifting and poor stowage

The risk generated by cargo shifting can be different in aviation and maritime transport. In aviation, it is crucial to assure a predefined stationary position of the load during flight. In maritime transport cargo shifting itself does not generate a risk but can lead to significant financial loss or be a precursor for dangerous damages leading to e.g. fire. Both cases require robust solutions preventing cargo movement and proper weight distribution.

- **Proper Loading Techniques**. In aviation high precision with regard to weight distribution is required for aircraft balance and stability. Therefore, the securing devices (nets, straps, and others to prevent cargo from shifting during flight) must be reliable and play very important role. In maritime transport, single movement itself does not lead to risk nevertheless it can trigger a chain reaction potentially dangerous as a result. Therefore, proper stowage reducing the uncontrolled large-scale cargo movement is very important and secured by similar means relevant in scale and performance, lashing and securing using ropes, chains, straps, and tensioning devices to secure cargo. Additionally, aircraft are equipped with an advanced monitoring system that tracks cargo conditions in real-time and detects any movement. The system is complemented with alerts warning crew about cargo shifts or changes in weight balance. More precise information about the location of centre of gravity of single container together with sensors detecting change and aggregated to the level of vessel would be considered solutions inspired by aviation technologies and seen as contributing to improving safety in maritime transportation.

- **Both sectors are regulated and supported by Safety Management Systems.** In aviation there are the IATA Guidelines for cargo stowage and securing and Safety Management Systems (SMS); to address risks associated with cargo transport holistically. In maritime, there is the IMDG Code. Adhering to the International Maritime Dangerous Goods (IMDG) Code for safe transport of hazardous materials and the Cargo Stowage and Securing (CSS) Code for general cargo. Similarly, as in case of other risk, more detailed and demanding regulation can be considered as assuring safety level, but it must be preceded with thorough and detailed analysis of the reasoning of accidents. Otherwise, agreed measures will be considered as not optimized, unjustified and leading to an unnecessary cost increase.
- Further important measures addressing cargo shifting risks are trainings and procedures, comprehensively addressed in both sectors, as mentioned above. Evaluation of level of adequacy as well as identification of areas where there is room for improvement with regard to cargo shifting risks in maritime transport would require data on performances/effectiveness of accident-related actions realized by crew.

Human error and inadequate training

Key differences need to be highlighted first. In aviation, crew is limited to pilots (predominantly two). They are responsible for all activities related to piloting and mitigating risks aboard. Vessels crew is often larger resulting with different and better task distribution strategy enabling separation of risk mitigation and vessels operation tasks which can be delegated to different crew members. In both sectors measures tailored on elimination of human errors are similar.

- **Training Programs:** in aviation emphasis is set on Crew Resource Management (CRM) and advanced flight simulators. Similarly in maritime the focus is on Bridge Resource Management (BRM) and ship simulators.
- **Fatigue Management**: in aviation there are regulated rest periods and fatigue monitoring for pilots. In maritime, Rest period regulations and fatigue monitoring for crew members are also present [9].
- **Competency-Based Training**. In aviation there is the Competency-Based Training and Assessment (CBTA), with a focus on pilot proficiency while in maritime similar CBTA approach for crew members, ensuring proficiency in key skills including, e.g. firefighting.
- **Safety Management Systems**. In aviation there is a proactive safety culture and non-punitive reporting systems, which is also implemented in maritime: SMS approach, encouraging proactive safety and reporting.

Very similar measures are implemented in both sectors. Indication on good practices or solutions applied in aviation that can be considered as promising and helpful in maritime should be evaluated with regard to very concrete detailed cases.

Mechanical failures in ship systems

Every aircraft component is included in the certification and maintenance system, assuring meeting of high quality and reliability in specific environmental conditions. Accidents history indicated that various components can contribute to catastrophic consequences in case of failure, not necessarily related to given component. As an example, fire resistance requirements imposed on everything aboard of aircraft can be provided. In maritime transport certification requirements are imposed on critical ship systems (engine, deck, etc.). Key measures and differences identified as addressing technical failures in aviation and maritime transport are reported below.

- **Monitoring Systems.** In aviation, real-time monitoring and advanced predictive maintenance technologies are implemented while in maritime focus is set on specific condition monitoring and vibration analysis.
- **Component Quality.** In aviation, high quality control standards during manufacturing confirmed with certificate. Certification process covering entire aviation system and almost entire product lifecycle. In maritime, marine-grade components are used that are resistant to corrosion. Quality requirement differentiated with regard to safety-criticality of component.
- **Training and Procedures.** In aviation, an emphasis set on pre-flight inspections and emergency protocols, while in maritime focus is set on routine inspections, safety drills, and handling harsh environments.
- Similarly, considerations on the possibility of applying aviation safety solutions require focus on details and consequent addressing concrete factors identified as reasons of accidents.

External factors such as collisions and stranding, piracy and deliberate arson

The set of external factors is very broad in comprises total aviation system, all its components as well as security aspects, which play equally important role as safety aspects. When it comes to traffic and routing aspects, the safety measures reported below are implemented in aviation and maritime traffic. They are considered as adequate to mode specific.

- **Traffic Management Systems.** Aviation relies on ATC systems, NextGen technologies, and TMIs to manage air traffic flow. Maritime utilizes ships' routing systems, VTS, and electronic navigation systems to manage vessel traffic.
- **Navigation and Communication.** Aviation focuses on performance-based navigation and data communication systems. Maritime emphasizes AIS and ECDIS for real-time tracking and digital navigation.

- **Collaborative Decision Making.** Aviation involves collaborative decision making among stakeholders to optimize traffic flow. Maritime relies on VTS centres to monitor and provide navigational assistance.
- **Training and Procedures.** Aviation is based on continuous training for air traffic controllers and clear SOPs. Maritime can count on comprehensive crew training and implementation of SMS.

Due to significant differences in environment, the aviation and maritime operate solutions mitigating hazards needs to be tailored to the hazards and preceded with detailed reasoning analysis.

Piracy and occurrences, like deliberate arson, should be covered by security measures. Aviation transport system addressed this type of risk with sealing the airport. All human and any product traffic entering the airport is controlled against smuggling dangerous items. In the case of maritime transport as the mechanism is different, pirates attack ships while on cruise, the solutions implemented in aviation sector might be inadequate.

11 SCENARIOS IDENTIFICATION AND SAFETY RISK MANAGEMENT

Within Work Package 3, all participants agree to examine 8 well-defined scenarios that aim to identify and assess potential fire risks on ships. These scenarios have been developed to cover a range of possible causes and contributing factors, from human error and equipment failure to external factors and cargo-related hazards. The goal of analysing these scenarios is to gain a deeper understanding of the complexities involved in ship fires and develop effective strategies for mitigating these risks. The scenarios below have been selected for examination.

1. **Misdeclared or Undeclared Dangerous Goods.** Undeclared hazardous materials, such as chemicals and batteries, can cause fires if improperly handled.
   - **Scenario:** a container with undeclared hazardous cargo (flashpoint 55°C) is placed on the upper tier under direct sunlight during summer.
2. **Declared Dangerous Goods.** Continuous heating can cause self-ignition, particularly in lithium-ion batteries.
   - **Scenario:** a container with lithium batteries is exposed to direct sunlight on the upper tier during summer.
3. **Electrical Failures in Reefer Containers.** Faulty wiring or short cuts in refrigerated containers can ignite fires, often undetected due to their deep placement in cargo holds.
   - **Scenario:** a short circuit occurs in a reefer container generator**.**
4. **Cargo Shifting and Poor Stowage.** Improperly secured cargo can shift, damage packaging, and cause hazardous spills leading to fires.
   - **Scenario:** a cargo shift damages hazardous liquid packaging, causing a spill that ignites due to smoking in an unauthorized area.
5. **Human Error and Inadequate Training.** Crew errors and insufficient fire safety training can worsen fire risks.
   - **Scenario:** improperly secured cargo shifts, causing a hazardous spill ignited by an accidental smoke spark.
6. **Mechanical Failures in Ship Systems.** Fires in engine rooms can spread rapidly, especially if fire suppression systems fail.
   - **Scenario:** a short circuit in the engine room power supply leads to a fire**.**
7. **External Factors (Collisions, Piracy, Arson).** External risks like collisions or deliberate attacks can cause fires.

- **Scenario:** a collision damages a container with flammable cargo, leading to ignition.

8. **Human Errors in Stowage.** Improper placement of hazardous cargo in hot conditions can increase fire risks.

    - **Scenario:** in summer, a container with hazardous cargo (flashpoint 55°C) is placed on the upper tier under direct sunlight .

11.1 SPANISH USE CASE

11.1.1 Description of the Spanish case (Sagunto)

The exercise will take place at the Intersagunto terminal (Port of Sagunto), in a real operating environment with a container vessel alongside and unloading. The incident focuses on a fire inside a refrigerated (reefer) container located on the quay (not on board), with potential spread to adjacent containers containing lithium-ion batteries, which increases severity due to possible thermal runaway and toxic emissions. The initial response is coordinated by Valencia Firefighters, the Port Authority of Valencia (APV), the Harbor Master, and the ship's crew, integrating OVERHEAT technologies for early detection, thermal tracking, and decision support (thermal-camera UAS and IoT sensors). This setup reflects the design of the Spanish UC and the specified use of drones and sensors for the pilot.

A safety perimeter will be established around the reefer area, segregating the terminal tractor (UTR) manoeuvring zone and the nearest STS gantry crane, while maintaining minimum vessel operations when safety allows. Access corridors for emergency services and an Advanced Command Post (ACP), coordinated with the APV Control Centre, will be defined. The vessel will remain under restricted operations (partial discharge or temporary pause for the affected hold/bay line), according to dynamic risk assessment.

11.1.2 Identification of scenario-relevant hazards

- Electrical failure in reefer (short circuits, overload, poor maintenance).
- Nearby Li-ion batteries (potential thermal runaway due to continuous heating).
- Misdeclared hazardous goods in the vicinity (increase uncertainty of spread/consequences).
- Human error/insufficient training during operations and initial response.
- External factors (wind, thermal conditions on the quay) that worsen fire development

11.1.3 KPIs

Table 29 represents list of the relevant KPI's for the Spanish Use Case.

KPI	Definition	Unit
Time-to-detection	From event start to first valid alert	s

True Positive Rate	Correct alerts / total alerts	%
False Positive Rate	False alerts / total alerts	%
UAS Area Coverage	Covered area / planned area	%
Time-to-decision	From valid alert to operational decision (isolate/attack/segregate)	min
Comms Reliability	Packets/frames correctly received / sent	%
Latency sensor→DS	Average transit time of IoT data to DS	s
Safety incidents	Safety incidents during the exercise	Nº

Table 29. List of the relevant KPI's

11.1.4 Risk assessment (pre- and post-mitigation)

Scope & legend. Assessment for a quay-side reefer fire with a container vessel alongside.

- **Probability (P)**: 5 Frequent, 4 Occasional, 3 Remote, 2 Improbable, 1 Extremely improbable.
- **Severity (S):** A Catastrophic, B Hazardous, C Major, D Minor, E Negligible.

Goal (per T3.1): shift all critical hazards to ≤ 3C (Tolerable with controls).

PRE-MITIGATION

In Table 30 are presented pre mitigation assessment results.

Hazard	Baseline	Justification
Electrical failure in reefer	P4 × SC = 4C	Common initiator (wiring/overload); ignition inside unit; personnel & assets nearby.
Nearby Li-ion batteries (thermal runaway)	P4 × SB = 4B	Sustained heating can trigger runaway; toxic plume & rapid spread potential.
Misdeclared hazardous goods	P3 × SB = 3B	Uncertainty inflates worst-case response; unknown incompatibilities.
Human error / insufficient training	P4 × SC = 4C	High tempo operations; multi-actor comms; initial decisions prone to delay/omission.
External factors (wind / thermal conditions on quay)	P3 × SB = 3B	Wind can accelerate spread and plume; heat load raises ignition risk; UAS limits in gusts.

Table 30. Pre Mitigation assessment results

POST-MITIGATION

In Table 31 are presented pre mitigation assessment results.

Hazard	Residual	Justification

Electrical failure in reefer	**P3 × SC = 3C**	Early detection + faster isolation reduce likelihood of escalation; consequence still Major until fully controlled.
Nearby Li-ion batteries (thermal runaway)	**P3 × SC = 3C**	Likelihood lowered by monitoring/segregation; severity down-rated to Major with effective containment & plume control.
Misdeclared hazardous goods	**P2 × SC = 2C**	Process controls and conservative cordons reduce exposure; some Major impact remains if incompatibility appears.
Human error / insufficient training	**P3 × SC = 3C**	Shared situational awareness + SOP discipline reduce decision latency and coordination errors.
External factors (wind / thermal conditions on quay)	**P2 × SC = 2C**	Environmental adaptation reduces hazard growth; residual Major due to possible operational constraints.

Table 31. Post mitigation assessment results

11.1.5 Comparison with safety criteria & goals

The Spanish Use Case results must be compared against the tolerability criteria and safety goals fixed in Task 3.1 to justify that risks are acceptable or tolerable with controls and to decide further treatment if not.

We apply the Likelihood (1–5) × Severity (A–E) matrix and export each rating to the tolerability table (Acceptable / Tolerable / Intolerable).

For each scenario-relevant hazard, we use the KPIs to evidence the shift from inherent (pre-mitigation) to residual (post-mitigation) risk when OVERHEAT controls (IoT, UAS, DS) are active.

Safety goals from T3.1 (operational translation):

- **Early detection & verification:** detect thermal anomalies fast enough to avoid escalation (demonstrated by reduced time-to-detection/decision).
- **Containment & consequence control:** prevent spread and limit exposure to people/assets (tracked via UAS coverage, cordon effectiveness, segregation decisions).
- **Procedural discipline & coordination:** use of common operational picture and SOPs to reduce human-factor errors and latency.
  These align with T3.1's mandate to set quantitative safety goals and a systematic process for assessing significance of risk and deciding treatment.

Acceptance/tolerability judgment.

- With OVERHEAT measures in place, all listed hazards move from **4B/4C** bands to ≤ **3C**, which is Tolerable with controls under the WP3 criteria. If any hazard remains Intolerable, immediate enhancement or suspension is required per the tolerability table.

Acceptance rule.

All hazards at ≤ 3C (Tolerable with controls) and no safety incidents during the exercise; otherwise, strengthen controls and re-assess.

11.2 FRANCH USE CASE

11.2.1 Description of the French case (Brest port)

The French scenario focuses on the **rescue component** of the overall “fire risk management” scenario addressed by the project.

The crew of the containership has detected fire on board, causing damage to the propulsion system. Extinguishing a fire in a container is a very specific exercise and one possible option is to puncture the container. To date, there are materials to deal with this problem, but it is important to target the nature of the goods and thus develop the right operational management to deal with the fire. The ship is located in the Atlantic / British Channel, an intense traffic area linking South and North Europe, as well as trans-Atlantic traffic. Fire on board always is critical. The vessel is close to the coast. Meteo and sea conditions are rough. Decision is taken to ask for assistance. The captain alerts the French surveillance agency in charge of the area: the Cross. The Cross station “Corsen” is the closest. It takes the communication with the captain. Currently, the 1st exchange between uses VHF (channel 16 sending the key words “may day may day may day”, adding the name of the vessel, its location, the nature of the accident). With this few verbal information, the CROSS must estimate the situation and coordinate the rescue, contacting concerned parties (the rescue vessel, the fire intervention teams and the PREMAR (regional maritime administration). Decision is taken to join the next port: Brest. Exchanges are now initiated with the captain of the port and the pilots. They define a ship rescue strategy, taking in consideration the local traffic, weathercast and sea conditions, hydrographic conditions (tides, water level, under keel clearance etc.) to estimate the best operational conditions including arrival time to take in charge the vessel in the port approach and area. Five teams are now involved: the captain and the crew, the Cross; the rescue vessel, the harbour master, the pilots and PREMAR which takes in charge the overall coordination. The scenario ends when the vessel is at the quay of destination.

11.2.2 Identification of scenario-relevant hazards

In this container-ship scenario, the main fire hazards tied to possible causes are cargo-related hazards (DG, self-heating, reactive, incompatible cargo)

- Incompatible or undeclared cargo stored together, leading to chemical reactions or heat buildup.
- Lithium-ion batteries or other damaged/poorly packed batteries (thermal runaway, fire spreading to adjacent containers).
- Flammable liquids and vapours from cargo or packaging.
- Vapours accumulating in holds or near cargo gear; ignition sources in or near the hold can trigger flash fires or explosions.
- Hot surfaces, overheated equipment, or electrical faults in engine rooms, switchboards, or reefer units igniting flammable vapours.
- Short circuits, insulation failures, or overheating in electrical systems and rigging near cargo spaces increasing ignition risk.
- Grain, flour, wood dust or other organic dust in holds can form explosive atmospheres if mixed with air and an ignition source is present.
- Human factors and operational risks contributing to ignition
- External factors (whether conditions like wind).

11.2.3 KPIs

Table 32 represents list of the relevant KPI’s for the French Use Case.

KPI	Definition	Unit
Time-to-detection	From event start to first valid alert	s
True Positive Rate	Correct alerts / total alerts	%
False Positive Rate	False alerts / total alerts	%
UAS Area Coverage	Covered area / planned area	%
Time-to-decision	From valid alert to operational decision (isolate/attack/segregate)	min
Comms Reliability	Packets/frames correctly received / sent	%
Latency sensor→DS	Average transit time of IoT data to DS	s
Safety incidents	Safety incidents during the exercise	Nº

Table 32. List of the relevant KPI’s

11.2.4 Risk assessment (pre- and post-mitigation)

Scope & legend. Assessment for a quay-side reefer fire with a container vessel alongside.

- **Probability (P)**: 5 Frequent, 4 Occasional, 3 Remote, 2 Improbable, 1 Extremely improbable.
- **Severity (S):** A Catastrophic, B Hazardous, C Major, D Minor, E Negligible.

Goal (per T3.1): shift all critical hazards to ≤ 3C (Tolerable with controls).

PRE-MITIGATION

In Table 33 are presented pre mitigation assessment results.

Hazard	Baseline	Justification
Lithium-ion batteries or other damaged/poorly packed batteries (thermal runaway, fire spreading to adjacent containers).	P4 × SB = 4B	Sustained heating can trigger runaway; toxic plume & rapid spread potential.
Incompatible or undeclared cargo stored together, leading to chemical reactions or heat buildup.	P3 × SB = 3B	Uncertainty inflates worst-case response; unknown incompatibilities.
Flammable liquids and vapours from cargo or packaging.	P4 × SA = 4A	The combination of ignition potential, rapid fire spread, and difficult firefighting, creates the potential for catastrophic consequences.
Vapours accumulating in holds or near cargo gear; ignition sources in or near the hold can trigger flash fires or explosions.	P3 × SC = 3C	If vapours are within ignition range, a flash fire or explosion can occur, with potentially catastrophic consequences for the ship, crew, and environment.
Hot surfaces, overheated equipment, or electrical faults in engine rooms, switchboards, or reefer units igniting flammable vapours.	P3 × SC = 3C	The enclosed, fuel-rich environment and the critical nature of the systems involved, could led to catastrophically consequence.
Short circuits, insulation failures, or overheating in electrical systems and rigging near cargo spaces increasing ignition risk	P4 × SC = 4C	Common initiator (wiring/overload); ignition inside unit; personnel & assets nearby.
Grain, flour, wood dust or other organic dust in holds can form explosive atmospheres if mixed with air and an ignition source is present.	P3 × SB = 3B	Organic dusts can form flammable dust clouds; under the right dispersion and concentration, a small ignition can trigger a deflagration or explosion.
Human factors and operational risks contributing to ignition	P4 × SC = 4C	High tempo operations; multi-actor comms; initial decisions prone to delay/omission.
External factors (wind / thermal conditions on quay)	P3 × SB = 3B	Wind can accelerate spread and plume; heat load raises ignition risk; UAS limits in gusts.

Table 33. Pre Mitigation assessment results

POST MITIGATION

In Table 34 are presented pre mitigation assessment results.

Hazard	RESIDUAL	Justification
Lithium-ion batteries or other damaged/poorly packed batteries (thermal runaway, fire spreading to adjacent containers).	P3 × SC = 3C	Likelihood lowered by monitoring/segregation; severity down-rated to Major with effective containment & plume control.
Incompatible or undeclared cargo stored together, leading to chemical reactions or heat buildup.	P2 × SC = 2C	Process controls and conservative cordons reduce exposure; some Major impact remains if incompatibility appears.
Flammable liquids and vapours from cargo or packaging.	P2 x SC = 2C	Proper packaging and segregation, effective container ventilation and gas detection where applicable, robust firefighting readiness for liquid fuels, prevention of leaks, active monitoring of hold conditions, and emergency response planning with explicit actions and drills.
Vapours accumulating in holds or near cargo gear; ignition sources in or near the hold can trigger flash fires or explosions.	P2 x SC = 2C	Control of all ignition sources near holds and cargo gear. Bond/ground to prevent static sparks. Prohibit hot work near cargo areas unless properly permitted and fire-watched. Use ventilation plans that minimize vapor accumulation.
Hot surfaces, overheated equipment, or electrical faults in engine rooms, switchboards, or reefer units igniting flammable vapours.	P2 x SC = 2C	Ensure proper bonding/earthing to minimize static discharge; control sparks from electrical devices. Adequate separation of potential ignition sources from flammable vapours.
Short circuits, insulation failures, or overheating in electrical systems and rigging near cargo spaces increasing ignition risk	P3 × SC = 3C	Early detection + faster isolation reduce likelihood of escalation; consequence still Major until fully controlled.
Grain, flour, wood dust or other organic dust in holds can form explosive atmospheres if mixed with air and an ignition source is present.	P2 x SC = 2C	Install fixed and portable dust/combustible gas detectors where feasible; monitor dust levels and VOCs around cargo gear and holds. Regularly inspect for dust build-up, damaged packaging, or leaks that could generate ignition sources
Human factors and operational risks contributing to ignition	P3 × SC = 3C	Shared situational awareness + SOP discipline reduce decision latency and coordination errors.
External factors (wind / thermal conditions on quay)	P2 × SC = 2C	Environmental adaptation reduces hazard growth; residual Major due to possible operational constraints.

Table 34. Post mitigation assessment results

11.2.5 Comparison with Task 3.1 safety criteria & goals

The French Use Case results must be compared against the tolerability criteria and safety goals fixed in Task 3.1 to justify that risks are acceptable or tolerable with controls and to decide further treatment if not.

We apply the Likelihood (1–5) × Severity (A–E) matrix and export each rating to the tolerability table (Acceptable / Tolerable / Intolerable).

For each scenario-relevant hazard, we use the KPIs to evidence the shift from inherent (pre-mitigation) to residual (post-mitigation) risk when OVERHEAT controls (IoT, UAS, DS) are active.

Safety goals from T3.1 (operational translation):

- **Early detection & verification:** detect thermal anomalies fast enough to avoid escalation (demonstrated by reduced time-to-detection/decision).
- **Containment & consequence control:** prevent spread and limit exposure to people/assets (tracked via UAS coverage, cordon effectiveness, segregation decisions).
- **Procedural discipline & coordination:** use of common operational picture and SOPs to reduce human-factor errors and latency.
  These align with T3.1's mandate to set quantitative safety goals and a systematic process for assessing significance of risk and deciding treatment.

Acceptance/tolerability judgment.

- With OVERHEAT measures in place, all listed hazards move from **4B/4C** bands to ≤ **3C**, which is Tolerable with controls under the WP3 criteria. If any hazard remains Intolerable, immediate enhancement or suspension is required per the tolerability table.

Acceptance rule.

All hazards at ≤ 3C (Tolerable with controls) and no safety incidents during the exercise; otherwise, strengthen controls and re-assess.

11.3 ITALIAN USE CASE

11.3.1 Description of the Italian Case (Genoa / IMAT Centre)

The Italian use case adopts a hybrid approach composed of a Real Time Simulation (RTS) and a Live Demonstration, designed to validate the safety and operational benefits of the OVERHEAT solution in maritime environments.

1. **Real Time Simulation (RTS):** Conducted at the IMAT training centre using the "Challenger" bridge simulator (360° visual field). The scenario simulates the Port of Genoa (Bettolo terminal) and "en-route" navigation phases. It involves containerships (Ship CAT A and CAT B) facing fire incidents on the weather deck. The objective is to test the effectiveness of collaborative systems (IoT sensors and UAS) for Early Warning and fire monitoring compared to current procedures (Baseline).
2. **Live Demonstration:** Conducted at the IMAT firefighting field using a real container equipped with IoT sensors and a controlled real fire.

Incident Scenario (Simulation & Demo):

The primary incident concerns the ignition of a fire within a container stowed on the weather deck.

In the "Baseline" scenario (current procedures), detection relies on visual observation by the crew and routine inspection rounds. These factors are heavily constrained by visibility, weather conditions, and the specific location of the container.

In the "Solution" scenario (OVERHEAT), IoT sensors detect the thermal anomaly and trigger an alarm. Subsequently, a UAS (Unmanned Aerial System) is deployed to confirm the alarm using AI algorithms and a temperature matrix, providing enhanced "Situational Awareness" to the bridge team and rescue squads.

The exercise draws upon the range of operational scenarios outlined in the Validation Plan. The associated risk management assessment is consequently guided by the specific objectives established for the Italian Use Case.

11.3.2 Identification of scenario-relevant hazards

The following main hazards have been identified which the OVERHEAT solution aims to mitigate:

1. **Late Detection:** In the absence of fixed sensors on the weather deck, the fire smoulders inside the container until it becomes externally visible (smoke/flames), making intervention difficult and increasing the risk of rapid development.
2. **Poor Situational Awareness (SA):** Difficulty for the Master and crew to precisely locate the fire source and understand the thermal spread due to smoke, visual obstacles, or the container's position within the stack (especially in VC2/Low Visibility conditions).
3. **Adverse Environmental Conditions:** Reduced visibility (fog/smoke) and wind accelerate propagation and impede traditional visual detection.

4. **Cognitive Overload (Human Workload):** Excessive workload for the bridge team in coordinating the emergency response with fragmentary information, leading to potential decision-making errors.

5. **False Alarms or Technological Failures:** The risk that IoT sensors or the UAS may malfunction or provide incorrect data (specifically tested during the Demonstration).

6. **Cargo Shifting and Loss:** Risks associated with poor stowage or securing, which can exacerbate fire scenarios or be triggered by them (a specific focus of the Italian UC regarding container loss prevention).

12.3.3 KPIs (Key Performance Indicators)

Table 35 represents list of the relevant KPI's for the Italian Use Case.

KPI	Definition	Unit
Time-to-detection	Time elapsed from the start of the event (ignition) to the first valid alarm received.	Minutes/Seconds
Accuracy of Thermal Matrix	Capability of the UAS/AI to correctly identify the hottest container compared to the surrounding area.	%
Situational Awareness (SA)	Subjective feedback from Masters regarding their understanding of the scenario (via post-run questionnaires).	Likert Scale
Time-to-decision	From valid alert to operational decision (isolate/attack/segregate)	min
Workload	Perception of the bridge team's workload (via post-run questionnaires).	Likert Scale
False Positive Rate	Number of false alarms generated by IoT sensors during the demonstration.	%
Sensor Reliability	Reliability of data transmission from IoT sensors to the Digital Solution (DS).	% packets received
UAS Area Coverage	Percentage of the target area successfully monitored by the UAS during the incident.	%

Table 35. List of the relevant KPI's

11.3.4 Risk assessment (pre- and post-mitigation)

Scope & legend. Assessment for a quay-side reefer fire with a container vessel alongside.

- **Probability (P)**: 5 Frequent, 4 Occasional, 3 Remote, 2 Improbable, 1 Extremely improbable.
- **Severity (S):** A Catastrophic, B Hazardous, C Major, D Minor, E Negligible.
- **Goal:** Reduce all critical hazards to ≤ 3C (Tolerable with controls).

PRE-MITIGATION

In Table 36 are presented pre mitigation assessment results.

Hazard	Baseline	Justification
Misdeclared hazardous goods	P3 × SB = 3B	Uncertainty inflates worst-case response; unknown incompatibilities.
Human error / insufficient training	P4 × SC = 4C	High tempo operations; multi-actor comms; initial decisions prone to delay/omission.
External factors (wind / thermal conditions on quay)	P3 × SB = 3B	Wind can accelerate spread and plume; heat load raises ignition risk; UAS limits in gusts.
Late Detection	P4 × SC = 4C	Without fixed sensors on the weather deck, detection is visual. Frequent delays lead to uncontrollable fires (rapid development).
Poor SA in Low Visibility	P4 × SB = 4C	Fog or dense smoke makes it impossible to locate the fire source from the bridge, increasing the risk of uncontrolled propagation.
Cognitive Overload (Workload)	P3 × SC = 3C	The team must manually gather information, communicate via radio, and navigate the ship. Medium-high risk of human error.
Propagation to Adjacent Containers	P3 × SB = 3C	Without a thermal matrix, it is difficult to determine which adjacent containers require boundary cooling.

Table 36. Pre Mitigation assessment results

POST-MITIGATION

The solution tested in the Italian use case is based to investigate the effectiveness of OVERHEAT key elements: IoT sensors and Unmanned Aerial Systems (UAS).

The IoT sensors are designed to analyse the gas parameters inside the container, detecting not only temperature but also examining the gas composition to identify the type of fuel involved in the combustion process. Once an incipient fire is detected, the sensors transmit the information to the digital solution, whose purpose is to channel data and information to create a virtual smart assistant for the teams involved in firefighting operations.

At the same time, the DS allows the deployment of a UAV to identify and monitor the fire. The collected information is then displayed within the DS, enabling early-stage fire detection from the moment of ignition, rapid identification of the initial outbreak, and continuous monitoring of the situation, also through thermal imaging. This ensures enhanced situational awareness and crew coordination even under low-visibility conditions, while reducing the stress experienced by the master, who can make decisions based on clear, reliable, and continuously available data.

In Table 37 are presented pre mitigation assessment results.

Hazard	Solution	Justification
Misdeclared hazardous goods	**P2 × SC = 2C**	The system can identify the specific type of fuel involved in the combustion process, thereby providing a clear framework for determining the most appropriate procedures for that fuel, even in cases where it has been incorrectly declared.
Human error / insufficient training	**P3 × SC = 3C**	Shared situational awareness, early detection and SOP discipline reduce decision latency and coordination errors.
External factors (wind / thermal conditions on quay)	**P2 × SC = 2C**	The use of container-mounted, maritime-calibrated sensors enables reliable identification of fire characteristics regardless of external conditions. In addition, the UAVs employed can detect ignition-induced hotspots even in high-temperature environments.
Late Detection	**P2 × SC = 2C**	IoT sensors immediately alert upon internal temperature rise, drastically reducing the probability of advanced fire development.
Poor SA in Low Visibility	**P2 × SC = 2C**	The UAS with a thermal camera provides a clear view even through fog/smoke, reducing the severity of decision-making uncertainty.
Cognitive Overload (Workload)	**P2 × SC = 2C**	Information is integrated into the Digital Solution; the Master makes decisions based on reliable data, reducing stress.
Propagation to Adjacent Containers	**P2 × SC = 2C**	The UAS thermal matrix identifies invisible hotspots, allowing for targeted cooling and preventing escalation.

Table 37. Post mitigation assessment results

11.3.5 Comparison with safety criteria & goals

The Italian Use Case results must be compared against the tolerability criteria and safety goals fixed in Task 3.1 to justify that risks are acceptable or tolerable with controls and to decide further treatment if not.

Applying the Likelihood (1–5) × Severity (A–E) matrix and export each rating to the tolerability table (Acceptable / Tolerable / Intolerable).

For each scenario-relevant hazard, the KPIs highlight the shift from inherent (pre-mitigation) to residual (post-mitigation) risk when OVERHEAT controls (IoT, UAS, DS) are active.

Safety goals from T3.1 (operational translation):

The expected results from the Italian Use Case demonstrate alignment with the safety objectives defined in Task 3.1:

- **Early detection & warning:** Detection of the fire before it becomes externally visible to provide an early warning to avoid escalation (demonstrated by reduced time-to-detection/decision).
- **Fire Monitoring & Situational Awareness:** Provide accurate data under adverse environmental conditions (as example Low Visibility)
- **Containment & consequence control:** prevent spread and limit exposure to people/assets (tracked via UAS coverage, cordon effectiveness, segregation decisions).
- **Procedural discipline & coordination:** use of common operational picture and SOPs to reduce human-factor errors and latency.
These align with T3.1's mandate to set quantitative safety goals and a systematic process for assessing significance of risk and deciding treatment.

Acceptance/tolerability judgment.

- With OVERHEAT measures in place, all listed hazards move from **4B/4C** bands to ≤ **3C**, which is Tolerable with controls under the WP3 criteria. If any hazard remains Intolerable, immediate enhancement or suspension is required per the tolerability table.

Acceptance rule.

All hazards at ≤ 3C (Tolerable with controls) and no safety incidents during the exercise; otherwise, strengthen controls and re-assess.

11.4 GERMAN USE CASE

Recent industry data indicate that cargo-related fire events at sea remain a persistent and escalating threat to maritime safety. Across the global container fleet, both the frequency and severity of cargo fires have shown an upward trajectory, particularly on larger vessels whose scale inherently magnifies the consequences of any onboard incident. Allianz's 2024/2025 safety reviews highlight fire and explosion as recurrent top incident categories, underscoring a systemic challenge that has not abated despite ongoing efforts in regulatory compliance, vessel design, and crew preparedness. The convergence of growing cargo volumes, increasingly complex supply chains, and difficulties in detecting undeclared or misdeclared dangerous goods (DG) amplify this risk landscape.

In response, the World Shipping Council's (WSC) Cargo Safety Program represents a significant structural evolution in industry practice. By introducing a shared AI-enabled screening layer – powered by NCB technologies – the program allows carriers to collectively scan millions of booking records for DG anomalies and route suspicious cases into harmonized inspection workflows. This marks an early example of *collective defence* in maritime cargo risk management: instead of each carrier independently attempting to identify hazardous bookings, the entire sector benefits from pooled intelligence and standardized alerting. The initiative demonstrates the tangible impact of leveraging digital tools and coordinated processes to reduce systemic vulnerabilities.

At the regulatory level, the EMSA CARGOSAFE study has already articulated a comprehensive set of risk-control options (RCOs) that span prevention, early detection, and onboard containment of cargo fires. These RCOs – subsequently advanced through submissions to the IMO Sub-Committee on Ship Systems and Equipment (SSE) – form a technically grounded and cost-effective roadmap for enhancing container ship fire safety. Together, they outline feasible improvements in cargo declaration integrity, stowage strategies, detection sensor architectures, boundary integrity, and firefighting capabilities. In other words, the analytical and regulatory foundation for meaningful safety enhancement is largely established.

Taken together, these developments highlight a critical juncture for maritime transport. Empirical evidence of worsening fire risk, emerging sector-wide digital screening mechanisms, and a well-developed suite of regulatory options collectively frame both the urgency and the opportunity for decisive action. The challenge now lies in translating these insights into coordinated, scalable, and enforceable measures across global liner shipping.

11.4.1 Prevent

<u>Mandate shared pre-load risk screening</u>

A significant proportion of fire incidents originate from misdeclared or undeclared dangerous goods, which result in inadequate stowage, handling, and firefighting preparedness. In response, the World Shipping Council (WSC) introduced the Cargo Safety Program (CSP) in 2025 as an industry-wide, cooperative framework aimed at mitigating the systemic causes of cargo-related fires through digital screening, standardized inspections, and cross-sectoral data sharing.

The principal objective of the CSP is to reduce the incidence of containerized cargo fires and hazardous incidents by identifying high-risk shipments prior to loading. The program seeks to achieve this by introducing a standardized cargo-screening infrastructure across the global shipping sector. The CSP does not alter the regulatory obligations of shippers under the International Maritime Dangerous Goods (IMDG) Code. Rather, it supplements existing conventions by introducing a data-driven, pre-emptive layer of risk control situated at the booking and inspection stages.

At the core of the CSP lies a real-time, AI-assisted cargo-screening system that evaluates all booking data for potential misdeclaration or concealment of dangerous goods. The tool mainly works with Keyword and pattern recognition, Trade-pattern anomaly detection and Machine learning-based risk scoring, to identify any hazardous or misdeclared goods.

By intercepting misdeclared dangerous goods prior to loading, the likelihood of onboard fires, explosions, and subsequent human or environmental losses is reduced.

Set high-risk cargo controls

Empirical analyses of maritime incident databases indicate that hazardous commodities such as lithium-ion batteries and charcoal are disproportionately represented in fire events due to their thermal instability and frequent misclassification under the International Maritime Dangerous Goods (IMDG) Code. To address these persistent risks, the Cargo Incident Notification System (CINS) has issued voluntary technical guidelines to standardize the carriage, declaration, and handling of these cargo types. Determine these measures across the shipping industry would represent a major step toward a consistent, science-based framework for cargo fire prevention.

Lithium-Ion Batteries

Lithium-ion cells and batteries (UN 3480, UN 3481) are prone to thermal runaway, which can escalate to venting, ignition, and explosion. CINS data and P&I club analyses identify multiple container fire events linked to undeclared Li-ion batteries, particularly where state-of-charge (SoC) exceeded safe transport thresholds (Loading >30 %) or where batteries were co-packed with incompatible goods.
Once ignited, the confined geometry of containerized stowage and limited accessibility of on-deck stacks make such fires extremely challenging to control.

Charcoal and Related Carbonized Products

Charcoal (UN 1361) and related pyrolyzed biomass cargoes exhibit self-heating and spontaneous combustion risks due to residual volatile compounds and incomplete oxidation during manufacture. The 2024 CINS Charcoal Carriage Guidelines reported at least 68 fire incidents between 2015 and 2022 involving misdeclared or improperly treated charcoal shipments.

While the IMDG Code provides a general framework for hazardous cargo management, it lacks cargo-specific process standards for certain commodities whose risk profiles evolve with technology or industrial practice. For example, IMDG requirements for lithium-ion batteries were formulated primarily for smaller-scale electronic batteries and do not fully account for high-capacity electric-vehicle (EV) modules. Similarly, exemptions under earlier IMDG amendments permitted charcoal shipments to be declared as non-dangerous under certain conditions – loopholes that were widely exploited.

The following aspects should be given when transporting this kind of dangerous goods:

- Transported battery should not exceed 30 % state of charge, minimizing residual chemical potential energy.
- Cells must be individually packaged in non-conductive materials, with spacing to prevent short circuits and thermal propagation. Containers should comply with Cargo Transport Unit (CTU) Code provisions.
- Li-ion batteries should be stowed in well-ventilated locations, away from heat sources and incompatible cargoes (e.g., oxidizers, flammables). Periodic temperature monitoring prior to loading should be implemented.
- Personnel across the supply chain (including packers, forwarders, and ship crews) should receive competency-based training in Li-ion battery risk management and emergency procedures.
- Charcoal and similar goods must be stored open air for a defined time to ensure residual heat dissipation and volatile off-gassing before shipping.
- Containers with dangerous and flammable goods should be prevented from long direct sunlight to avoid heating.

Risk-based stowage at planning stage

Safe stowage planning is a cornerstone of cargo fire prevention and emergency management in containerized shipping. The International Maritime Dangerous Goods (IMDG) Code and the Emergency Schedules (EmS) Guide published by the International Maritime Organization (IMO) provide comprehensive but textual regulations that govern the segregation, ventilation, and handling of hazardous goods. While these documents are indispensable to human operators, their current form presents challenges for automation and large-scale operational decision making in modern containership stowage systems, where tens of thousands of containers must be positioned under tight spatial and temporal constraints.

A properly designed stowage-planning should respect rules as a hard constraint layer, preventing violations such as incompatible cargo proximity or inappropriate deck placement. For example, a container carrying lithium-ion batteries (UN 3480) should be excluded from lower holds near engine room bulkheads due to both segregation and thermal exposure reasons.

The storage plan should respect the following aspects

- Minimum distances from accommodation blocks or escape routes
- Ventilation requirements for self-heating substances
- Temperature-gradient considerations within cargo holds
- Spatial redundancy for firefighting access and monitoring sensors

11.4.2 Detect

Given complex cargo structures and increasing shipments of hazardous materials, early detection of fires on container ships requires a holistic mixed-methods approach that combines different methodological and systemic perspectives. In this context, detection technology, digital, organizational, and personnel methods are particularly important, as they together form a robust and redundant detection system. The strength of this approach lies in the integration of complementary methods that combine both technical-automated and human-situational forms of perception.

Key elements of the technical methods are networked sensors, thermal cameras, and AI-based anomaly detection systems. Temperature, gas, and smoke detectors continuously provide quantitative measurements, while thermal cameras detect abnormal heat developments and AI algorithms recognize patterns that indicate smouldering or incipient fires. These systems generate a data-driven, objective stream of information that enables early and automated alerting. These technology-based processes are supplemented by digital IoT infrastructures that centralize and analyse sensor data and transmit it to the ship's command in real time. This creates a cyber-physical monitoring system that accesses both real-time data and historical comparative values to assess risks more accurately.

Organizational methods help ensure that technical detection systems function effectively under real operating conditions. Optimized loading processes, separate stowage of dangerous goods, structured documentation checks, and systematic maintenance of detection technology ensure that risks are minimized, and measurement systems are configured correctly. In addition, standardized reporting chains and clearly defined decision-making structures support rapid response in the event of an alarm. These organizational components ensure that technical detection signals can be translated into appropriate operational measures.

Complementary to technical and organizational processes, personnel methods play a crucial role. Trained crew members, regular inspection rounds with mobile thermal imaging devices, and situational risk assessments serve as a qualitative supplement to automated systems. Human perception is particularly relevant when systems are prone to errors, false positive signals occur, or unexpected cargo constellations are present. The combination of human expertise and system-based monitoring provides a redundant safety net that significantly reduces the likelihood of undetected incipient fires.

11.4.3 Respond

A number of measures that are ready for practical application but have not yet been systematically implemented in container shipping show considerable potential for improving firefighting on board. These include, first and foremost, container-penetrating extinguishing lances, which are already established in hazardous goods logistics and firefighting but are only used sporadically on container ships. These systems enable targeted penetration of container walls and the direct introduction of water, foam, or inert gas into closed containers. This allows concealed smouldering fires and incipient fires to be reduced quickly and effectively. Despite their advanced technical maturity, they have not yet been systematically integrated into ship design or institutionalized in on-board procedures, which severely limits their use.

Another area of action concerns large-format container insulation covers, such as those already used in the battery industry or in land transport for thermal control and oxygen reduction. These fireproof covers make it possible to encapsulate individual containers against thermal effects and prevent the spread of fire to neighbouring cargo units. Although such systems are technically mature, maritime shipping lacks the normative foundations, storage concepts, and organizational structures for systematic integration on board, meaning that they have not yet been put into practical use.

In addition, other industries have developed the concept of standardized fire response containers, which are preconfigured modules equipped with firefighting robotics, precision water cannons, power supply units, and personal protective equipment. In principle, maritime container logistics would allow for the easy integration of such an emergency module, for example by carrying a dedicated container designed for immediate firefighting and isolation needs. However, such a concept has not yet been translated into operational or regulatory frameworks.

Digitally supported operational management systems, such as those used in energy plants and industrial parks in the form of digital hazard maps or digital twins, are also considered ready for practical use, but are not standardized for maritime firefighting. On container ships, such systems could automatically project thermal hotspots, visualize spread paths, and provide targeted recommendations for action based on substance class-specific container data. Despite their technical availability, they have not been integrated into SOLAS, IMO, or classification regulations, which has prevented their maritime implementation to date.

A comparable concept that is ready for practical application but has not yet been introduced is the structured prioritization of hazardous goods and risk containers in the event of a fire. In land logistics and hazardous materials storage facilities, there are software-based procedures that classify cargo units according to their thermal and chemical reactivity and use this information to derive automatic recommendations for isolation and response measures. Transferring this to container ships would be technically feasible and would allow for dynamic adaptation of evacuation, cooling, and separation strategies. However, there is currently a lack of organizational anchoring in the operational processes of ship management and in the digital infrastructure of shipping companies.

Finally, the personnel dimension also opens up previously untapped potential. While specialized forces for battery, hazardous material, and industrial fires have long been established in civil emergency response, no comparable function exists on board container ships. The introduction of a “container fire specialist” would be technically and organizationally feasible and could be supplemented by specific training in container logistics, the assessment of thermally active cargoes, and the application of structured decision-making models, such as the recognition-primed decision model. Nevertheless, such specialization has not yet been incorporated into the personnel structure of container ships, primarily due to economic considerations and a lack of regulatory requirements.

11.4.4 Recover & learn

With regard to organizational learning, it is apparent that systematic lessons learned processes do exist in container shipping in broad terms, but are only rudimentary compared to other high-risk industries. In aviation, for example, the structured evaluation of incidents, supported by digitized incident databases, is mandatory practice. A comparable maritime system could collect extensive fire and incident data in anonymized form, recognize patterns, and generate recommendations for action on this basis. AI-based evaluation methods that correlate event data, crew reports, and sensor data and could identify systematic weaknesses in cargo planning, detection, or response are also ready for practical use. Although the relevant technologies exist, maritime shipping lacks standardized platforms and binding reporting processes that would enable automatic feedback into operational and regulatory measures

11.4.5 Safety Culture

Human factors play a key role in fire detection on container ships, as the effectiveness of technical and organizational measures is significantly influenced by human perception, decision-making, and action capabilities. In this context, human factors include cognitive processes – such as attention, situational awareness, and decision-making – as well as physical, social, and organizational influencing factors. The integration of human factors perspectives into a mixed-methods approach to fire detection helps to optimize the interaction between humans and technical systems and to identify potential weaknesses in the safety structure at an early stage.

A crucial aspect is the crew's situational awareness (SA). The multitude of parallel information sources – sensor data, visual impressions, alarm signals, and organizational protocols – requires a high degree of information integration and prioritization. Deficits in situational awareness can lead to early signs of a fire being overlooked or misinterpreted. Training, standardized procedures, and ergonomically designed information interfaces can reduce these risks and lessen the cognitive load on the crew.

In addition, workload, fatigue, and resource availability play a significant role. Especially during night watches, when work is intense, or under adverse environmental conditions, the crew's performance can be impaired, leading to a reduced probability of detection. Aspects such as sufficient staffing levels, rotation-based watch systems, and break regulations therefore contribute directly to improving early fire detection.

Communication processes are also a key human factor element. Unclear reporting channels, inconsistent terminology, or hierarchical barriers can delay the transmission of safety-related information. A clear, redundant, and transparent communication structure increases the robustness of the system and facilitates the correct classification of technical alarms. This is particularly relevant in situations where there is uncertainty or technical signals appear contradictory.

After all, the crew's experience, expertise, and mental models have a significant influence on the interpretation of technical detection signals. Crew members with extensive experience in hazardous material handling, firefighting, and ship operations typically develop sophisticated mental models of hazardous situations, which leads to more accurate assessments and faster responses. Continuous training and education, practical exercises, and the use of simulation technologies such as VR training can provide lasting support for building this knowledge and expertise.

11.4.6 Comparison safety goals Task 3.1

The safety-related objectives defined in Task 3.1 form the basis for the approaches developed in this report. The comparison shows that the key protection objectives – particularly with regard to prevention, detection, fire response, organizational safety structures, and consideration of human factors – are comprehensively addressed by the content developed. The following sections present the thematic correspondence of the respective target areas.

<u>Preventive risk reduction and secure cargo processes</u>

Task 3.1 emphasizes the need for systematic risk identification and preventive measures to minimize fire-related hazards. The content described in the PREVENT section fully addresses these requirements. This includes ensuring cargo integrity, risk analysis of dangerous goods, the use of digitally supported screening mechanisms, and risk-based stowage and segregation processes. These preventive measures directly correspond to the objectives formulated in Task 3.1 for the early identification and control of potential hazards.

<u>Technical detection and monitoring of critical conditions</u>

A key objective of Task 3.1 is to establish reliable and redundant technical systems for the early detection of thermal or chemical anomalies. The DETECT section specifies these requirements through multimodal, networked detection systems, including sensor technology, thermographic monitoring, gas detection, IoT infrastructures, and AI-supported analysis mechanisms. These measures correspond to the requirements for robust, continuous, and technology-supported early detection methods described in Task 3.1.

Fire response, containment, and operational response mechanisms

The importance of effective response and containment measures in the event of a fire, as highlighted in Task 3.1, is reflected in the RESPOND section. Here, practical solutions are being developed, including container-penetrating extinguishing lances, thermally insulated container covers, modular deployment containers, and digitally supported situation and hazard assessments for deployment coordination. These elements correspond to the capabilities required in Task 3.1 for structured, effective firefighting and hazard mitigation on board.

Organizational learning and continuous safety development

Task 3.1 emphasizes the need for continuous improvement processes and a systematic approach to safety-related knowledge. The RECOVER & LEARN section addresses these requirements by describing mechanisms for the structured evaluation of incidents, pattern recognition in safety-related data, and the establishment of common lessons learned structures. This topic area thus corresponds to the objectives formulated in Task 3.1 for long-term improvement of safety levels through data- and knowledge-based development.

Human factors and safety-related performance

Another focus of Task 3.1 is the consideration of human factors in safety management. The SAFETY-CULTURE ENABLERS section addresses these perspectives in detail by systematically considering aspects such as situational awareness, workload, decision-making behaviour, communication processes, and crew expertise. The content presented corresponds to the requirements for a comprehensive, human-cantered understanding of safety highlighted in Task 3.1.

Summary assessment

The comparison shows that the safety-related objectives defined in Task 3.1 are fully taken into account in the concepts and measures developed. The content is directly consistent with the target areas of prevention, detection, fire response, continuous improvement, and human factors, and concretizes these through practical, technically sound, and organizationally anchored solutions.

11.5 POLISH USE CASE

Safety on container ships relies on effective management of risks associated with the operation and transportation of hazardous and non-hazardous goods. Identifying risks, analysing and developing preventive and mitigating actions are essential to reduce the consequences of incidents, such as fires, mechanical failures, human errors, and external factors. This section addresses a list of risks identified in T3.2 and outlines the measures designed to either prevent their occurrence or minimize their impact if they materialize as well as specify safety contribution resulted from implementation of UAV based entry monitoring system as depicted and simulated in WP7 – Polish Use Case

11.5.1 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.

Application of UAS-based mitigation measures as specified and validated in WP7 will generate additional safety barrier for this hazard contributing to system capabilities for preventing escalating of fire and increasing probability of successful extinguishing thanks to early detection.

Sources

As indicated in T3.2 the following set of factors can be identified as root causes for his hazard:

- Human Errors,
- Fraud,
- Complex Supply Chains,
- Regulatory Gaps.

Scanning and detection UAS port based system will not contribute to the probability of occurring of identified root causes.

As indicated in T3.2 likelihood is defined as dependent on:

- Volume of Trade,
- Limited Inspection,
- Growing Use of Lithium-Ion Batteries.

Scanning and detection UAS port based system will not affect the phenomena presented and the same the risk probability resulted from them.

Additionally affected by following uncertainties

- Quality of Data,
- Technological Variability,
- Evolving Regulations.

Scanning and detection UAS port based system does not contribute to the reduction of uncertainties when related to the situation before implementation of the system.

The consequences of misdeclared or undeclared dangerous goods are severe and multifaceted.

- Direct Consequences: Fires and Explosions, Loss of Life and Property.
- Indirect Consequences: Environmental Impact, Economic Losses, Disruption to Global Trade.

Scanning and detection UAS port based system devoted to primarily protect the port infrastructure from risk related to entering the vessels on fire significantly contribute to both direct and indirect consequences in area of port. Additionally, in favourable circumstances the system can contribute to the vessel safety through early detection of fire aboard enabling quick reaction.

As indicated in T3.2 effectiveness of Preventing Actions

- Stricter Regulations,
- Enhanced Training and Awareness,
- Advanced Screening Technologies,
- Random Physical Inspections.

Scanning and detection UAS port based system will not contribute to the effectiveness of preventing actions.

As indicated in T3.2 effectiveness of Mitigating Actions are identified as depending on:

- Fire Detection and Suppression Systems,
- Segregation of Cargo,
- Emergency Response Plans.

Scanning and detection UAS port based system will provide additional mean to detect fire aboard of vessel contributing the same to the effectiveness of fire detection systems. Additionally, direct and continuous link with a port will entail improved response and more efficient severity reducing efforts. On the other side operation of the system is limited to the port area.

Summary

The issue of misdeclared or undeclared dangerous goods represents a significant risk to container ship safety. Scanning and detection UAS port based system will be able to significantly contribute to the hazard through enabling additional aerial fire detection mean and preventing entering the vessel on fire to the port. The open see conditions are outside of system operation envelope.

11.5.2 Declared dangerous goods

Contrary to the misdeclared declared goods enable implementing of mitigation means enabling more effective preventing activities as well as extinguishing action in case of fire as thy can be of special attention during transport. Nevertheless they still remain dangerous as for example in case of lithium-ion batteries, which if continuously heated may be the reason for the self-ignition and uncontained fire.

Application of UAS-based mitigation measures as specified and validated in WP7 will generate additional safety barrier for this hazard contributing to system capabilities for preventing escalating of fire and increasing probability of successful extinguishing thanks to early detection.

Sources

As indicated in T3.2 the primary sources of the problem are related to the properties of lithium-ion batteries and their handling during transport:

- Thermal Runaway,
- Environmental Factors,
- Mechanical Damage
- Defective Batteries
- Battery Overpacking.

Scanning and detection UAS port based system will not contribute to the probability of occurring of identified root causes.

As indicated in T3.2 likelihood of fires involving declared lithium-ion batteries is influenced by several factors:

- Proliferation of Lithium-Ion Batteries,
- Regulatory Compliance,

- Packaging Standards,
- Cargo Hold Conditions,
- Temperature Fluctuations,
- Battery Design,
- Detection of Defects.

The all above factors are outside the scope of impact of Scanning and detection UAS port based system.

As identified in T3.2 consequences of fires caused by declared dangerous goods like lithium-ion batteries are significant:

- Direct Consequences: (Fires and Explosions, Crew Safety Risks)
- Indirect Consequences: (Economic Losses, Reputational Damage, Environmental Impact)

Similarly as in case of risk related to transport of miscdeclard and nondeclared dangerous goods it is stated that scanning and detection UAS port based system is devoted to primarily protect the port infrastructure from risk related to entering the vessels on fire and therefore, it significantly contributes to both direct and indirect consequences in area of port. Additionally, in favourable circumstances the system can contribute to the vessel safety through early detection of fire aboard enabling quick and effective reaction.

As identified in T3.2 effectiveness of Preventing Actions depends on:

- Improved Packaging Standards,
- Temperature-Controlled Containers,
- Battery State of Charge (SoC),
- Enhanced Regulations,
- Training and Awareness.

Scanning and detection UAS port based system will not contribute to the effectiveness of preventing actions.

As identified in T3.2 effectiveness of Mitigating Actions depends on:

- Fire Suppression Systems,
- Thermal Management,

- Emergency Protocols.

Scanning and detection UAS port based system will provide additional mean to detect fire aboard of vessel contributing the same to the effectiveness of fire detection systems. Additionally, direct and continuous link with a port will entail improved response and more efficient severity reducing efforts. On the other side operation of the system is limited to the port area.

Summary

Mitigation measures, including advanced fire suppression systems and robust emergency protocols, are essential to minimize the consequences of such fires. Scanning and detection UAS port based system will be able to significantly contribute to the hazard through enabling additional aerial fire detection mean and preventing entering the vessel on fire to the port as well as significantly supporting fire extinguishing activities. The open see conditions are outside of system operation envelope.

11.5.3 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.

Application of UAS-based mitigation measures as specified and validated in WP7 will generate additional safety barrier for this hazard contributing to system capabilities for preventing escalating of fire and increasing probability of successful extinguishing thanks to early detection.

Sources

As indicated n T3.2 the primary sources of electrical failures in reefer containers include:

- Aging Equipment,
- Faulty Maintenance,
- Overloading Circuits,
- Environmental Factors,
- Installation Errors.

Scanning and detection UAS port based system will not contribute to the probability of occurring of identified root causes.

As identified in T3.2 likelihood of electrical failures in reefer containers leading to fires depends on several factors:

- High Demand for Reefer Containers,

- Complexity of Electrical Systems,
- Limited Inspection Access,
- Variability in Maintenance Standards,
- Undetected Pre-Existing Faults,
- Cargo Placement.

The all above factors are outside the scope of impact of Scanning and detection UAS port based system.

The consequences of electrical failures in reefer containers can be severe and far-reaching:

- Direct Consequences (Fires in Cargo Holds, Loss of Refrigerated Goods).
- Indirect Consequences (Damage to the Ship, Crew Safety Risks, Disruption of Operations).

Similarly as in case of risk related to transport of miscdeclard and nondeclared dangerous goods it is stated that scanning and detection UAS port based system is devoted to primarily protect the port infrastructure from risk related to entering the vessels on fire and therefore, it significantly contributes to both direct and indirect consequences in area of port. Additionally, in favourable circumstances the system can contribute to the vessel safety through early detection of fire aboard enabling quick and effective reaction.

Effectiveness of Preventing Actions depends on (according to results of T3.2):

- Regular Maintenance and Inspection,
- Use of Modern Equipment,
- Enhanced Crew Training,
- Centralized Monitoring Systems.

Scanning and detection UAS port based system will not contribute to the effectiveness of preventing actions.

Effectiveness of Mitigating Actions (as identified in T3.2):

- Fire Detection and Suppression Systems in Cargo Holds,
- Improved Reefer Placement Strategies,
- Emergency Response Protocols.

Scanning and detection UAS port based system will provide additional mean to detect fire aboard of vessel contributing the same to the effectiveness of fire detection systems. Additionally, direct and continuous link with a port will entail improved response and more efficient severity reducing efforts. On the other side operation of the system is limited to the port area.

Summary

Electrical failures in reefer containers represent a significant fire hazard due to the complexity and location of their systems. Scanning and detection UAS port based system will be able to significantly contribute to the hazard through enabling additional aerial fire detection mean and preventing entering the vessel on fire to the port as well as significantly supporting fire extinguishing activities. The open see conditions are outside of system operation envelope.

11.5.4 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.

Sources

According to the results of T3.2 the problem of cargo shifting and poor stowage arises from multiple causes:

- Improper Lashing and Securing,
- Inadequate Weight Distribution,
- Stowage Planning Errors,
- Human Error,
- Dynamic Forces.

Scanning and detection UAS port based system will not contribute to the probability of occurring of identified root causes.

As identified in T3.2 the likelihood of cargo shifting and poor stowage contributing to fire hazards is moderate to high due to the following factors:

- Volume and Complexity,
- High Risk in Hazardous Goods,
- Crew Expertise,
- Variability in Ship Design,

- Weather Conditions,
- Inspection Rates.

The all above factors are outside the scope of impact of Scanning and detection UAS port based system.

According to the results of T3.2, the consequences of cargo shifting and poor stowage can be severe, especially when hazardous materials are involved.

- Direct Consequences (Damage to Containers, Ignition Sources),
- Indirect Consequences (Loss of Stability, Crew Safety Risks, Environmental Hazards)

Similarly as in case of above addressed risks it is stated that scanning and detection UAS port based system is devoted to primarily protect the port infrastructure from risk related to entering the vessels on fire and therefore, it significantly contributes to both direct and indirect consequences in area of port. Additionally, in favourable circumstances the system can contribute to the vessel safety through early detection of fire aboard enabling quick and effective reaction.

Following the output from T3.2 effectiveness of Preventing Actions depends on:

- Improved Lashing and Securing Practices,
- Advanced Stowage Planning Software,
- Compliance with International Guidelines,
- Enhanced Crew Training,
- Pre-Voyage Inspections.

Scanning and detection UAS port based system will not contribute to the effectiveness of preventing actions.

Effectiveness of Mitigating Actions (based on T3.2):

- Damage Control Plans,
- Fire Suppression Systems,
- Monitoring Systems.

Scanning and detection UAS port based system will provide additional mean to detect fire aboard of vessel contributing the same to the effectiveness of fire detection systems. Additionally, direct and continuous link with a port will entail improved response and more efficient severity reducing efforts. On the other side operation of the system is limited to the port area.

Summary

Cargo shifting and poor stowage present a significant fire risk on container ships, particularly when hazardous materials are involved. Preventing such incidents requires a combination of improved lashing practices, advanced stowage planning, and adherence to international regulations. Mitigation measures like fire suppression systems and real-time monitoring can limit the impact of shifting cargo. Scanning and detection UAS port based system will be able to significantly contribute to the hazard through enabling additional aerial fire detection mean and preventing entering the vessel on fire to the port as well as significantly supporting fire extinguishing activities. The open see conditions are outside of system operation envelope.

11.5.5 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.

Sources

According to the T3.2, the sources of human error and inadequate training that contribute to fires can be traced to several factors:

- Lack of Fire Safety Training,
- Operational Mistakes,
- Inadequate Knowledge of Cargo,
- Communication Failures,
- Time Pressure.

Scanning and detection UAS port based system will not contribute to the probability of occurring of identified root causes.

As identified in T3.2 the likelihood of human error or inadequate training contributing to fire hazards is high due to the following reasons:

- High-Stress Environment,
- Training Gaps,
- Human Fatigue,
- Insufficient Experience.

And corresponding uncertainties depends on:

- Training Gaps Across Fleets,
- Complexity of New Cargo Types,
- Stress and Fatigue Impact.

The all above factors are outside the scope of impact of Scanning and detection UAS port based system.

Following the output from T3.2 the consequences of human error and inadequate training are potentially catastrophic, as they directly impact the ability of crew members to prevent, detect, and fight fires.

- Direct Consequences (Failure to Prevent Fires, Delayed Fire Detection, Inadequate Firefighting)
- Indirect Consequences (Loss of Life and Injury, Environmental Damage, Financial Loss, Reputational Damage).

Scanning and detection UAS port based system will contribute to the reducing of human errors listed above through providing additional source of information about the fire. Nevertheless, this contribution is limited to the port area.

As identified in T3.2 effectiveness of Preventing Actions depends on:

- Enhanced Training Programs,
- Regular Drills and Simulations,
- Standardized Safety Protocols,
- Fatigue Management,
- Use of Technology.

Scanning and detection UAS port based system will contribute to the reducing of human errors listed above through providing additional source of information about the fire (Use of Technology). Nevertheless, this contribution is limited to the port area.

Effectiveness of Mitigating Actions (as identified in T3.2):

- Emergency Response Teams,
- Clear Communication Protocols,
- Real-Time Monitoring Systems.

Scanning and detection UAS port based system will contribute to the reducing of human errors listed above through providing fire detection and monitoring system in entry to the port phase. Nevertheless, it must be taken into account that this functionality is limited to the port area (range of UAV include into the system).

Summary

Human error and inadequate training are key contributors to fire risks on container ships, especially when crew members fail to follow established protocols or lack knowledge of emergency procedures. In this context operation of Scanning and detection UAS port based system will improve the safety through providing additional information about the fire. Nevertheless, as the probability of human error is outside of the system impact, effectiveness of its contribution is difficult to assess.

11.5.6 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.

Sources

As identified in WP3 mechanical failures in ship systems that lead to fires typically stem from a variety of issues:

- Engine Room Overheating,
- Fuel Leaks,
- Electrical Failures,
- Exhaust System Failures,
- Corrosion and Wear,
- Improper Maintenance.

Scanning and detection UAS port based system will not contribute to the probability of occurring of identified root causes.

Following the result of T3.2 the likelihood of mechanical failures leading to fires in machinery spaces is significant due to the following factors:

- Complex Machinery Systems,
- Environmental Stressors,

- Increased Operational Demands,
- Lack of Regular Maintenance.

And corresponding uncertainties as depending on:

- Condition of Machinery,
- Fire Suppression System Effectiveness,
- Age of the Vessel.

The all above factors are outside the scope of impact of Scanning and detection UAS port based system.

In terms of probable consequences identified in T3.2, fires originating from machinery spaces can have devastating consequences, both for the vessel and the crew.

- Direct Consequences (Fire Spread to Cargo Holds, Engine Room Damage, Explosion Risk).
- Indirect Consequences (Crew Safety Risks, Loss of Cargo, Environmental Pollution, Extended Operational Delays).

Scanning and detection UAS port based system will not affect consequences listed above. It is assumed that source of fire source will be probably outside of the system detection capabilities as under the deck.

As identified in T3.2 the effectiveness of Preventing Actions depends on:

- Routine Maintenance and Inspections:
- Monitoring and Early Detection Systems:
- Fire-Resistant Materials:
- Preventive Training for Crew:
- Improved Ventilation Systems:

Scanning and detection UAS port based system will not contribute to the effectiveness of preventing actions.

Effectiveness of Mitigating Actions factors identified in T3.2 are following:

- Fire Suppression Systems,
- Fire Containment Barriers,

- Emergency Response Protocols,
- Automated Shutoff Systems.

Scanning and detection UAS port based system will insignificantly contribute to the effectiveness of mitigating actions. The system is dedicated to scan the upper deck of the vessel in order to detect temperature anomalies indicating on fire. Fire resulted from mechanical failures of ship system originates in lower deck. This area will be outside of the system detection capabilities.

Summary

Mechanical failures in ship systems, especially in engine rooms, represent a major fire hazard, with the potential to cause extensive damage to the vessel, cargo, and the environment. Due to common location of the fire area it is assessed that scanning and detection UAS port based system will not contribute to both preventive nor mitigating means allocated to this hazard,

11.5.7 External factors such as collisions and strandings, 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 short circuits in electrical systems.

Sources

As identified in T3.2 external factors that can contribute to fires on container ships are typically related to unforeseen events or malicious acts:

- Collisions,
- Strandings,
- Piracy and Armed Attacks,
- Deliberate Arson.

Scanning and detection UAS port based system will not contribute to the probability of occurring of identified root causes.

Following the results of T3.2 the likelihood of fires due to external factors such as collisions, piracy, and arson is relatively low but significant due to the following reasons:

- Collisions and Strandings,
- Piracy,
- Deliberate Arson.

And corresponding uncertainties:

- Piracy Trends,
- Collision Severity,
- Arson Motivation.

The all above factors are outside the scope of impact of Scanning and detection UAS port based system.

As identified in T3.2 the consequences of fires resulting from external factors can be severe, especially if the fire spreads to critical systems or hazardous cargo:

- Direct Consequences (Damage to Ship Infrastructure, Explosion Risks, Loss of Cargo, Crew Injury or Fatalities, Ship Loss or Severe Damage).
- Indirect Consequences (Environmental Pollution, Disruption to Trade Routes, Reputation Damage, Legal and Financial Consequences).

Operation of scanning and detection UAS port based system will insignificantly affect consequences listed above. The system capabilities enable decrease the severity of fire if its source is located in upper deck and the ship is in port area.

As identified in T3.2 effectiveness of Preventing Actions depends on:

- Navigational Risk Management,
- Piracy Risk Management,
- Ship Design and Maintenance,
- Arson Prevention Measures.

Scanning and detection UAS port based system will not contribute to the preventive actions listed above.

As identified in T3.2 effectiveness of Mitigating Actions:

- Fire Suppression Systems,
- Emergency Response Protocols,
- Insurance and Crisis Management Plans,
- Real-Time Monitoring and Communication.

Scanning and detection UAS port based system will provide additional mean to detect fire aboard of vessel contributing the same to the effectiveness of fire detection systems. Additionally, direct and continuous link with a port will entail improved response and more efficient severity reducing efforts. On the other side operation of the system is limited to the port area.

Summary

External factors, such as collisions, strandings, piracy, and deliberate arson, present significant fire risks to container ships. Although these events are less frequent, their consequences can be catastrophic, especially when fires spread to critical systems or hazardous cargo. Scanning and detection UAS port based system will contribute to increase safety in this aspects through provision of additional mean to detect fire aboard of vessel contributing the same to the effectiveness of fire detection systems. Additionally, direct and continuous link with a port will entail improved response and more efficient severity reducing efforts. Operation of the system is limited to the port area. In terms of effort devoted to reduction of probability of fire due to external factors the system is seen as not having impact.

11.5.8 Regarding human errors and inadequate training

Mistakes regarding the stowage of containers are due to human errors, inadequate training and falsely declared cargo. Containers having goods with a low flashpoint accidentally stowed on the top row on deck might cause a fire since temperatures inside a container in direct sunlight might rise up to 55°C.

Sources

As identified in T3.2 human errors in the stowage of containers can significantly increase the risk of fire, especially when coupled with inadequate training and misdeclared cargo:

- Incorrect Stowage of Containers,
- Misdeclared or Undeclared Cargo,
- Inadequate Crew Training,
- Failure to Follow Safety Protocols.

Scanning and detection UAS port based system will not contribute to the probability of occurring of identified root causes.

Following output from T3.2 the likelihood of fires resulting from human error and inadequate training is significant, as several factors contribute to it:

- Human Error:

- Inadequate Training:.
- Misdeclared Cargo:.
- Lack of Clear Guidelines or Procedures:.

And corresponding uncertainties"

- Training Quality:.
- Cargo Declaration Accuracy:.
- Stowage Procedures:.

The all above factors are outside the scope of impact of Scanning and detection UAS port based system.

As identified there are serious consequences of fires resulting from human error or inadequate training:

- Direct Consequences (Container Ignition, Spread of Fire to Cargo Holds, Ship Infrastructure Damage, Loss of Cargo).
- Indirect Consequences (Environmental Contamination, Injuries to Crew, Operational Delays, Legal and Financial Repercussions).

Operation of scanning and detection UAS port based system will affect consequences listed above through contributing to contained fire detection.

As identified in T3.2 effectiveness of Preventing Actions depends on:

- Comprehensive Crew Training,
- Cargo Declaration Verification,
- Clear Stowage Guidelines,
- Regular Audits and Inspections.

Scanning and detection UAS port based system will not contribute to the preventive actions listed above.

Effectiveness of Mitigating Actions (as defined in T3.2):

- Fire Detection and Suppression Systems,
- Cargo Temperature Monitoring,

- Emergency Response Drills,
- Access Control and Container Inspection.

Scanning and detection UAS port based system will provide additional mean to detect fire aboard of vessel contributing the same to the effectiveness of fire detection systems. Additionally, direct and continuous link with a port will entail improved response and more efficient severity reducing efforts. On the other side operation of the system is limited to the port area.

Summary

Human errors and inadequate training are key contributors to the risk of fires on container ships, particularly when it comes to improper stowage and misdeclared cargo. Scanning and detection UAS port based system will contribute to increase safety in this aspects through provision of additional mean to detect fire aboard of vessel contributing the same to the effectiveness of fire detection systems. Additionally, direct and continuous link with a port will entail improved response and more efficient severity reducing efforts. Operation of the system is limited to the port area. In terms of effort devoted to reduction of probability of fire due to external factors the system is seen as not having impact.

SECTION 12 RISK MINIMIZATION STRATEGIES AND METHODS

12.1 MISDECLARED OR UNDECLARED DANGEROUSE GOODS

Misdeclared or undeclared hazardous materials are a leading cause of fires on container ships, posing significant risks to crew members, cargo, and the environment [57]. The International Maritime Dangerous Goods (IMDG) Code, which regulates the transportation of hazardous materials by sea, emphasizes the importance of accurate documentation and proper stowage planning to mitigate these risks.

Shipping companies must enforce strict documentation and inspection procedures, to address this issue. This includes requiring shippers to provide complete and accurate information regarding cargo contents, with severe penalties for misdeclaration. Random cargo inspections and audits should be increased to ensure compliance with the IMDG Code. Studies show that increased inspections, new technologies and audits can significantly reduce the incidence of misdeclared or undeclared cargo [58],[59]. Advanced technology can also be crucial in detecting hazardous substances before loading. AI-based cargo scanning and X-ray spectroscopy can quickly and accurately identify potentially hazardous materials, allowing prompt action.

Additionally, AI-driven software can be used to automatically flag high-risk placements, ensuring that hazardous cargo with low flashpoints is kept in temperature-controlled areas below deck, away from ignition sources. Furthermore, proper stowage planning is also critical. Specific (AI-driven) software can be used to optimize stowage planning and reduce the risk of hazardous materials coming into contact with ignition sources [60]. Temperature monitoring systems can also be installed within containers to detect unsafe temperature increases in real-time, allowing for immediate corrective actions, such as adjusting ventilation or relocating cargo. Furthermore, blockchain technology can be used to create a secure and transparent record of cargo documentation, reducing the risk of misdeclaration or tampering. Of course, all of these measures come with high prices and structural changes.

Despite significant advances in technology and inspection protocols, detecting mis- or un-declared dangerous goods remains one of the most pressing challenges in container shipping. This issue is unlikely to be fully resolved unless a reliable and efficient solution for 100% container scanning in real-time is developed and implemented across the industry. Researchers have proposed various solutions, including the use of next-generation X-ray technology and machine learning algorithms to enhance the accuracy and speed of cargo scanning. The International Maritime Organization has also launched initiatives to increase awareness and education among shippers, carriers, and regulatory authorities on the importance of accurate documentation and proper stowage planning.

The presence of un-declared or mis-declared hazardous materials is a significant threat to container ship safety, requiring a multi-faceted approach that incorporates advanced technology, strict documentation, inspection procedures, and increased awareness and education. While significant progress has been made, continued innovation and collaboration are needed to address this persistent challenge and ensure the safe transportation of goods by sea.

12.2 DECLARED DANEROUSE GOODS (Lithium-Ion Batteries)

Declared Dangerous Goods, such as lithium-ion batteries, present a unique fire hazard due to their potential for thermal runaway, particularly when exposed to excessive heat. Lithium-ion batteries have been responsible for several notable container ship fires, highlighting the need for heightened regulations and safety measures.

Proper stowage and cargo placement must be a priority to minimize the risk of thermal runaway. Lithium battery containers should be stored in cool, well-ventilated areas below deck and away from direct sunlight, following International Maritime Dangerous Goods (IMDG) Code regulations. Specifically, the IMDG Code recommends storing lithium-ion batteries in a cargo hold with a dedicated ventilation system. Different sources recommend a storage temperature between 0°C and 25°C, but it is even better in the range of 15°C to 25°C [61],[62]. To protect containers against overheating, thermal insulation and ventilation measures should be implemented, such as using reflective covers and ensuring proper airflow around containers. The use of reflective covers could probably reduce the temperature inside a container without using external energy.

To prevent further fire spread, specialized fire suppression systems, such as fine water mist or dry powder extinguishing units, should be installed in designated lithium-ion storage areas onboard. Traditional suppression methods may not be effective enough to fight battery fires, highlighting the need for more advanced suppression systems.

Another crucial step is to regulate battery charge levels before shipment, ensuring they are transported at a state of charge (SOC) of 30% or lower to reduce thermal runaway risks. This can be achieved through the use of specialized battery management systems, which can monitor and control the charge level of lithium-ion batteries (UN 3480).

Furthermore, all lithium-ion battery shipments should adhere to strict packaging regulations, requiring reinforced, fireproof casings with internal separators to prevent short circuits. This can include the use of specialized packaging materials, such as lithium-ion battery-specific packaging cells, to avoid thermal runaway.

12.3 ELECTRICAL FAILURES IN REEFER CONTAINERS

Electrical failures in reefer containers are a significant fire hazard in the maritime industry, particularly when transporting perishable goods. Reefer containers are designed to maintain a controlled temperature. Still, electrical failures can ignite fires that are difficult to detect early, especially when containers are located deep within the ship's cargo holds.

To prevent such incidents, routine electrical inspections and preventive maintenance should be conducted regularly, with a focus on checking wiring integrity, insulation resistance, and grounding. This can include the use of specialized equipment, such as multimeters and insulation testers, to identify potential electrical faults [63].

Additionally, overload protection and circuit isolation measures should be implemented by installing circuit breakers and surge protection devices to prevent electrical overloads that may lead to short circuits. These devices can help prevent electrical fires by interrupting the power supply during an overload or short circuit.

Faulty reefer containers should be automatically disconnected from the power supply to prevent fire propagation. This can be achieved through the use of automated disconnection systems, which can detect electrical faults and disconnect the power supply to prevent further damage. Fire detection systems within reefer compartments should also include sensors that provide real-time alerts for overheating or electrical faults. These sensors can help detect fires early, allowing for prompt action to be taken to prevent further damage.

Furthermore, reefer containers should be equipped with fire-resistant electrical components, such as marine-grade insulated cables, to minimize the likelihood of electrical sparks or overheating. These components can help reduce the risk of electrical fires, ensuring the safe transportation of perishable goods. Of course, these technologies will probably also be hard to implement, as they will raise the prices of reefer containers.

12.4 CARGO SHIFTING AND POOR STOWAGE

Cargo shifting and poor stowage are significant risk factors for fires on container ships, particularly when hazardous materials are involved. When cargo is not properly secured, it can shift during transport, leading to physical damage, leaks, and spills that may ignite upon contact with a spark or open flame. To prevent this, proper cargo securing methods must be enforced, including the use of high-quality lashing, dunnage bags, and anti-slip mats. Lashing and securing mechanisms should be performed to withstand various weather conditions and sea states, ensuring that containers remain stable and secure throughout the journey. Multi-port stowage plans, especially for containers with hazardous goods, are needed to provide all parties involved with comprehensive data on the position of (hazardous) containers [64].

Fire-proof and leak-proof packaging requirements should be strictly followed, ensuring that hazardous liquid cargo is stored in reinforced, impact-resistant containers with double-layered packaging. This includes the use of UN-approved containers and packaging materials, such as leak-proof bags and absorbent pads.

Preventing ignition sources is also crucial. Therefore, strict no-smoking policies must be enforced throughout cargo handling areas. Any ignition sources and fire should be monitored with surveillance systems. This includes the use of smoke detectors and CCTV cameras to detect and respond to potential ignition sources. All hazardous cargo areas should be equipped with spill containment kits containing absorbent materials and chemical-neutralizing agents, in the event of a spill. Crew members should be trained in rapid containment and emergency response procedures to minimize spill-related risks.

12.5 HUMAN ERROR AND INADEQUATE TRAINING

Human error is a significant factor in many fire-related incidents on container ships, including mistakes in cargo stowage and failure to follow fire safety protocols. To address this issue, comprehensive fire safety training programs should be mandatory for all crew members, covering hazardous material handling, fire suppression techniques, and emergency response procedures.

Human errors in shipping can be broadly categorized into three types:

1. **negligence errors,** including failure to maintain proper lookout, inadequate watch-keeping, and poor situational awareness,
2. **judgment and operation errors,** involving incorrect assessment of traffic conditions, use of unsafe sailing speeds, improper collision avoidance actions, and non-compliance with navigation rules,
3. **simultaneous negligence and judgment/operation errors**, where both forms of errors occur concurrently, increasing accident probability.

Understanding the conditions under which human errors are most likely to occur provides insights for improving maritime safety. Several measures can help mitigate the risks. Enhanced training programs are essential for strengthening crew competence in adverse weather navigation, emergency response, and fatigue management. Stricter regulatory compliance must be enforced, particularly for high-risk vessel types such as fishing boats and sand dredgers. Additionally, improved work schedules and fatigue management strategies are necessary to ensure adequate rest for crew members operating during night shifts. Routine safety audits and compliance checks should be conducted by third-party inspectors to ensure proper cargo handling practices. These audits can identify potential safety risks and provide recommendations for improvement, helping to reduce the likelihood of human error. Furthermore, the use of computer and AI-based systems to assist humans in detecting errors and hazards is beneficial [65].

Real-time cargo monitoring systems can also be implemented to provide automated alerts to notify the crew if hazardous materials are placed in an unsuitable location. These systems can track cargo movement and provide real-time updates on cargo status, allowing crew members to take prompt action in the event of a safety issue.

Improving training, oversight, and technology-assisted stowage planning can significantly reduce human errors, thereby enhancing fire safety on container ships. Shipping companies can take proactive steps to reduce the risk of fire by implementing comprehensive training programs, investing in technology-assisted stowage planning, and conducting regular safety audits and compliance checks.

12.6 MEDICAL FAILURES IN SHIP SYSTEMS

Mechanical failures in ship systems, particularly in the engine room, significantly contribute to maritime fire incidents. To minimize the risk of these types of fires, a strict preventive maintenance schedule should be established for all shipboard electrical and mechanical systems. This can include the use of monitoring tools, such as thermal imaging cameras and infrared sensors, to detect overheating components, insulation degradation, and potential short circuits before failures occur. These tools can provide real-time data on system performance and enable predictive maintenance, allowing shipowners to identify and address potential issues before they lead to a fire. This is important because improper maintenance is found to be the main cause of fires and explosions in ship systems [65].

Fire suppression and containment systems should also be reinforced to ensure that CO_2 flooding systems and water mist fire suppression units are regularly tested and fully operational. This includes ensuring that fire detection and alarm systems are functioning properly and that crew members are trained to respond quickly and effectively during a fire.

Crew members must be trained in rapid emergency shutdown and isolation procedures to stop fires before they escalate. This includes training on the use of fire extinguishers, the operation of fire suppression systems, and the procedures for isolating affected areas to prevent fire spread.

Regular emergency drills should also be conducted to ensure preparedness in handling engine room fires effectively. This can include exercises to test the crew's response to fires, including evacuation procedures, fire suppression tactics, and communication protocols.

12.7 EXTERNAL FACTORS: COLLISIONS, PIRACY, ARSON

External factors, including collisions, piracy, and deliberate acts of arson, significantly contribute to the risk of fire onboard ships. To mitigate these threats, shipping companies must implement robust security measures to prevent unauthorized access and ensure the integrity of their vessels and cargo.

Enhanced surveillance and security patrols are essential, particularly in high-risk areas. Round-the-clock monitoring through CCTV, motion sensors, and infrared cameras can help to detect suspicious activities or unauthorized access. This can be achieved by installing advanced surveillance systems, including IP cameras and video analytics software, which can provide real-time alerts to security personnel.

Advanced navigation and collision avoidance systems should be integrated and kept up-to-date to prevent accidental impacts with other vessels or objects. These systems can provide real-time data on the vessel's surroundings and predict potential hazards, enabling crew members to take evasive action.

Fire-resistant container seals should be used to prevent tampering and electronic tracking systems should be installed to detect any unauthorized access to cargo. This can include the use of digital locks and container tracking devices, which can provide real-time data on container movements and any attempts to breach the seal [65].

Emergency response drills specifically addressing external threats should be conducted regularly, ensuring that crew members are well-prepared to handle fire incidents resulting from collisions or security breaches. These drills can include simulated emergency scenarios, such as pirate attacks or collisions, and allow crew members to practice their response and decision-making skills.

12.8 HUMAN ERRORS IN STOWAGE

The improper placement of hazardous cargo in high-temperature environments can significantly increase fire risks. The combination of elevated ambient temperatures and prolonged solar radiation exposure can lead to hazardous conditions, including cargo overheating, vapor expansion, and potential ignition. A comprehensive risk minimization strategy is necessary to prevent fire hazards and ensure safe transport and storage.

In principle, the measures for the prevention of human error should also be employed in this context. However, given the potential for human error, further measures are required to minimize the effect of sunlight on incorrectly stowed containers.

To mitigate these risks, the placement of hazardous cargo should be carefully controlled. Positioning containers in lower tiers significantly reduces exposure to direct sunlight, thereby minimizing heat absorption. Containers should be stored in shaded areas whenever possible to further decrease thermal accumulation. If relocation is not feasible, alternative protective measures, such as thermal insulation and reflective coverings, could be applied to reduce internal temperature buildup. Adequate ventilation must be ensured to dissipate heat and prevent the accumulation of flammable vapors inside the container. The use of temperature-controlled units, such as refrigerated containers, should be considered for highly temperature-sensitive cargo.

Real-time monitoring of container temperatures is critical for early hazard detection. Therefore, temperature sensors should be installed to track internal heat levels and provide alerts if dangerous thresholds are reached. Periodic inspections must be conducted to assess cargo integrity and identify potential risks, such as heat stress, leaks, or unusual pressure buildup. Fire detection and gas sensors should be implemented to detect early signs of ignition or vapor accumulation. In addition to automated monitoring systems, manual inspections by trained personnel should be conducted at regular intervals to ensure compliance with safety protocols.

SECTION 13 PREVENTING AND MITIGATING MEASURES TO BE CONSIDERED FOR THE FURTHER RISK ASSESSMENT

Regarding the proposed methodology, the T3.2 risk framework (risk matrix and tolerability criteria) and its hazard catalogue have been used as the baseline, each measure includes the expected effect (↓ Likelihood and/or ↓ Severity), the implementation context (on-board / terminal / port-wide coordination), and the means of verification (inspection, training, digital monitoring). Preventing and mitigating methods for different use cases are presented in Table 38, Table 39 and Table 40.

Hazard type	Preventing and mitigating measures
Misdeclared / undeclared dangerous goods (DG)	**Prevent** (L↓): mandatory correct classification, packaging, documentation and location; awareness actions with shippers/forwarders; enhanced gate/yard screening. Verification: documentation audits + random inspections. **Mitigate** (S↓): early fire detection in cargo areas; crew training for DG anomalies. Integration: DS with IoT/UAS for anomaly spotting in stacks.
Human error / inadequate training	**Prevent** (L↓): monthly drills on abandon-ship and shipboard firefighting; competency-based stowage checks (two-person rule); port-community checklists aligned with T3.1 goals. **Mitigate** (S↓): clear emergency SOPs and job aids; surge capacity via specialized fire teams (on-call).
Tactical doctrine for shipboard firefighting (MIRG alignment)	**Mitigate** (S↓): adopt Contain & Maintain as default at-sea strategy; ICS roles, dynamic risk assessment, tactical modes (Offensive/Defensive/Transitional), and phased withdrawal/evacuation triggers to protect responders and stabilize until alongside.
Late Detection of Fire	**Prevent (Likelihood reduction):** The installation of fixed IoT fire detection systems on the weather deck ensures continuous monitoring, detecting thermal anomalies at the earliest stage and significantly reducing the likelihood of a fire reaching an uncontrollable/advanced phase.
Poor Situational Awareness (SA)	**Prevent (Likelihood reduction):** The integration of diverse data sources (sensors, UAS, ship data) into a centralized Digital Solution prevents decision-making based on incomplete or erroneous information, reducing the likelihood of command errors. **Mitigation (Severity reduction)**: The deployment of UAS with thermal cameras provides real-time visualization of the fire's extent and "hotspots" (even through smoke or fog), enabling targeted firefighting tactics that minimize damage and rescue team exposure.
Cognitive Overload	**Prevent (Likelihood reduction):** The Digital Solution automates data aggregation and filtering, presenting a clear "Common Operational Picture" to the bridge team. This prevents information saturation and reduces the likelihood of human error during critical decision-making phases.
Adverse Environmental Conditions	**Prevent (Likelihood reduction):** A redundant network of diverse sensors (thermal, smoke, visual) reduces the likelihood of total detection failure caused by specific weather conditions (e.g., fog blinding cameras or wind dispersing smoke away from a single sensor).

Table 38. Preventing and mitigating measures Italian UC

Hazard type	Preventing and mitigating measures
Misdeclared / undeclared dangerous goods (DG)	**Prevent** (L↓): mandatory correct classification, packaging, documentation and location; awareness actions with shippers/forwarders; enhanced gate/yard screening. Verification: documentation audits + random inspections. **Mitigate** (S↓): early fire detection in cargo areas; crew training for DG anomalies. Integration: DS with IoT/UAS for anomaly spotting in stacks.
Declared DG — Lithium-ion batteries	**Prevent** (L↓): pre-shipment inspection to detect damage; packaging/segregation rules; thermal exposure controls and stowage away from heat sources. **Mitigate** (S↓): dedicated cooling in battery stowage areas; Li-ion suited extinguishers; DS alerts on rising surface temperatures.
Electrical failures in reefer containers	**Prevent** (L↓): periodic inspections and preventive maintenance; remote monitoring of current/leakage/temperature; use of certified connectors and sockets. **Mitigate** (S↓): rapid/safe access procedures; localized oxygen-reduction or clean-agent systems in reefer racks; tactical cordons and boundary cooling if escalation.
Cargo shifting / poor stowage (ship & yard)	**Prevent** (L↓): proper dunnage, airbags, netting inside containers; lashings per code; "double-check" for critical stows; digital verification of slot and segregation (low flash-point cargo). **Mitigate** (S↓): quick access procedures to affected units; first-aid extinguishing on damaged boxes; on-deck sun-exposed tiers — sprinkling/active cooling readiness.
Human error / inadequate training	**Prevent** (L↓): monthly drills on abandon-ship and shipboard firefighting; competency-based stowage checks (two-person rule); port-community checklists aligned with T3.1 goals. **Mitigate** (S↓): clear emergency SOPs and job aids; surge capacity via specialized fire teams (on-call).
Mechanical failures in ship systems	**Prevent** (L↓): condition-based maintenance (temp/pressure/vibration/fuel KPIs); assurance of fixed fire-protection systems functionality. **Mitigate** (S↓): automatic fire containment in machinery spaces; fast evacuation protocols; critical spares management.
External factors (collision, stranding), piracy/sabotage	**Prevent** (L↓): navigational rule compliance; ship security measures (citadels/defensive posture); crew training for post-impact fire scenarios. **Mitigate** (S↓): robust comms and rapid coordination with SAR/authorities; pre-defined tactical modes and withdrawal criteria.
Port-wide emergency coordination (terminals & waters)	**Mitigate systemic impact** (S↓): activation playbooks (PMA/ACPs, cordons, mass-evac support), medical/psychological care, logistics flows and ship movement control per the Port of Valencia PAU action sheets. These measures bound escalation and support multi-agency command during ship or terminal fires.
Tactical doctrine for shipboard firefighting (MIRG alignment)	**Mitigate** (S↓): adopt Contain & Maintain as default at-sea strategy; ICS roles, dynamic risk assessment, tactical modes (Offensive/Defensive/Transitional), and phased withdrawal/evacuation triggers to protect responders and stabilize until alongside.

Table 39. Preventing and mitigating measures Spanish UC

Hazard type	Preventing and mitigating measures
Declared DG — Lithium-ion batteries	**Prevent** (L↓): pre-shipment inspection to detect damage; packaging/segregation rules; thermal exposure controls and stowage away from heat sources. **Mitigate** (S↓): dedicated cooling in battery stowage areas; Li-ion suited extinguishers; DS alerts on rising surface temperatures.
Incompatible or undeclared cargo stored together	**Prevent** (L↓): mandatory correct classification, packaging, documentation and location; awareness actions with shippers/forwarders; enhanced gate/yard screening. Verification: documentation audits + random inspections. **Mitigate** (S↓): early fire detection in cargo areas; crew training for DG anomalies. Integration: DS with IoT/UAS for anomaly spotting in stacks.
Flammable liquids and vapours from cargo or packaging	**Prevent** (L↓): Ensure accurate declarations for flammable liquids; strict segregation and stowage; minimize incompatible cargo interactions. Manage vapour generation: monitor boil-off, use appropriate venting/boiling-off controls, and apply inserting where applicable. **Mitigate** (S↓): Ensure accurate declarations for flammable liquids; strict segregation and stowage; minimize incompatible cargo interactions. Manage vapour generation: monitor boil-off, use appropriate venting/boiling-off controls, and apply inerting where applicable.
Vapours accumulating in holds or near cargo gear	**Prevent** (L↓): Ensure accurate declarations for flammable liquids; strict segregation and stowage; minimize incompatible cargo interactions. Manage vapour generation: monitor boil-off, use appropriate venting/boiling-off controls, and apply inserting where applicable. **Mitigate** (S↓): adequate extinguishing media for hydrocarbon fires (foam, appropriate dry chemical); ensure access for firefighting teams. Procedures for rapid isolation, cooling, and containment to prevent spread to adjacent cargo and structures.
Hot surfaces, overheated equipment, or electrical faults in engine rooms	**Prevent** (L↓): Regular inspection and thermography of electrical gear, switchboards, and heat sources. Ensure proper insulation, clearance, and loading to prevent overheating. Proactive replacement of aging cables, switchgear, and insulation. **Mitigate** (S↓): Reliable engine-room fire suppression systems (water spray, foam/water-mist, or approved systems) with readily accessible extinguishants. Ensure reefer units have proper protection and automatic shutoff when overheating is detected.
Short circuits, insulation failures	**Prevent** (L↓): periodic inspections and preventive maintenance; remote monitoring of current/leakage/temperature; use of certified connectors and sockets. **Mitigate** (S↓): rapid/safe access procedures; localized oxygen-reduction or clean-agent systems in reefer racks; tactical cordons and boundary cooling if escalation
Grain, flour, wood dust or other organic dust	**Prevent** (L↓): Regularly inspect for dust build-up, damaged packaging, or leaks that could generate ignition sources **Mitigate** (S↓): Use industrial vacuum systems with explosion-proof adherence.
Human factors and operational risks contributing to ignition	**Prevent** (L↓): monthly drills on abandon-ship and shipboard firefighting; competency-based stowage checks (two-person rule); port-community checklists aligned with T3.1 goals. **Mitigate** (S↓): clear emergency SOPs and job aids; surge capacity via specialized fire teams (on-call).
External factors (wind / thermal conditions on quay)	**Prevent** (L↓): navigational rule compliance; ship security measures (citadels/defensive posture); crew training for post-impact fire scenarios. **Mitigate** (S↓): robust comms and rapid coordination with SAR/authorities; pre-defined tactical modes and withdrawal criteria.

Table 40. Preventing and mitigating measures French UC

SECTION 14 SAFETY CULTURE

Task 3.3 examines the human and organisational dimensions of maritime safety culture within the framework of the OVERHEAT project. As maritime operations increasingly rely on complex technologies, multicultural crews and dynamic risk environments, understanding safety culture has become essential for ensuring resilient and reliable shipboard practices. Safety culture encompasses the shared values, attitudes, behaviours and organisational structures that shape how safety is understood and enacted in daily work. A mature safety culture is therefore a prerequisite for effective safety management and for preventing accidents and near-miss events.

The aim of Task 3.3 is to analyse how maritime professionals perceive and experience safety culture in their operational environments. To achieve this, an online survey was conducted in 2025, gathering quantitative and qualitative data from a diverse range of maritime stakeholders. The survey explored key dimensions of safety culture, including leadership, communication, reporting behaviour, training practices, digitalisation and the perceived prioritisation of safety in routine operations.

The results of this analysis provide valuable insights into strengths, weaknesses and emerging challenges in current maritime safety practices. Furthermore, they allow a systematic comparison with the safety goals established in Task 3.1, enabling a conceptual integration of empirical realities and project objectives. Building on these findings, Task 3.3 develops a practical safety culture checklist designed to support maritime organisations in assessing and improving their internal safety culture. This report presents the survey results, the derived conceptual framework and the resulting checklist to guide future safety-related practices across maritime operations.

14.1 METHODOLOGY

An online survey was conducted using the SurveyMonkey platform to collect both quantitative and qualitative data on safety culture in the maritime sector. The aim was to capture the perceptions, attitudes and experiences of professionals working in different maritime contexts relevant to Task 3.3.

The questionnaire was designed in English to ensure broad accessibility among international participants. Respondents were first asked to indicate their organisation type (e.g., shipping company, port authority, training institution, or other maritime-related field) and their current role (e.g., seafarer, officer, instructor, safety manager, or researcher). This approach ensured that the questions were relevant across diverse professional backgrounds and operational levels.

The survey consisted of both closed and open questions. Closed questions collected factual and frequency-based information on training, communication and safety behaviour. Open-ended questions invited participants to describe their personal views and experiences regarding safety awareness, reporting culture, leadership and potential improvement measures.

14.1.1 Data collection

Data collection took place between June and October 2025. Participation in the survey was voluntary and anonymous. All respondents received an information sheet outlining the purpose of the study, the intended use of the data and their rights under the General Data Protection Regulation (GDPR).
In total, 44 participants (N = 44) completed the questionnaire. They represented various sectors of the maritime domain, including shipping companies, training institutions, maritime authorities, insurance, offshore services and firefighting. The diversity of the respondents provided a comprehensive basis for analysing safety culture across both seagoing and shore-based perspectives. (SurveyMonkey Europe UC, 2025)

14.1.2 Data analysis and interpretation

All survey responses were analysed using a combination of descriptive statistics and qualitative content analysis. Quantitative data (e.g., agreement levels, frequencies) were summarised to identify general trends and highlight differences between stakeholder groups. Qualitative answers were systematically coded and categorised to extract recurring themes and relationships related to safety culture dimensions such as leadership, communication, learning and reporting.

14.2 RESULTS OF THE SURVEY

A total of 44 (N = 44) respondents participated in the survey. The sample represents a diverse range of professional backgrounds within the maritime domain. This diversity supports a broad understanding of safety culture from both operational and managerial perspectives.
More than half of the participants 52,6 % (n = 20) were employed by shipping companies, 31,6 % (n = 12) working in maritime education and training institutions and 15,8 % (n = 6) employed by other organisations such as insurance, offshore services and firefighting. No shares came from port authorities and maritime safety and security agencies. This distribution illustrates that the responses reflect both seagoing and shore-based viewpoints.
Regarding geographical distribution, participants were mainly located in Italy 61,5 % (n = 16), followed by Germany 19,2 % (n = 5) and individual responses from France (n = 1), Australia (n = 1), Malta (n = 1), Guyana (n = 1) and Romania (n = 1). The international composition ensures that the survey captures national and organisational differences in safety culture.
Respondents reported a broad spectrum of professional roles. These included captains, chief officers, deck officers, deck cadets, teacher and trainer, professors and representatives from fire departments and research organisations. Such variety reflects a comprehensive cross-section of maritime expertise. (SurveyMonkey Europe UC, 2025)
The participants (n = 26) also differed in terms of work experience, ranging from newcomers with less than one year of service to professionals with over 40 years of experience. The average

professional experience among respondents was approximately nine years, which suggests a balance between operational familiarity and long-term insight.
Overall, the sample offers a heterogeneous, yet coherent overview of maritime professionals involved in safety-relevant activities. Although the number of responses is limited, the diversity of roles, countries and institutions strengthens the reliability of the qualitative interpretations presented in the following section. (SurveyMonkey Europe UC, 2025)

Safety awareness and prioritisation
The survey results (N = 44) show a strong overall commitment to safety among participants. Figure 16 shows, that most respondents (65,2 %, n = 15) agreed that safety is a top priority in their daily work, with a mean score of 4,48 (n = 23) on a five-point scale. A large majority (88,5 %, n =23) also stated that they regularly participate in safety drills or briefings, indicating that structured safety routines are well established. (SurveyMonkey Europe UC, 2025)

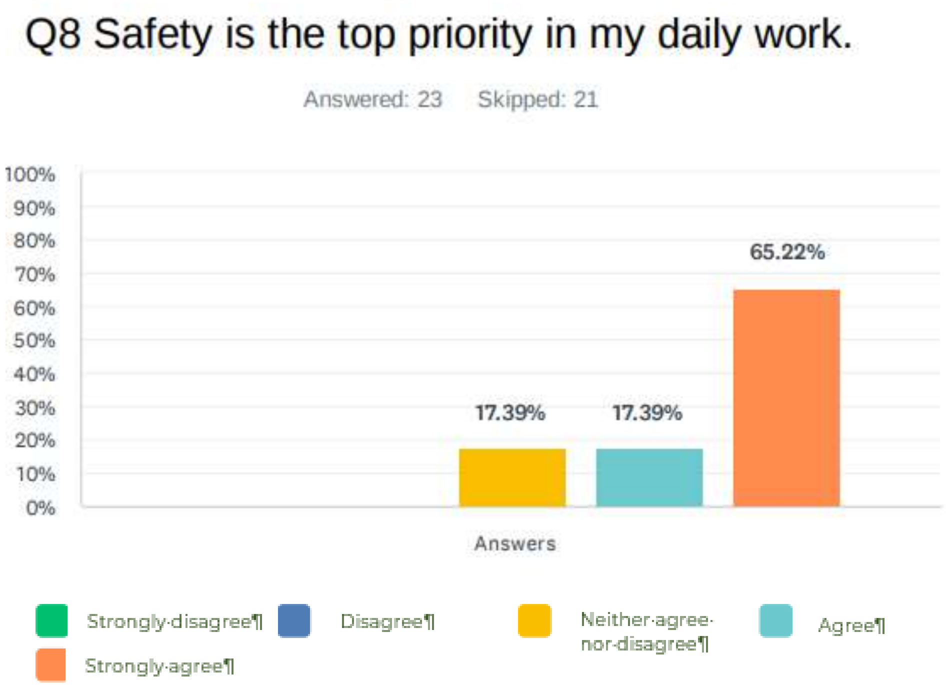


Figure 16: Q8 Safety is the top priority in my daily work.

Leadership and communication

Leadership behaviour emerged as a significant factor influencing safety culture. Respondents widely recognised that the attitude and example of supervisors play a decisive role in shaping onboard practices. The average response for leadership influence was 4,04 (n = 23), showing strong agreement that management behaviour impacts safety outcomes. At the same time, Figure 17 shows, only about one-third of participants (30,4 %, n= 7) felt that supervisors clearly communicate that safety takes precedence over commercial targets. Communication across hierarchies, particularly between crew, management and port authorities, was rated positively (mean 3,95, n = 21). (SurveyMonkey Europe UC, 2025)

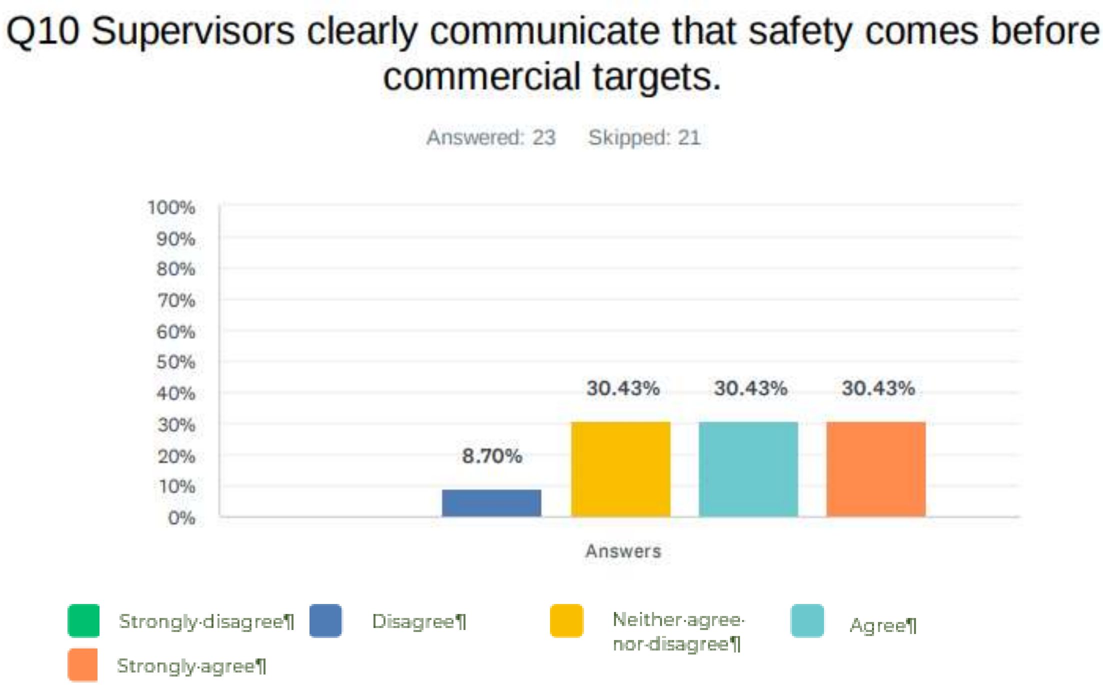


Figure 17: Q10 Supervisors clearly communicate that safety comes before commercial targets.

Reporting culture

The reporting culture in maritime organisations appears to be functional but not fully open. Most participants stated that they know how to report safety issues or near-misses (90,5 %, n = 19) and believe that such reports are taken seriously and lead to action (mean 4,10, n = 21). Despite this, 19,1 % (n = 4) admitted that they or colleagues had, at some point, hesitated to report incidents. The main reasons cited were fear of punishment (n = 1), concerns about consequences (n = 2) or conflicts with company management (n = 1). (SurveyMonkey Europe UC, 2025)

Training and competence

Training participation among respondents was high. 76,9 % (n = 20) had completed core STCW safety courses such as fire prevention and personal survival techniques within the past five years. Additional qualifications included confined space entry (23,1 %, n = 6), medical first aid, (50,5 %, n = 13) and dangerous goods handling (23,1 %, n = 6). While these figures reflect a solid foundation of technical safety competence, several participants emphasised the need for more practical, scenario-based training and continuous refreshers. In qualitative responses, crew members and instructors alike noted that repetitive training without context may lose impact, underscoring the importance of linking safety education to real operational experiences. (SurveyMonkey Europe UC, 2025)

Rule compliance and consequences

The perception of rule compliance varied. Figure 18shows, only 42,1 % (n = 8) of respondents agreed that safety rules are followed equally by all crew members. Most participants confirmed that repeated safety violations lead to clear consequences (63,2 %, n = 12), ranging from verbal warnings to dismissal. The open-text responses revealed a broad spectrum of enforcement strategies, from informal discussions with captains to strict disciplinary actions. (SurveyMonkey Europe UC, 2025)

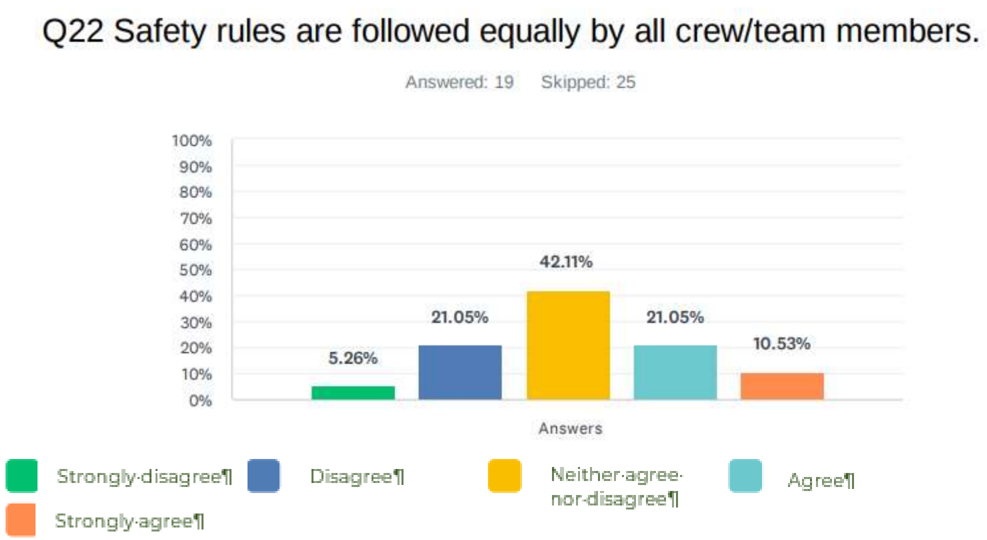


Figure 18: Q22 Safety rules are followed equally by all crew/team members

Learning culture

Figure 19 shows that many respondents agreed that safety audits and inspections are shared with the crew (61,1 %, n = 11) and that lessons learned from incidents lead to procedural improvements (77,8 %, n = 14). The mean value of 4,22 (n = 18) indicates that learning from experience is recognised, though the qualitative comments suggest inconsistencies. Some participants described active feedback processes and regular updates, while others mentioned that audit results are often “kept at management level.” (SurveyMonkey Europe UC, 2025)

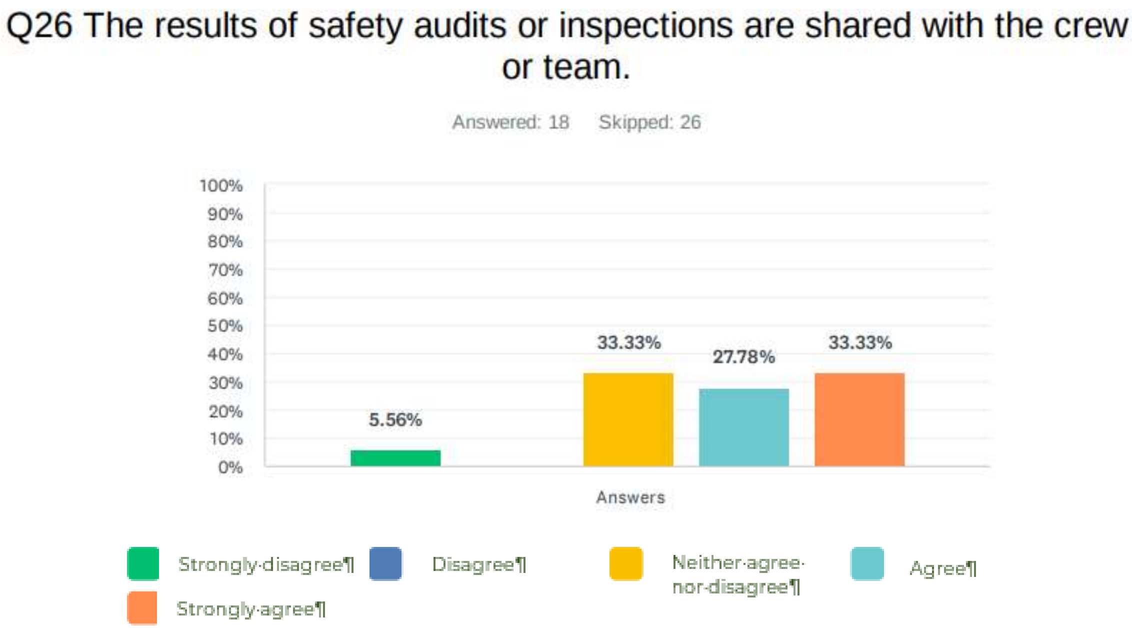


Figure 19: Q26 The results of safety audits or inspections are shared with the crew or team.

Technological and digital aspects

The role of new technologies and digitalisation received mixed responses. 55,6 % (n = 10) of the participants believed that new technologies such as AI-based monitoring are evaluated before being implemented, yet the mean score (3,39, n = 18) shows only moderate agreement. Figure 20 shows, respondents expressed cautious optimism about digitalisation improving safety culture (mean 3,61, n = 18). (SurveyMonkey Europe UC, 2025)

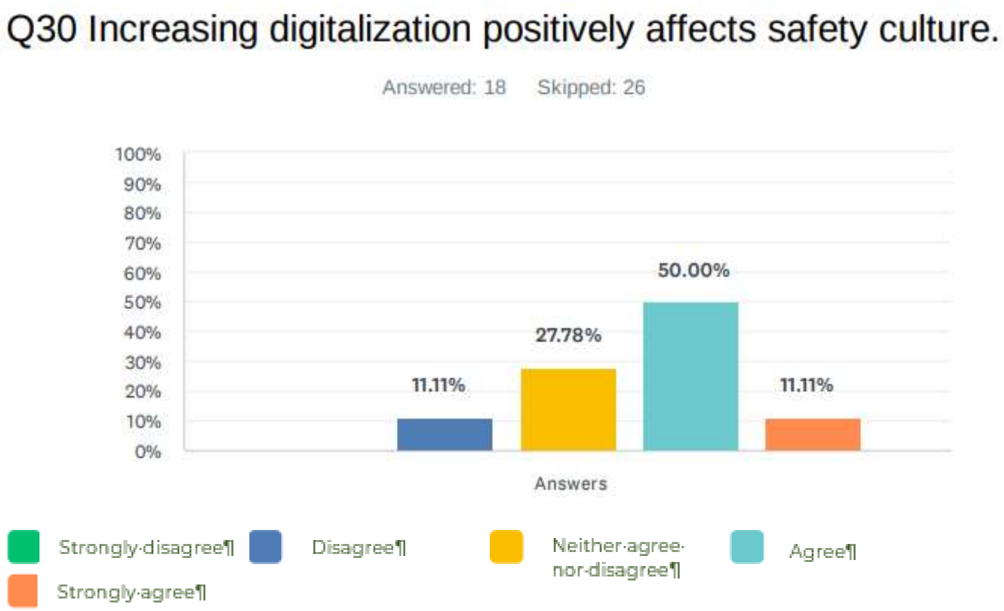


Figure 20: Q30 Increasing digitalization positively affects safety culture.

Definition and improvement of safety culture

The open-ended responses (n = 13) provide valuable insight into how maritime professionals define a strong safety culture. Many described it as a shared mindset where safety is not only a rule but a habit and collective responsibility. Recurrent themes included leadership, continuous training, open communication, awareness of risk and cooperation. Several participants stressed that a safety culture must begin “from the top” and be maintained through example and consistency. Others called for more realistic drills (n = 3), a stronger link between management and crew (n = 2) and a clear separation between safety and commercial priorities (n = 2). (SurveyMonkey Europe UC, 2025)

14.3 DERIVATION AND CONCEPTUAL INTEGRATION FOR TASK 3.3: FROM EMPIRICAL FINDINGS TO PRACTICAL FRAMEWORK

The derivation of results for Task 3.3 builds upon the empirical insights gained through the safety culture survey and aligns them with the overarching safety goals defined in Task 3.1. This section aims to translate the observed perceptions, attitudes and behaviours of maritime professionals into actionable cultural indicators. It thus forms the conceptual bridge between descriptive data and the development of the safety culture checklist.
The survey results revealed that safety is widely recognised as a key organisational value; however, the degree to which this awareness is embedded in daily practice varies across institutions and professional roles. Consequently, the derivation process focused on identifying patterns of alignment and deviation between the stated safety goals and the observed organisational realities. These patterns provide the foundation for targeted recommendations and practical assessment tools within the OVERHEAT framework.

14.3.1 Overview of safety goals defined in Task 3.1

Task 3.1 established a set of six overarching safety goals that form the conceptual foundation for strengthening maritime safety within the OVERHEAT project. These goals integrate technical, organisational and behavioural dimensions and aim to promote a proactive, learning-oriented safety environment. They represent the benchmark against which the empirical findings of Task 3.3 are evaluated.

The safety goals are defined as follows (C. Piccioni et al., 2024):

1. Enhancing crew awareness and safety behaviour

This goal focuses on promoting individual responsibility, risk awareness and adherence to safety practices. It emphasises that safe behaviour must be consistently embedded in daily operations and reinforced through shared norms and routines.

2. Strengthening leadership and communication structures

Leadership plays a central role in shaping safety culture. The goal includes fostering trust, ensuring transparent communication between ship and shore and enabling supervisors to actively prioritise safety over commercial pressures.

3. Improving training and competence

This goal aims to ensure that crew members possess the necessary theoretical and practical skills to handle safety-critical situations. It includes compliance with STCW requirements as well as the implementation of realistic, scenario-based training formats.

4. Establishing a just and reporting culture

A just culture requires that incidents, errors and near-misses can be reported openly without fear of punitive consequences. This goal addresses both procedural accessibility and the psychological safety needed to encourage transparent reporting.

5. Fostering learning and feedback mechanisms

To prevent repeated incidents, organisations need systematic processes for analysing events, sharing lessons learned and implementing improvements. This goal emphasises organisational learning, feedback loops and transparent communication of safety-related findings.

6. Integrating digitalisation and innovation in safety management

The maritime sector increasingly adopts digital tools, including monitoring systems and AI-driven solutions. This goal aims to ensure that technological innovations are implemented responsibly, evaluated transparently and aligned with user needs to support overall safety performance.

14.3.2 Comparison with safety goals of Task 3.1

The comparison between the empirical findings of Task 3.3 and the safety goals defined in Task 3.1 provides a structured assessment of how well maritime organisations achieve behavioural and organisational safety objectives. While Task 3.1 formulated six overarching goals, the survey results reveal a differentiated picture of their practical implementation. The following analysis evaluates the degree of alignment between intended goals and observed cultural reality.

1. <u>Enhancing crew awareness and safety behaviour</u>

The survey data show a high level of safety awareness among respondents, with the majority emphasising that safety is a core priority in daily operations. Regular participation in drills and familiarity with safety procedures are well established. These findings suggest substantial alignment with the first safety goal.
However, qualitative comments indicate variability in behavioural consistency across teams and organisations. This confirms that awareness alone does not always translate into robust daily practice. The goal can therefore be considered largely achieved, though reinforcement of situational awareness remains necessary.

2. Strengthening leadership and communication Structures

Leadership emerges as one of the least mature safety culture dimensions. Only a minority of respondents confirm that supervisors clearly prioritise safety over commercial interests. Although communication is generally evaluated positively, the qualitative feedback points to deficits in transparency, feedback provision and consistency of leadership behaviour.
The results reveal a partial fulfilment of this safety goal, indicating a need for targeted leadership development, improved role modelling and strengthened communication practices between ship and shore.

3. Improving training and competence

The data suggest that training requirements, particularly those governed by STCW, are widely met. Most respondents possess valid and up-to-date certifications. Nonetheless, many participants criticise the limited practical orientation of training and express a need for scenario-based exercises that reflect operational realities.
This discrepancy indicates that while regulatory compliance is high, training effectiveness is uneven. The goal is partially achieved but requires further development, particularly regarding experiential learning formats.

4. Establishing a just and reporting culture

The survey shows that formal reporting structures are well understood, with most participants knowing how and where to report incidents or near-misses. Despite this procedural readiness, approximately one fifth of respondents report hesitation to submit safety reports, mainly due to fear of negative consequences or punitive reactions.
These results demonstrate that psychological safety is insufficiently developed. The structural component of reporting is in place, but the cultural foundation for an open, just reporting environment remains weak. As such, this goal is not yet achieved.

5. Fostering learning and feedback mechanisms

The results indicate that learning processes exist but are inconsistently implemented. While many respondents confirm that lessons learned lead to procedural changes, others report that audit outcomes and incident analyses are not regularly communicated to crews.
This asymmetry limits collective learning and reduces the long-term impact of safety improvements. The goal is partially fulfilled, but organisations need more systematic, transparent feedback loops and inclusive learning structures.

6. Integrating digitalisation and innovation in safety management

The integration of digital tools, such as AI-based monitoring, is viewed cautiously but generally positively. Respondents acknowledge that technological innovations are typically evaluated before implementation; however, their perceived contribution to safety culture remains moderate.
This goal appears emergent rather than established. A stronger focus on user involvement, transparent assessment processes and crew-centred technology adoption is required to ensure effective and trusted integration of digital innovations.

14.4 SAFETY CULTURE CHECKLIST

The analysis of the survey results and their comparison with the safety goals defined in Task 3.1 form the foundation for developing the safety culture checklist. This checklist translates the empirical findings of Task 3.3 into a clear and practical self-assessment tool that can be applied directly on board and within maritime organisations. Its purpose is to support the evaluation and continuous improvement of safety culture by focusing on behavioural, organisational and communicative aspects of safety management.

Each assessment item corresponds to one of the six safety goals established in Task 3.1 and is formulated as an operational question (Table 41). The checklist enables users to evaluate current practices through a simple rating system (Yes, Partially, No) and to record required follow-up actions in a dedicated comments field. This structure helps identify strengths, highlight deficiencies and derive targeted improvement measures.

When used regularly, the checklist promotes continuous learning, strengthens awareness of cultural factors influencing safety and supports organisations in monitoring their progress over time. It thereby contributes to aligning cultural development with the technical and procedural objectives of D 3.1.

Safety Goal	Assessment Question	Yes	Partially	No	Action Needed / Comments
1. Crew awareness and safety behaviour	Is safety actively prioritised in daily operations?				
	Are risks consciously assessed before tasks?				
	Do crew members address safety observations among peers?				
2. Leadership and communication	Do supervisors clearly communicate that safety comes before commercial interests?				
	Is safety-related communication between ship and shore regular and transparent?				
	Do leaders act as role models by consistently following safety procedures?				
3. Training and competence	Are all mandatory STCW trainings valid and documented?				
	Are practical drills conducted regularly?				
	Are trainings realistic, scenario-based and linked to actual operations?				
4. Just and reporting culture	Do employees know how and where to report incidents or near misses?				
	Do employees feel safe reporting issues without fear of punishment?				
	Are submitted reports reviewed promptly and followed by feedback?				
5. Organisational learning and feedback	Are audit results, inspections or incident analyses shared with the crew?				
	Are lessons learned documented and used to improve procedures?				
	Are regular feedback sessions conducted to discuss safety-related experiences?				
6. Digitalisation and innovation	Are new technologies assessed before implementation?				
	Is the crew involved in or trained on new technologies before they are deployed?				
	Do digital systems practically support safety?				

Table 41: Safety culture checklist

14.5 RESULTS

Task 3.3 provides a comprehensive assessment of safety culture within the maritime sector by analysing the perceptions and experiences of a diverse group of professionals. The survey results highlight a strong general commitment to safety but also reveal notable inconsistencies across key organisational dimensions. While many respondents demonstrate high safety awareness and compliance with established procedures, critical areas such as leadership behaviour, transparent communication, just culture principles and systematic learning processes require further development.

By comparing the empirical findings with the safety goals defined in Task 3.1, the analysis shows that technical compliance alone cannot guarantee effective safety performance. Organisational and behavioural factors, particularly trust, psychological safety and clear leadership priorities, play a decisive role in shaping safety outcomes on board. These insights underscore that safety culture must be continuously reinforced, evaluated and adapted to evolving operational challenges.

The safety culture checklist synthesises the findings of Task 3.3 into a practical tool that enables maritime organisations to assess their cultural maturity and identify targeted improvement actions. When applied regularly, it supports long-term learning, strengthens crew engagement and enhances the alignment between organisational goals and daily practice. Through this contribution, Task 3.3 supports the overarching aims of Work Package 3 and the OVERHEAT project by promoting a proactive and resilient approach to maritime safety culture.

SECTION 15 ROLE OF D3.1 WITHIN WP3 AND INTERFACE WITH OTHER TASKS

Deliverable D3.1 provides the conceptual, methodological and regulatory foundations for the work to be carried out in the subsequent tasks and deliverables of WP3. In particular:

- The **navigation safety occurrence design and classification** introduced in Section 2 offers a common structure for describing and comparing safety-relevant events across the four OVERHEAT use cases. This structure will be used as a reference in Tasks 3.2 and 3.3 when defining detailed scenarios and selecting representative cases for further analysis.
- The **hazard identification and classification work** presented in Sections 2, 8 and 9 constitutes the baseline for the **risk assessment methodology** to be applied in Task 3.4. The hazard categories, severity and probability classes, as well as the risk matrix proposed in Section 7, will be directly reused and refined in that task.
- The **comparative analysis of risk assessment methods** (Section 4) and the **transferability study from aviation to maritime safety management** (Section 5) provide guidance for selecting consistent and efficient analytical tools in the subsequent quantitative and qualitative risk evaluations.
- The **scenario-based assessments** for the Spanish, German, Italian and Polish use cases in Section 11 serve as first operational applications of the occurrence design and classification framework. They will be further extended and, where appropriate, used as input for simulation-supported analyses and validation activities in later stages of the project.
- Finally, the **risk minimisation strategies and preventive / mitigating measures** summarised in Sections 10, 12 and 13 create a structured catalogue of possible interventions that can be assessed, optimised and prioritised in collaboration with end-users and stakeholders, contributing to the overall objectives of WP3 and the OVERHEAT project.

In this way, D3.1 does not only deliver a stand-alone review and conceptual framework, but also acts as a **key enabler and reference document** for all subsequent safety-related analyses within WP3.

CONCLUSIONS

This deliverable establishes a coherent and harmonised framework for analysing navigation safety occurrences in container transport, forming the conceptual and methodological foundation for Work Package 3 of the OVERHEAT project. Through the development of a unified occurrence design and taxonomy, the document bridges the gap between regulatory requirements, hazard identification, risk-assessment methodologies and practical scenario analysis.

The review of international, European and national regulations confirms the existence of a strong but fragmented safety framework, with notable inconsistencies in implementation and limited focus on emerging risks such as lithium-ion batteries, complex supply chains and misdeclared dangerous goods. The structured hazard classification presented in this deliverable provides a higher-resolution lens through which these risks can be analysed, integrating technical, operational, human-factor and external elements.

The comparative analysis of risk-assessment methodologies demonstrates that no single tool is sufficient to capture the multifaceted nature of fire-related hazards in container transport. Instead, the application of FMEA, FTA, ETA, HAZOP and What-If analysis must be coordinated within the unified occurrence design proposed in Section 2, which clarifies the relationships between hazards, initiating events, occurrences, consequences and safety barriers. The examination of aviation safety practices further highlights opportunities for enhancing maritime safety through structured reporting, predictive analysis, safety management systems, and continuous improvement cycles.

The four use cases included in Section 11 show how the occurrence design and taxonomy can be operationalised to support scenario building, risk evaluation and mitigation planning. The consistency achieved through this common structure enables meaningful comparison between different national contexts, operational environments and hazard profiles.

Finally, the risk-minimisation strategies and preventive and mitigating measures consolidated in this deliverable offer a comprehensive basis for subsequent WP3 activities. These measures will be further evaluated through simulation-supported analysis and integrated into broader safety frameworks designed to reduce the likelihood and consequences of fire-related events.

Overall, D3.1 delivers a well-defined conceptual backbone and a methodological foundation essential for achieving the objectives of the OVERHEAT project. By introducing a structured, cross-modal and scalable approach to navigation safety occurrences, the deliverable provides a critical enabler for improved fire-risk understanding, more effective operational planning and strengthened safety performance across the maritime container-transport chain.

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