Horizon 2020

Project acronym:	**LASH FIRE**
Project full title:	**Legislative Assessment for Safety Hazard of Fire and Innovations in Ro-ro ship Environment**
Grant Agreement No:	**814975**
Coordinator:	**RISE Research Institutes of Sweden**

Deliverable D08.1

Definition and parametrization of critical fire hazards, classification of cargoes, transport units, engines, fuels and vessels and identification methodologies

May 2021

Dissemination level: **Public**

Abstract

Based on historical data and previous projects; FIRESAFE 1& 2 (EMSA, 2021), Lighthouse In-door positioning on RoRo vessels (2017), these studies includes conclusions taken from the fire cause perspective and highlights the differences in fire sources, from the ship's equipment and the cargo. The statistics regarding the probability related to fires originating in ro-ro spaces was performed and subsequently used as input for a Hazard Identification (HAZID) workshop (LASH FIRE, 2020) where the main takeaways are:

- The ship's equipment is rarely the cause of fire, rather the ship's cargo is generally the culprit.
- Electrical fault originating in the ship's cargo is the most common cause of fires in ro-ro spaces.
- Although refrigerated units typically constitute a relatively limited proportion of all the carried cargo onboard it is statistically the most fire hazardous type of cargo in terms of probability and severity.
- While electrical failures in internal combustion engine vehicles constitute an apparent hazard, especially if the vehicles are in poor condition, there is little, if any, data that suggests electrical vehicles are more prone to fire than internal combustion engine vehicles.
- Gas leaks in Alternatively Powered Vehicles (APV) that leads to fire is a rare occurrence.

The HAZID workshop used the analytical component of the hazard identification from the background studies and was enriched with a future scope of work, based on the experiences from the participants. This ensured that identified hazards were not confined to those which have materialized in the past but also the experience from participants was collected and incorporated in the future scope of work. The workshop also elaborated on potential safety measures. Examples include advancing technologies such as drones, supplying crew and staff with dedicated thermal cameras, improved routines e.g. avoiding long cables, cable routing and using only ship cables. Several potential fire origins were identified, refrigeration units being one of them. Historical data shows that refrigeration units are more prone to fire than other types of cargo, and that refrigeration unit fires tend to be more severe; it was deemed beneficial to put special focus on these units.

These findings are used as input to define conditions for manual screening (WP06 Effective Manual Operations) of cargo fire hazards, more effective fire patrols and methods for automatic screening, identification of cargoes and a novel database that comprises of known risk e.g., IMDG and new challenges that has been identified in the HAZID. It is based on these findings that the foundation of the work in LASH FIRE, Work Package 8 (WP08) has been built.

A novel Cargo fire hazard database is being developed, it will serve as a tool in the stowage planning phase for specific cargos and vehicles e.g. placement onboard the ship, for a specific voyage. It will be supporting the online tool developed by WP07 Inherently Safe Design that, that supports the persons responsible for the loading of the ship. The goal is to increase the safety in the planning phase and assist in the decisions made during the loading phase by addressing LASH FIRE identified hazards. Two systems that uses sensor technologies are being developed, one is a gate system capable of screening a whole truck and trailer, while the other is a drone capable of monitoring specific types of vehicles and/or cargo. The gate system, Vehicle Hotspot Detection system (VHD) uses machine learning to provide a real time indication of heat signatures and anomalies as the unit passes through. The Automatic Guided Vehicle (AGV) will be used to monitor Battery Electric Vehicles (BEV) during charging to look for anomalies in the heat signatures of undercarriages and the battery banks, placed there. These systems will also support the work in WP06, WP09 Detection and WP07 by enriching the crews and stevedores with better assessment tools for the cargo and vehicles both during loading and voyage.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 814975

Document data

Document Title:	D08.1 – Definition and parametrization of critical fire hazards, classification of cargoes, transport units, engines, fuels and vessels and identification methodologies		
Work Package:	WP08 – Ignition		
Related Task(s):	T08.2, T08.3, T08.4		
Dissemination level:	Public		
Deliverable type:	Report		
Lead beneficiary:	01 – RISE		
Responsible author:	Robert Rylander		
Co-authors:	Martin Torstensson, Joakim Lundman		
Date of delivery:	2021-05 -05		
References:	D04.1		
Approved by	África Marrero, CIM on 2021-05-04	Erik Styhr Petersen NTNU on 2021-05-04	Maria Hjohlman, RISE on 2021-05-04

Involved partners

No.	Short name	Full name of Partner	Name and contact info of persons involved
01	RISE	Research Institutes of Sweden AB	Robert Rylander, robert.rylander@ri.se Martin Torstensson, martin.torstensson@ri.se Joakim Lundman, joakim.lundman@ri.se
16	CIM	Centre Internacional de Metodes Numerics en Enginyeria	África Marrero, amarrero@cimne.upc.edu Franisco Rodero, francisco.rodero@upc.edu
13	SIC	SICK AG	Markus Haas, markus1.haas@sick.de
17	MAG	Magellan Associacaop Para A representacao dos intereses portugueses no exterior	Filipe Ribeiro, fbr@magellan-association.org Manuela Flachi, maf@magellan-association.org
9	BV	Bureau Veritas Marine & Offshore Registre International De Classification De Navires Et De Plateformes Offshore	Blandine Vicard blandine.vicard@bureauveritas.com

Document history

Version	Date	Prepared by	Description
01	2020-02-29	Robert Rylander	Preliminary structure
02	2021-03-05	Robert Rylander	First draft of final report,
03	2021-03-17	Robert Rylander	Second draft of final report,
04	2021-03-24	Robert Rylander	Draft circulated to reviewers
05	2021-04--26	Robert Rylander	Revision circulated to reviewers
06	2021-05-04	Robert Rylander	Final report

Content

1 Executive summary

Main author of the chapter: Robert Rylander, RISE

This report covers the work in first stage of the LASH FIRE work package 8 Ignition prevention part, action 8 A.

1.1 Problem definition

Current cargo monitoring and stowage tools in ro-ro spaces are not optimal when it comes to prevention of fires. There have been several fire incidents in the previous years that have originated mainly in vehicles in the cargo holds. These incidents are a matter of grave concern as they not only pose a threat to loss of lives, but also due to the environmental aspects as well as large economic impacts related to fires onboard.
Hence, not only ship operators but any stakeholder related with maritime transport and even any client, should require risk-based stowage to be able to ensure a minimized fire risk. Such risk-based stowage must be flexible to any ship, to any deck and to any distribution of cargo.
To achieve this, an assessment procedure, able to organize the specific types of cargo and vehicles the different ro-ro spaces of a ship, minimizing the fire hazards on the decks will be developed.
The use of remote sensing, both to scan various types of vehicles and rolling cargo and detection of heat anomalies on vehicles and cargo, as well as enrich the situational awareness by monitoring certain vehicles during the sea voyage with drones running underneath the undercarriage of alternative powered vehicles.

1.2 Technical approach

As mentioned, minimization of the fire hazards is to be done through an assessment of the cargo in the ro-ro space. This assessment will consider three main variables: the ro-ro space (closed, open, or weather deck), the cargo type (dangerous or non-dangerous goods) and if it is transported by a vehicle or not and if so which type of vehicle, etc.

Cargo Fire Hazard Database

Statistics regarding probability and severity gathered from previous projects as well as other sources has been collected and evaluated and is used as base for the database. This historical data will then be available to be applied on the current planning phase of the stowage and segregation plan for a specific voyage. In the planning phase, once cargo and vehicles that need special attention is available, this information is used (input) in the procedure to assess and calculate not only the risk that a certain cargo has for a given position onboard, but also the risk considering the other types of cargo that are located in its surroundings. After evaluating different cargo distributions on the deck, the one with minimum fire risk can be uses by the operator (output). This output can then be used as input to either a tool such as a computer-based optimisation software, or direct to an operator.

Sensors

From other domains the usage of remote sensing technologies to scan and monitor objects of interest LASHFIRE brings this concept to include the dynamic situation of cargo and vehicles to be loaded onboard ships. The vehicles and cargo that WP08 will monitor is derived from the concept used to automatically screen rolling vehicles and cargo prior to entering some of the longest tunnels in central Europe. After the vehicle and/or cargo is parked/stowed onboard, a mobile automated guided vehicle will be used to repeatedly monitor specific type of vehicles such as battery electric vehicles or other specific cargo. The sensor platform could be stationary, flying or driving on the cargo deck depending on the operational context. In WP08 the work is directed to monitoring and inspection of rolling cargo/vehicles on a deck, using a ground-based drone to look for anomalies and the primary scope is to detect heat anomalies from the undercarriage of vehicles during the sea voyage using thermal sensors.

1.3 Results and achievements

The results obtained show a current picture of the main hazards that can cause fire in the cargo of ro-ro spaces.

A cargo fire hazard database, which aims to establish relations between the cargo and risk of ignition, has been successfully created from heterogeneous sources as further explained below in Chapter 6, in this document. Such kind of specific compilation did not exist, so the completion of the database represents an important achievement for later exploitation in the LASH FIRE project.
Data of 446 accidents on ships and other areas of interest have been evaluated. The role played by conventional vehicles, refrigerated units and electric vehicles as the main sources of fire is highlighted, as well as electrical failure as the main fire cause identified in prior projects; FIRESAFE 1& 2 (EMSA, 2021), Lighthouse In-door positioning on RoRo vessels (2017) and collaboration with the ALBERO project (ALBERO , 2021). The literature assessment results in a series of recommendations for the location and management of the different transported units that can be found on this type of Ro-Ro ship based on their associated potential risk.

This deliverable builds on the results from tasks T08.2 – T08.4 and will feed directly into future deliverables D08.2 and D08.3 and indirectly into D08.4 and D08.5. It supports the future work in WP06 Effective Manual Operations, WP07 Inherently Safe Design and WP09 Detection.

1.4 Contribution to LASH FIRE objectives

This deliverable contributes to the LASH FIRE objective of strengthening the independent fire protection of ro-ro ships by developing and validating effective operative and design solutions addressing current and future challenges in all stages of a fire. Work package 8 on Ignition Prevention focuses on improving prevention of fire.
The contribution documented in this report is a novel new assessment methods that will allow a risk-based stowage of cargo. Applying this method, a new cargo distribution will be imposed that will entail a greatly reduced fire risk. Sensors will be used to better understand the state of the vehicle and cargo, before loading onboard and under the transport.

It will also allow to recognize risks in the cargo planning tool developed, so that means of rapid identification of fire can be provided, resulting in less consequences of fires on the ship.

1.5 Exploitation and implementation

The results and conclusions of this report will improve fire safety in ro-ro ships so any stakeholder or individual involved in maritime transport will be beneficiated. Nevertheless, ship operators will probably be the most benefited stakeholder since the flow of vehicles and cargo, loading and unloading on board the ships, is directly related to them. Moreover, reducing the fire hazards entails reducing the probability of consequences to the marine life and economic loss due to repairs etc.

Furthermore, this assessment can be useful for other organisation such as research centres, university departments or even insurance companies to assess other situations. It could even be exploited or slightly changed to evaluate scenarios for spaces similar to a ro-ro space, such as tunnels or parking spaces.

In the end, the goal of work package 8 is to demonstrate several future tools, such as a an efficient, flexible and fast algorithm able to organize the available cargo. This algorithm should be used at any loading operation to minimize the fire hazards. Usage of remote sensing and drone technology to understand the state of the vehicles and cargo, prior and during the sea voyage.

2 List of symbols and abbreviations

2D	Two Dimensional
3D	Three Dimensional
AC	Air Conditioning unit
ADR	A Accord européen relatif au transport international des marchandises Dangereuses par Route
AFV	Alternative Fuel Vehicle, see APV
AGV	Automated Guided Vehicle
ANSI	American National Standards Institute
APU	Application-Processing Unit
APV	Alternative Powered Vehicle
ATEX	Appareils destinés à être utilisés en ATmosphères EXplosives
BEV	Battery Electric Vehicle
BV	Bureau Veritas
CIAIM	Comisión Permanente de Investigación de Accidentes e Incidentes Marítimos
CFHD	Cargo Fire Hazard Database
CSV	Comma Separated Values
DB	Data Base
DBMS	Data Base Management System
EMSA	European Maritime Safety Administration
ER/ERF	Entity Relationship / Entity Relationship Diagram
EX	Explosive atmosphere e.g area were hazardous gases and/or dust could be present
FIFI	Fire Fighting equipment
FLIR	Forward-Looking IR
FK	Foreign Key
FOV	Field of view
FSI	Flag State Implementation
GISIS	Global Integrated Shipping Information System
Hazmat	Hazardous materials

HBMCI	Hellenic Bureau for Marine Casualties Investigation
HMI	Human Machine Interface
IBC	Intermediate Bulk Container
ICE	Internal combustion engines
IMDG	International Maritime Dangerous Goods Code
IMU	Inertial Measuring Unit
IR	Infrared light
ISO	International Organization for Standardization
LiDAR	Light Detection and Ranging
MAFI	Transport-Systeme GmbH, flatbed cargo carrier
MEMS	Microelectromechanical systems
MOAG	Maritime Operators Advisory Group
MTIP	Ministry for Transport, Infrastructure and Capital Projects
NIST	National Institute of Standards and Technology
NTP	Network Time Protocol
PK	Primary Key
PTP	Precision Time Protocol
RFID	Radio-Frequency Identification
Reefer	Refrigeration Unit e.g. air conditioning unit on a trailer or container
Ro-ro cargo ship	Roll On-Roll Off cargo ship
Ro-pax	Roll On Roll Off passenger ship
SHA	Secure Hash Algorithms
SMS	Safety Management System
SoS	System of systems
SQL	Structured Query Language
SW	Software
TOF	Time-of-flight
VBA	Visual Basic for Applications
VC	Vehicle Carrier
VDG	Detection of vehicles transporting hazardous materials
VHD	Vehicle hot spot detector

UWB	Ultra Wide Band radio technology
WP04	Assesement
WP06	Work Package 06 Effective Manual Operations
WP07	Work Package 07 Inherently Safe Design
WP09	Work Package 09 Detection

3 Introduction

Main author of the chapter: Robert Rylander, RISE

This document has three systems to describe: database, sensors for scanning whole cargo and vehicles and a drone system for monitoring vehicles and cargo. They all share the cargo and vehicles, but they operate in very different conditions and face different challenges, and operational aspects that have to be considered. The report will describe a generic flow road to road, the systems place in this flow and how they add value to an increased safety of passengers, crew, environment, cargo and ships.

3.1 Document structure

Chapter:

3. Introduction, includes background to the tasks in WP08 that lead up to the proposed solutions.

4. Definition of hazardous goods and vehicles looks to today's governing codes when it comes to stowage and segregation of good and vehicles and the IMDG code.

5. Definition and classification of transportation units, focuses on the vehicles and trailers including new energy carries for vehicles.

6. Cargo fire hazard database, how WP08 aims to creating a novel concept to be able to capture the increasing variety of cargo and vehicles and a software tool to support decisions to be made during planning and stowage of cargo and vehicles on a specific voyage.

7. Definition and parameterization of ships, is about the definitions and the conditions the physical designs of the ships have been defined in LASH FIRE.

8. Identifications methodologies, this and the following chapter 9 to 11 describes methods and challenges for different technologies and systems used to scan and monitor both vehicles and cargo. In this chapter a Vehicle Hotspot Detection (VHD) system, customized for the usage in this project is introduced.

9. Tracking and positioning of cargo/vehicles onboard ships, this chapter describes different technologies that could be used to enable an automatization of tracking and registrations of the individual cargo or vehicles position onboard a ship.

10. Drone techniques for surveying cargo/vehicles, this chapter describes the operational context for flying and ground-based drones.

11.System of systems, describes briefly how an architecture that make use of other systems and human input, is the foreseen solution.

12. Demonstration of systems, this briefly describes the work package planned activities to validate the subsystems performance in a real-life context.

13. Conclusions, short report on what has been done, what is ongoing at this stage in the project and the next stage.

3.2 Background

A background study concerning fire causes in ro-ro spaces was performed and subsequently used as input for a Hazard Identification D04.1 (LASH FIRE, 2020). The main takeaways from the background study are:

- The ship's equipment is rarely the cause of fire–rather, the ship's cargo is generally the culprit;
- Electrical fault originating in the ship's cargo is the most common cause of fire in ro-ro spaces;
- Although refrigerated units typically constitute a rather limited proportion of all the carried cargo onboard, it is, according to statistics, the most hazardous type of cargo, in terms of probability, but also in severity;
- While electrical failures in internal combustion engine vehicles constitute an apparent hazard, especially if the vehicles are in poor condition, there is little, if any, data that suggests electrical vehicles are more prone to fire than internal combustion engine vehicles; and
- Gas leak in Alternatively Powered Vehicles that leads to fire is a rare occurrence.

The background study comprised the analytical component of the hazard identification and was subsequently complemented with a creative element, i.e. the HAZID workshop which ensured that the identified hazards were not confined to those which have materialized in the past. The workshop also focused on identifying potential safety measures. Examples include advancing technologies like drones, supplying ro-ro space personnel with dedicated thermal cameras, improved routines e.g. avoiding long cables and cable routing, and using only ship cables i.e. prohibiting passengers from using their own cables.

Several potential fire origins were identified, refrigeration units being one of them. Taking into account that refrigeration units are more prone to fire than other types of cargo, and that refrigeration unit fires tend to be more severe; it was deemed to put special focus on these units.

These findings are used as input to define conditions for manual screening of cargo fire hazards and effective fire patrols as well as describing methods for automatic screening and identification of cargoes and a novel database that comprises of known hazards e.g. IMDG and new that has been identified in the HAZID, that work package 8 and this report is based on.

3.3 General flow of cargo and vehicles considered in WP08

Main author of the chapter: Robert Rylander, RISE

In WP08 analysis have been conducted to create a general flow of cargo/vehicles, based on input from various ship operators, terminals and type of trade.

In the illustration below in Figure 1, a general Road to Road flow is depicted, from left to right:

1. The cargo/vehicle (object) arrives to the terminal/port on road, but it could be other types of carrier such as rail.
2. The object passes the gate and enters the terminal/yard area, and is directed to a designated lane/parking spot/area
3. When the cargo/vehicle enters the terminal/yard controlled by the port/shipping company
4. At point of time during the cargo operation, new cargo will start rolling onboard the ship. Depending on the ships and terminal specific physical layout, single or multiple flows of cargo/vehicle occurs.
5. When the cargo/vehicle is inside the hull of the ship, the flow can be diverted into multiple decks/lanes and the cargo/vehicle comes to its final position onboard the ship. Cargo is stowed and secured by fastenings/lashings, and on some occasions even vehicles will be lashed to the ship e.g. securing for harsh weather.
6. When the cargo/vehicle off-loading begins in the arrival port, lashings/fastenings will be removed, electrical connections will be removed. After that the cargo/vehicle is ready to roll off the ship.
7. During the offloading, there can be several flows out of the ship and over the quayside.
8. At one point, the cargo/vehicle exits the port/terminal control area and back on the public roads.

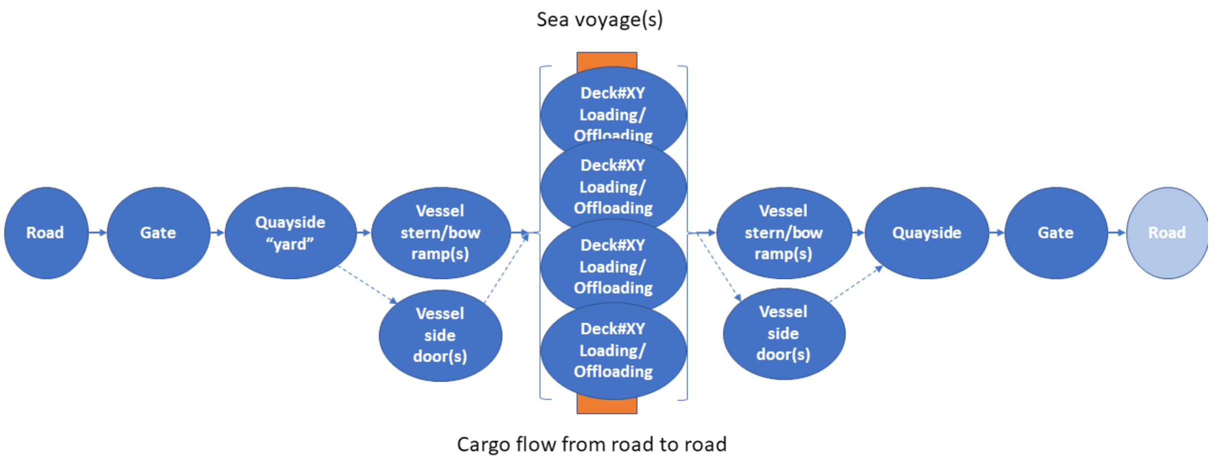


Figure 1 Road to road flow for an object Source Robert Rylander RISE

In the above road to road flow there is mesh of information flowing between actors and an iterative process ongoing, for some trade and routes it is an open process right up to time for departure and the ramps are lifted and doors of the ship is closed.

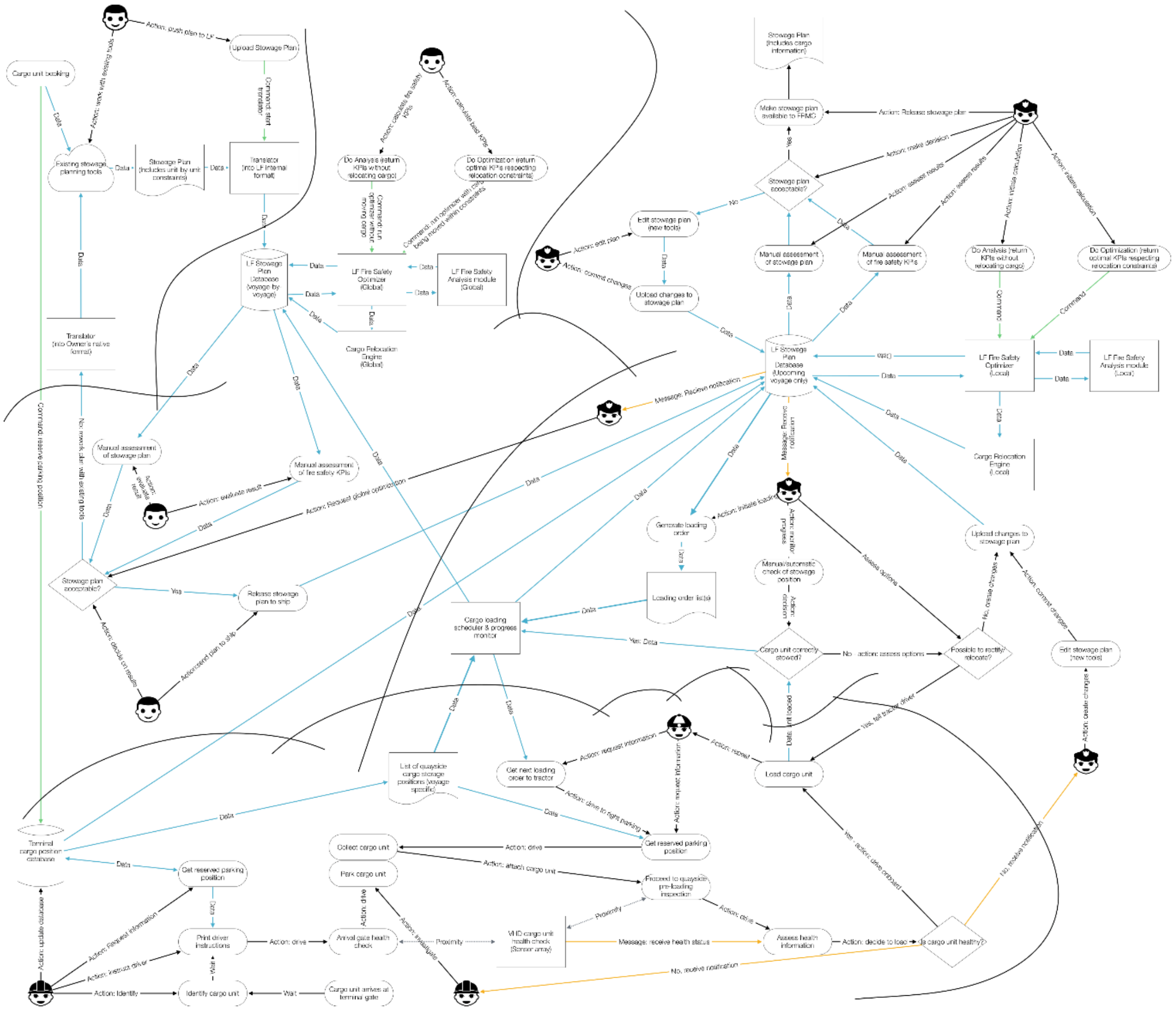


Figure 2 Actors and actions in stowage planning iteration (Source Erik Styhr Petersen, NTNU)

In the illustration above there are four roles illustrated, depending on trade and company, this could look very different. But in general, there is a booking/planning phase that transition to a cargo operation phase and ends in a documentations phase that should be completed prior to departure.

Table 1 Roles in planning and cargo operation

Icon		
	Staff, Load Master (usually from shore)	Handling booking, IMDG and performs planning of the upcoming voyages
	Staff at the terminal includes stevedores	Directing incoming cargo and vehicles, tug operators if unaccompanied trailers, could perform duties as cargo securing etc.
	Ship deck crew,	Supervising the loading/unloading operation, connecting/disconnect reefers on the ship. Acting as eyes on the scene during loading/offloading operations.
	Ships Chief Officer,	Responsible for loading, stowage, segregation and ship stability on behalf of the ships master.

As illustrated in Figure 2 above, a lot of information flows between all actors, and they have support systems and procedures to support them in their roles. A general description of these systems will follow in the next chapter Support systems today below.

3.3.1 Support systems today

To facilitate the flow of cargo/vehicles, there are several support functions, procedures and systems in place and in WP08, novel support systems are introduced. In general, they are identified as:

Booking system, a ship operators' system to manage timetable, ship capacity (number of passengers/cabins/lane meters etc). In the booking system several useful attributes to the cargo/vehicle can be stored e.g. type of object, registration plates, IMDG, size etc

Trim and stability calculations, ship specific system for management of planned and actual trim and stability calculations, normally computer assisted calculations.

IMDG -procedure, how to handle IMO IMDG classified goods. It can be based on a paper procedure or a computerised system. The ship should have information about booked IMDG goods in advances so appropriate stowage and segregation can be fulfilled.

Gate control, secure entrance and exit to/from port/terminal. This can be manually operated to fully automated systems. In general, a verification between at the gate present cargo/vehicle and the booking is done. Outbound cargo/vehicles are generally also undertaken some kind of control, either by the ship operator/terminal but it is in many cases also a matter for the customs.

Yard/Terminal, all ports/terminal are different, but in general a local/company specific practice is used to store/park and control cargo/vehicles. And cargo/vehicles in need of extra attention/separation are handled, e.g. by specific lanes/spots/areas for IMDG, reefers that need electrical power from the ship during sea passage etc. All types of systems are used, manual to software supported.

Cargo/Stowage procedure, depending on trade/type of ship, all levels of planning and execution of loading procedures are in place. Shorter routes have in general less need for pre-planning and the actual loading is ad-hoc depending on what kind of cargo is waiting on the quayside. Other trades where the ship have several ports of call during one voyage for a specific cargo/vehicles or group of cargo/vehicles correct planning and execution is crucial for effective port calls. Ships roaming the world such as Vehicle carriers (VC) is one example. This procedure can be manual or supported by software.

At the moment many of these systems are standalone in the sense they do not communicate machine to machine, on the other hand, they operate all over the world, in all conditions. Sometimes, keeping system separated is beneficial in a cyber security perspective but efficiency is lower.

3.4 LASH FIRE WP08 introduced concepts

3.4.1 Cargo Fire Hazard Database

The cargo fire hazard database with its statistics on probability and severity of type of incident, aims to support a pre-emptive fire hazard management application and operations, such as the stowage planning process, resulting in a direct reduction of consequences of a fire. Thus, it represents a direct contribution to one of the strategic objectives of the project by providing a recognized technical basis for the revision of international IMO regulations. To be more specific, by developing and validating effective operative and design solutions addressing current and future challenges in all stages of a fire. To achieve this, a two-step methodology has been performed, composed of a compilation of information and a subsequent structuring in terms of a relational model to ease the development of applications on top of the database.

3.4.2 Usage of sensors to scan and monitor objects

The other two uses sensors to survey the cargo and or vehicles, one is stationary, and one is mobile as a drone. As depicted below and highlighted in red, the use of sensors can screen the object as it enters the terminal in the gate, follow it and keep track of its position at the yard/terminal and follow the object as in rolls onboard the ship. Inside the ship it can be used track the movements, record the objects final position, and during the sea voyage same sensors can monitor the objects and give live feed of the situation onboard.

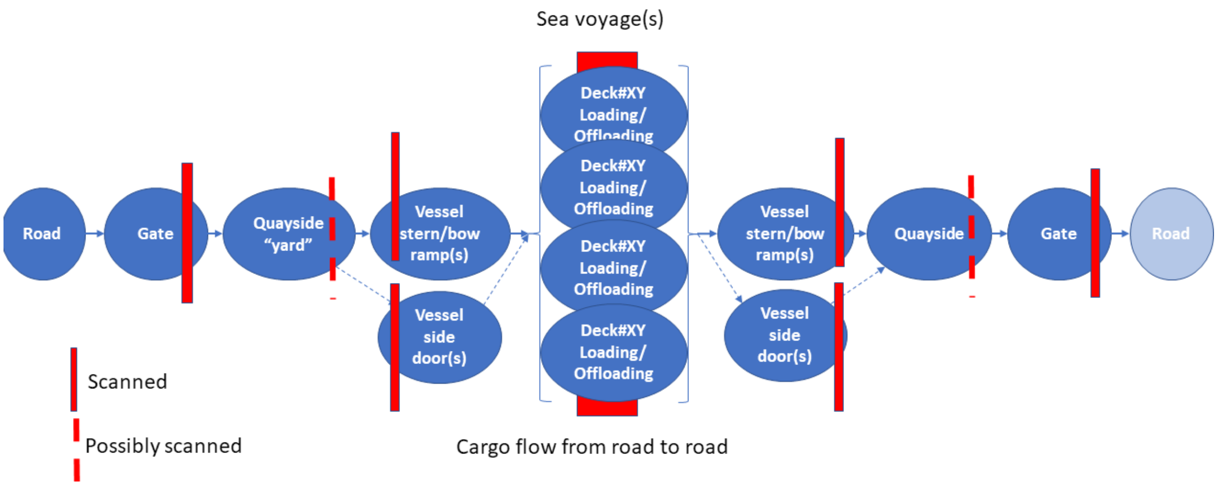


Figure 3 Possible points of scanning of objects. Source Robert Rylander, RISE

These systems can be both fixed and mobile, depending on many factors.

3.4.2.1 Fixed

In this report a fixed state of the art system called Vehicle Hotspot Detection (VHD) (described in chapter 8.5.7) and Vehicle Dangerous Goods (VDG) (described in 8.6.2) systems produced by project partner SICK AG, is used and modified for the specific new challenge identified in LASH FIRE HAZID in chapter 3.2 , the reefer units. The system combines colour cameras, laser scanning (LiDAR) and infrared sensors (IR) to build a 3D model of the object and add hot spots on the model. Such system also brings a lot of added values to the project since it is already capable of detecting many other segments of the unit that is of interest from a fire safety perspective such as overheated mechanical parts, heat signature of the cargo area/volumes and type of object(s) and is proven as a safeguard at longer tunnels across the world to prevent vehicles with mechanical malfunctions or other hot spot anomalies from entering.

3.4.2.2 Mobile

In work package 8, a novel test is developed to use an Automated Guided Vehicle (AGV) to complement fixed sensors systems with a system that can go underneath or between objects on a cargo deck, into areas that humans cannot reach and elevated sensors cannot see.

The AGV will be fitted with different sensors, but the main sensors for early detection is infrared sensors. Other sensors such as gas detectors, linear heat sensors could also be fitted on such system.

Cameras used for navigation and object detection, can also act as input to a flame detection algorithm.

Both the fixed and mobile systems sensor platforms and functionality goes in line with the work conducted in WP 06, 07 and 09, the concept of a systems of system approach is recommended and it will make best use of the technology and increase the return of investment.

Below is a simplified illustration of the proposed concept, there are several dynamic information streams into a future system. How a final implementation looks will be depending on many local factors. And also the result of the proposed stowage will affect other systems such as stability and calculations, that might be rejecting the plan and a new iteration with load and stowage planning might have to take place. And the planned and final residual risk factor could be part of the cargo manifest in the future.

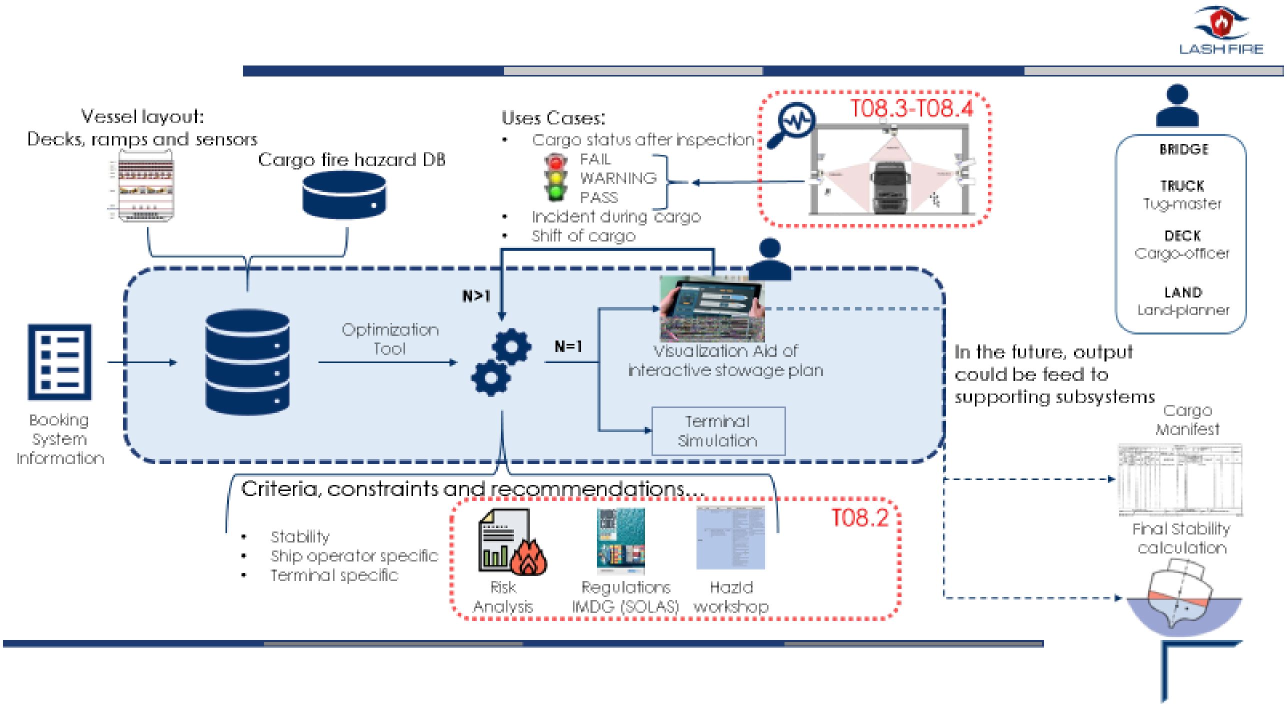


Figure 4 Dynamics of a Fire Hazard Management Tool and support systems in WP08 (CIMNE & RISE)

On a more global level the system could be used during planning, cargo operations and at sea as illustrated below. The traffic light is shown to illustrate the supporting systems status. How it will look in real life is not defined by this part of the project. A system on a green light level, would indicate a low risk or no know issues. Amber, a raised level of risk or an early indication of anomaly. And finally, red, would be considered an unacceptable level of risk requiring mitigating actions must be implemented or direct actions done. Similar analogy of usage of lights to indicate the status of operations can be found in the oil and gas industry of shipping (Martime, 2021).

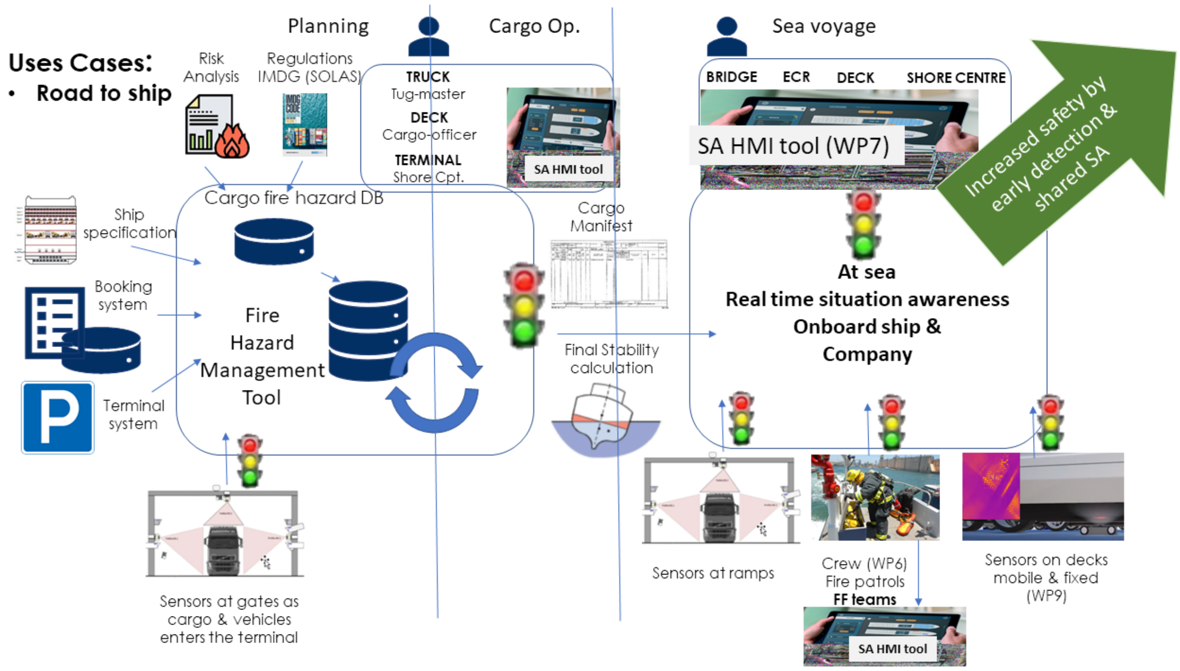


Figure 5 Use case for WP08 is road to ship (RISE/CIRM)

The calculated residual risk after the cargo operation is completed, will be visible to crew onboard and the personnel ashore. With this enriched information, adequate mitigations during the voyage can be implemented. The continuous feed of real time information from sensors onboard does not only support early detection capability but also adds vital on scene situational awareness if an incident should occur. The operational picture above does not exclude the more traditional sensor arrays onboard such as smoke/heat detectors, ship internal CCTV systems. And it is a system that must allow human interaction, and both enrich the picture and be able to correct errors and enter data manually. In the era of Internet of Things, this type of tools could be enriched with many new types of data in the future and processing could be supported by machine learning techniques.

All proposed solutions from WP08 are based on a cooperative information technology system architecture also known as system of systems (SoS), where data is mainly exchanged machine to machine, but also manually operations are a source of input and output from such system. It is recommended that standards or de facto standards that are used in other domains and over Internet, are reused for robustness and interoperability between systems.

The results of WP08 will compose of tested prototypes aiming at demonstrate how new components can be integrated in a near future by the industry (with a bit of further development) driving to fit in existing products and new systems that will enhance the fire safety at sea, terminals and ports.

4 Definition and classification of cargoes

Main author of the chapter: África Marrero, CIM

Definition of hazardous goods and vehicles are today's governing codes when it comes to stowage and segregation of good and vehicles. The IMDG code is the most comprehensive and LASHFIRE is adding a new dimension to these standards by addressing the occurrence of recorded incidents as well as APVs as risks to be considered when planning and loading the ship. In this chapter the focus is items classified as dangerous goods onboard a ship.

4.1 General Cargo

General cargo is any type of cargo that is transported in small quantities and in independent units. The number of packages can be counted and are therefore handled as units. They are transported and stored together. This cargo is divided into single (non-unitized) and unitized.

Single (non-unitized): this type of cargo consists of single or individual goods, handled and shipped as separate units.

Unitized: Unitized cargo is composed of individual items such as boxes, packages or other disunited items or individual cargo grouped in units such as pallets and containers, which are ready to be transported.

4.2 Dangerous Goods

Dangerous Goods are articles or substances that may pose a significant risk to the health, safety or environment of both persons handling them and other cargo that may share the space within a ship.

4.2.1 Classification according to IMO IMDG

Class 1- Explosive substances and articles

Explosives are materials or items which could rapidly conflagrate or detonate as a consequence of chemical reaction.

Subdivisions

- Division 1.1: Substances and objects that present a risk of explosion of the entire mass
- Division 1.2: Substances and objects that present a projection risk, but not an explosion risk of the whole mass
- Division 1.3: Substances and objects that present a fire risk and a risk of occurrence small shock wave or projection effects, or both, but not a risk explosion of the entire mass
- Division 1.4: Substances and objects that do not present any considerable risk
- Division 1.5: Very insensitive substances that present a risk of explosion of the entire mass
- Division 1.6: Extremely insensitive objects that do not present a risk of explosion of the entire mass

Class 2- Gases

Gases are defined by dangerous goods regulations as substances which have a vapour pressure of 300 kPa or greater at 50°c or which are completely gaseous at 20°C at standard atmospheric pressure, and items containing these substances. The class encompasses compressed gases, liquefied gases, dissolved gases, refrigerated liquefied gases, mixtures of one or more gases with one or more vapours of substances of other classes, articles charged with a gas and aerosols.

Subdivisions

- Division 2.1: Flammable gases
- Division 2.2: Non-flammable, non-toxic gases
- Division 2.3: Toxic gases

Class 3- Flammable liquids

Flammable liquids are defined by dangerous goods regulations as liquids, mixtures of liquids or liquids containing solids in solution or suspension which give off a flammable vapour (have a flash point) at temperatures of not more than 60-65°C, liquids offered for transport at temperatures at or above their flash point or substances transported at elevated temperatures in a liquid state and which give off a flammable vapour at a temperature at or below the maximum transport temperature.

Class 4- Flammable solids

Flammable solids are materials which, under conditions encountered in transport, are readily combustible or may cause or contribute to fire through friction, self-reactive substances which are liable to undergo a strongly exothermic reaction or solid desensitized explosives. Also included are substances which are liable to spontaneous heating under normal transport conditions, or to heating up in contact with air, and are consequently liable to catch fire and substances which emit flammable gases or become spontaneously flammable when in contact with water.

Subdivisions

- Division 4.1: Flammable solids
- Division 4.2: Substances liable to spontaneous combustion
- Division 4.3: Substances which, in contact with water, emit flammable gases

Class 5-Oxidizing substances and organic peroxides

Oxidizers are defined by dangerous goods regulations as substances which may cause or contribute to combustion, generally by yielding oxygen because of a redox chemical reaction. Organic peroxides are substances which may be considered derivatives of hydrogen peroxide where one or both hydrogen atoms of the chemical structure have been replaced by organic radicals.

Subdivisions

- Division 5.1: Oxidizing substances
- Division 5.1: Organic peroxides

Class 6- Toxic substances and infectious substances

Toxic substances are those which are liable either to cause death or serious injury or to harm human health if swallowed, inhaled or by skin contact. Infectious substances are those which are known or can be reasonably expected to contain pathogens. Dangerous goods regulations define pathogens as microorganisms, such as bacteria, viruses, rickettsia, parasites and fungi, or other agents which can cause disease in humans or animals.

Subdivisions

- Division 6.1: Toxic substances
- Division 6.2: Infectious substances

Class 7- Radioactive goods

Dangerous goods regulations define radioactive material as any material containing radionuclides where both the activity concentration and the total activity exceeds certain pre-defined values. A radionuclide is an atom with an unstable nucleus, and which consequently is subject to radioactive decay.

Class 8- Corrosive substances

Corrosives are substances which by chemical action degrade or disintegrate other materials upon contact.

Class 9- Miscellaneous dangerous substances and articles

Miscellaneous dangerous goods are substances and articles which during transport present a danger or hazard not covered by other classes. This class encompasses, but is not limited to, environmentally hazardous substances, substances that are transported at elevated temperatures, miscellaneous articles and substances, genetically modified organisms and micro-organisms and (depending on the method of transport) magnetized materials and aviation regulated substances.

4.3 Management of cargo hazards

4.3.1 General

SOLAS includes general requirements for cargo proper handling and management of cargo hazards:

- SOLAS II-2/16.2 requires fire safety operational booklets, which are to detail all precautions to be taken when handling the cargoes to be carried onboard and the crew's responsibility in this respect.
  Furthermore, the ISM Code requires that any company operating a ship sets up a safety management system with identified persons in charge of the relevant duties and procedure to report incidents, prepare for and respond to emergency situations;
- SOLAS VI/2 requires that the shipper provides adequate shipping information regarding any cargo loaded onboard;
- SOLAS VI/5 requires proper cargo stowage and securing, referring especially to:
  - The Code of Safe Practice for Cargo Stowage and Securing;
  - The IMDG Code for the carriage of dangerous goods.

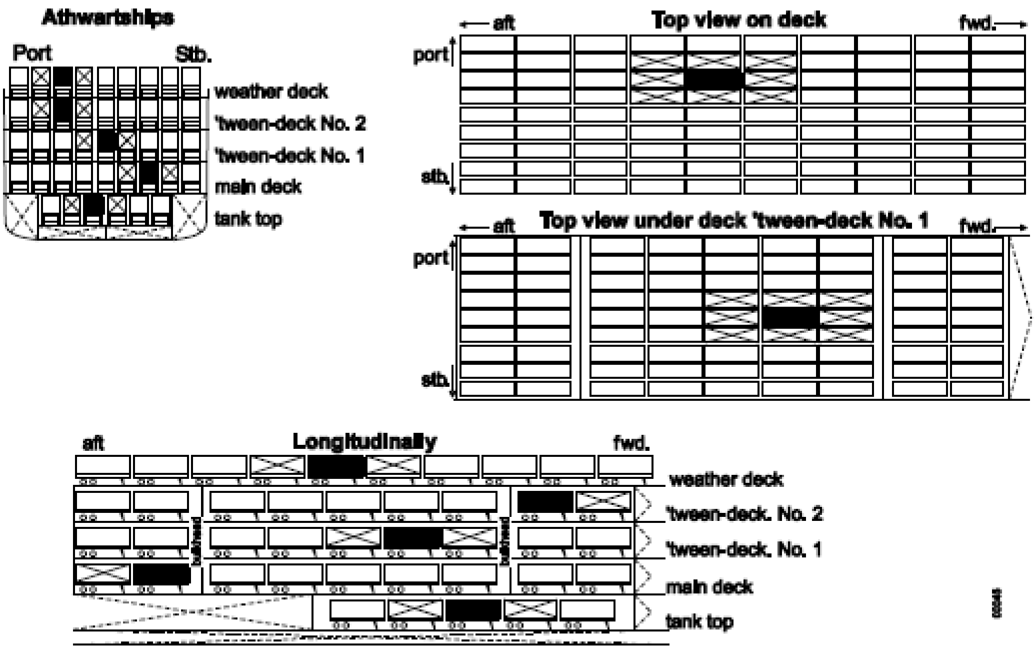
Chapter 7.5 of the IMDG Code focuses on the stowage and segregation of cargo transport units which are transported in ro-ro cargo spaces. In particular, provisions for segregation between cargo transport units onboard ro-ro ships are given in the table included in Reg. 7.5.3.2 (see Table 2).

Segregation requirement	Horizontal						
		Closed versus closed		Closed versus open		Open versus open	
		On deck	Under deck	On deck	Under deck	On deck	Under deck
"Away from" .1	Fore and aft	No restriction	No restriction	No restriction	No restriction	At least 3 m	At least 3 m
	Athwartships	No restriction	No restriction	No restriction	No restriction	At least 3 m	At least 3 m
"Separated from" .2	Fore and aft	At least 6 m	At least 6 m or *one* bulkhead	At least 6 m	At least 6 m or *one* bulkhead	At least 6 m	At least 12 m or *one* bulkhead
	Athwartships	At least 3 m	At least 3 m or *one* bulkhead	At least 3 m	At least 6 m or *one* bulkhead	At least 6 m	At least 12 m or *one* bulkhead
"Separated by a complete compartment or hold from" .3	Fore and aft	At least 12 m	At least 24 m + deck	At least 24 m	At least 24 m + deck	At least 36 m	*Two* decks or *two* bulkheads
	Athwartships	At least 12 m	At least 24 m + deck	At least 24 m	At least 24 m + deck	Prohibited	Prohibited
"Separated longitudinally by an intervening complete compartment or hold from" .4	Fore and aft	At least 36 m	*Two* bulkheads or at least 36 m + *two* decks	At least 36 m	At least 48 m including *two* bulkheads	At least 48 m	Prohibited
	Athwartships	Prohibited	Prohibited	Prohibited	Prohibited	Prohibited	Prohibited

Table 2 Table of segregation of cargo transport units on board ro-ro ships

In this regard, MSC.1/Circ.1440 aims to facilitate the familiarization with these requirements and to support training of relevant personnel by providing illustrations applicable to the segregation requirements on ro-ro ships (example of illustration is provided in Table 2 above.

"SEPARATED FROM" .2		
CLOSED VERSUS CLOSED	ON DECK	UNDER DECK
FORE AND AFT	At least 6 metres	At least 6 metres or ONE bulkhead
ATHWARTSHIPS	At least 3 metres	At least 3 metres or ONE bulkhead



2 – Situation *closed* versus *closed*
Note: All bulkheads and decks shall be resistant to fire and liquids.

Figure 6 Illustration of segregation requirements on ro-ro ship (for the situation Closed versus Closed) extracted from MSC.1/Circ.1440

As a side note, it is outlined that the Ship Security Assessment required by IMO ISPS Code for ship security purposes normally includes cargo screening, including dangerous cargo and with a focus on unaccompanied luggage, as outlined by IACS Rec.81.

4.3.2 Dangerous goods

When dangerous goods are carried on ro-ro decks, IMO IMDG Code applies and details, for each product or class of dangerous good:

- Stowage and packaging rules (inside the container or tank);
- Onboard stowage and segregation rules;
- Provisions in case of an incident and fire precautions.

The above is complemented by "The EmS Guide: Emergency Response Procedures for Ships Carrying Dangerous Goods" which includes detailed recommendations and schedules for each class of dangerous goods in case of fire or spillage. (IMO, 2020)

4.3.3 Vehicles

When they are carried in a vehicle, special category or ro-ro space, vehicles do not fall in the scope of the above-mentioned IMDG Code. However, it can be outlined that IMDG Code however mentions that there should be “no signs of leakage from the battery, engine, fuel cell, compressed gas cylinder or accumulator, or fuel tank when applicable.” (IMO, 2020)

4.3.3.1 Vehicles with compressed hydrogen or compressed natural gas

It may be mentioned that SOLAS II/20-1 provides additional safety measures for vehicle carriers with vehicle and ro-ro spaces intended for carriage of motor vehicles with compressed hydrogen or compressed natural gas in their tanks for their own propulsion as cargo.

In particular, MSC.1/Circ.1471 recommends that “the shipper should provide a signed certificate or declaration that the vehicle fuel system, as offered for carriage, has been checked for leak-tightness and the vehicle is in proper condition for carriage prior to loading. In addition, the shipper is to mark, label or placard each vehicle, after it has been checked for leak-tightness and that it is in proper condition for carriage. During loading, the crew should check each vehicle for the shipper’s markings”. (Maritime Safety Committee Circulars, 2014)

5 Definition and classification of transport units

Main author of the chapter: Kujtim Ukaj, RISE

The scope for WP08 is pre-emptive actions, and focus is reefer units and alternative powered vehicles. But at the same time, concepts can be used to assess most types of cargo and vehicles.

This chapter describes the different vehicles categories used in LASHFIRE and background information on each type.

5.1 Classification

5.1.1 Refrigeration unit

Refrigeration units, commonly referred to as reefer units, are subject to electrical fault and constitute a significant fire hazard in ro-ro spaces (Wikman, 2016); (DNV, 2016). Electrical malfunction may occur due to a faulty/damaged cable, connection, or unit and can develop to cause ignition. Not only are reefer units more likely to catch fire than other sources of ignition, 4 out of the 5 major ro-ro passenger ship fires in recent years have been the result of faulty reefer units (DNV, 2016). Three of those resulted in a total loss, all of which occurred on open ro-ro spaces (Ibid.). Open ro-ro spaces are particularly vulnerable to increased fire growth, as was concluded in FIRESAFE II (2018) and RO5 (2019), due to the unlimited access to oxygen permitted by the side openings. Ro-ro space fires caused by reefer units are noteworthy since the proportion of vehicles with reefer units is relatively low in comparison to vehicles with other cargo types. In a study performed by Germanischer Lloyd together and Stena (2013) it was estimated that vehicles with reefer units comprised 10 % of all transported lorries.

5.1.2 Conventional vehicle

Vehicles are the most common source of fire in ro-ro space. Ignition, which is typically caused by electrical faults, may occur in the vehicle's engine compartment, cab or if it is a truck, in the cargo unit (The North of England P&I Association, 2017). A fire that occurs inside the cab of a vehicle may self-extinguish due to oxygen deprivation if side windows are kept closed (Swedish Accident Investigation Authority, 2019).

5.1.3 Used vehicles

A significant proportion of vehicle fires are caused by electrical faults. Used vehicles that await shipment in a port area for an extended period of time are exposed to corrosion-inducing elements which may lead to the deterioration of electrical and wiring systems, which in turn may increase the likelihood of fire (The North of England P&I Association, 2017).Reconnecting an electrical system that has been idle to a charged battery increases the probability of electrical failure (Ibid.). Measures which may assist in isolating the circuit, thereby preventing arc faults, include removing the key and disconnecting the battery (Ibid.). Leaving the key in stop/park may not be enough to isolate circuits (Ibid.). Additionally, used vehicles may contain combustible materials such as gas canisters, jerry cans, and welding equipment which may contribute to fire growth (Ibid.).

5.1.4 New vehicles

New vehicles are normally shipped with their batteries connected and keys in their ignition. To reduce the likelihood of unwanted electrical faults, many new vehicles are fitted with a transportation mode, which enables turning off internal circuits during transportation. This needs to be activated prior to the vehicle's shipment, which is not always adhered to, meaning that some vehicles are shipped in live condition.

5.1.5 Special vehicle

There are various types of non-conventional vehicles that also require consideration, including tractors, wheel loaders, sky lifts, process machines, forest vehicles, forklifts, military vehicles and recreational vehicles. Certain special vehicles are fitted with a main power switch, allowing operators to turn off the electrical power.

Hydraulic machinery like wheel loaders, tractors and forest vehicles rely on hydraulic fluid to transfer power and drive machinery. Although most hydraulic fluids are combustible (Yuan, 2006), they are typically considered much less flammable than middle distillates (Mushrush, 2006). Middle distillates, e.g. diesel, kerosene and jet fuel, are fractions of petroleum with boiling points in the range 175 °C to 375 °C (Hemighaus, 1998).

Apart from hydraulic machinery, special attention should also be paid recreational vehicles and military vehicles. The latter may include ammunition, while the former contain propane tanks which are used for refrigerators, furnaces, ovens and stovetops. Disconnecting the gas tanks and closing the main valves will reduce the risk of fire.

5.2 New energy carrier

New energy carrier is referred to those vehicles that use alternative fuels. There are several categories based on the fuel type: liquid fuels (methanol, biodiesel and other alcohols), liquified gas such as Liquified Natural Gas (LNG), compressed gas such as Compressed Natural Gas (CNG), hydrogen in compressed or liquified, and electricity.

Alternative liquid fuels share similar properties with conventional transportation fuels regarding fire and explosion hazards but differ in some respects from the other fuel types mentioned above. One major difference is how the fuels are stored in the vehicle.
These types of energies have during LASH FIRE become categorized as Alternative Powered Vehicles (APV)

5.2.1 Vehicles powered by liquids and gases kept under high pressure

There is limited data in literature concerning accidental release of liquids and gases that are kept under high pressure (Brzezinska, 2019) has noted that LPG car installations are often in poor condition, and that gas leaks occur frequently, particularly at the pipe joints. Experiments and simulations (Brzezinska, 2019) have shown that accidental release of LPG from a car in an enclosed area poses a significant fire and explosion hazard. However, having analysed a total of 135 accidents involving CNG powered vehicles between 1976–2010, the U.S. Department of Transportation (Transportation, 2013) concluded that ignition could, in almost all cases, be attributed to other sources than the CNG tank or fuel storage system.

5.2.2 Electric vehicles

Electric vehicle (EV) is a term that includes battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs) and hybrid electric vehicles (HEVs). BEVs rely entirely on electric energy for propulsion whereas the latter two combine an internal combustion engine with an electric motor. There are various battery technologies that can be used to power the electric motor in EVs. Li-ion batteries (LIBs) have emerged as the preferred technology in EVs due to their superior energy density and capacity. However, concerns have been raised about their safety following numerous EV fires in recent years. According to the State Administration for Market Regulation, there were more than 40 EV fire incidents in China in 2018 (Bloomberg.com., 2019), which at the time had an EV stock of approximately 2.6 million (Sun, 2019). Most of the reviewed incidents involved EVs that caught fire during charging (Sun, 2019).

Hence, charging of electric vehicles on-board Ro-pax ships has been identified as a potential hazard (DNV, 2016), possibly in part due to the accident involving M/S Pearl of Scandinavia. On November 16, 2010, a fire broke out on board the Ro-pax ship M/S Pearl of Scandinavia. Because of the accident, several Danish Ro-pax ship operators introduced policies to prohibit charging of electrical vehicles on board their ships (Transportstyrelsen., 2018). Nonetheless, many ship operators do not offer or allow charging of electric cars on board Ro-pax ships (DNV, 2016).

6 Cargo fire hazard database

Main author of the chapter: Francisco Rodero, CIM

One of the main tasks to be completed in the context of the action 8-A is the development of a stowage planning tool featuring a fire hazard management that supports the loading process by means of guidelines and recommendations or even suggesting appropriate placement of the cargo based on historical data from the database and additional constraints.

To achieve this objective, the software has to consider many inputs such as the information coming from the booking system, the configuration of the decks and how they are organized in terms of available space, regulations on loading sequence or criteria to be used during the loading process. In addition, a cargo fire hazard database, which aims to establish relations between the cargo and risk of ignition, must be the foundation of such tool in order to minimize the overall risk.

Unfortunately, although most of the inputs are more or less available, such kind of cargo fire hazard database does not exist and it must therefore be created. This section describes how a fire cargo hazard database, as basis for further exploitation in the project, has been carried out, including both methodologies and technical approach.

The cargo fire hazard database aims at supporting fire hazard management applications featuring, for example, new ways of planning the stowage process where distribution and placement of cargo is designed in such a manner that reduces the consequences of a fire. Thus, one of the main results has a relevant impact on fire prevention, which automatically represents a direct contribution to the objectives of the project.

Further developments on top of that database may include not only suggestions about how to distribute the cargo but also what are the recommendations and guidelines these suggestions are based on. Therefore, it can be stated that there is also a clear contribution to the IMO Strategic Plan 2018-2023, where integration of new and advanced technologies in the regulatory framework is strongly recommended.

Some underlying technical concepts are referenced from deliverable D04.1 ("Review of accident causes and hazard identification workshop report").

6.1 Overview

Two main steps involve the development of the database. On the one hand, a systematic procedure supporting the information acquisition process with tips and guidelines on how the data that can be found in a given source should be treated and filtered to get useful information for the database. On the other hand, the set of homogenous information from the previous step is structured again, in terms of a relational data model, to build a database, which is fully functional from the software engineering point of view and ready to be integrated in further developments concerning fire hazard management applications.

As extra added-value items, intermediate actions between the abovementioned steps of the methodology and the population of the database are supported by automated mechanisms that allow easily updates in case of having new data available during the rest of life of the project.

In order to put in to context how the database can be used by other components of the work package, a brief description of the general architecture of the stowage-planning tool is depicted It is important to remark that, at this stage, the final scope and specifications of this tool is still being defined. So, what is presented is an overview of the general idea, which will be specified in detail in the upcoming tasks.

6.2 Sources of information

Several data sources were used for building the cargo fire hazard database in ro-ro spaces. These sources are the following:

- IMO, FSI 21/5
- GISIS database
- LASH FIRE WP04 Workshop background summary
- Internal records from ship operators, such as internal incident records from the Maritime Operators Advisory Group (MOAG)
- ForeSea database
- RISE, vehicle fire cause investigations database
- Official organizations in Mediterranean countries, CIAIM, HBMCI and MTIP
- Different sources for casualties in parking spaces and tunnels
- Other sources such as journals or private companies reports to complement information on incidents already recorded.
- EMCIP

Moreover, accidents already covered by more than one source were only include once.

By gathering from each source just those incidents occurring in a ro-ro space, a database with 446 incidents was generated. The chart in Figure 7displays an overview of the number of fire accidents recorded from each source.

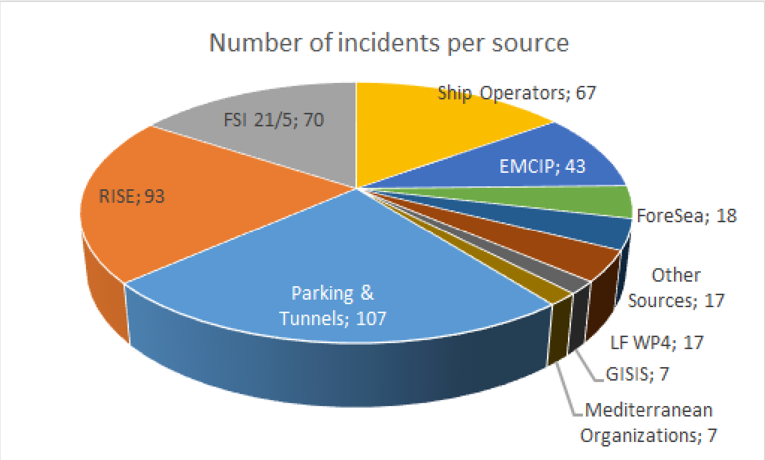


Figure 7. Number of incidents gathered per source.

It should be noted that incidents that were found in several sources were only accounted from one of the source databases. Those incidents were assigned to the source that provided the most information. For example, several incidents reported in the document FSI 21/5 were accounted for in the LASH FIRE WP04 source since this source gave more detailed information about the incidents.

Regarding the date of occurrence, the histogram depicted in Figure 8 shows how incidents are distributed in time. The period between 2013 and 2019 has a relevant quantity of records compared to previous years. It is supposed to have a similar number of incidents for 2020 but the compilation only includes the first half of this year. Due to the large number of years without reported incidents in the interval between 1965 and 1995 and with the aim of improving readability, the charts groups all these years in a single column.

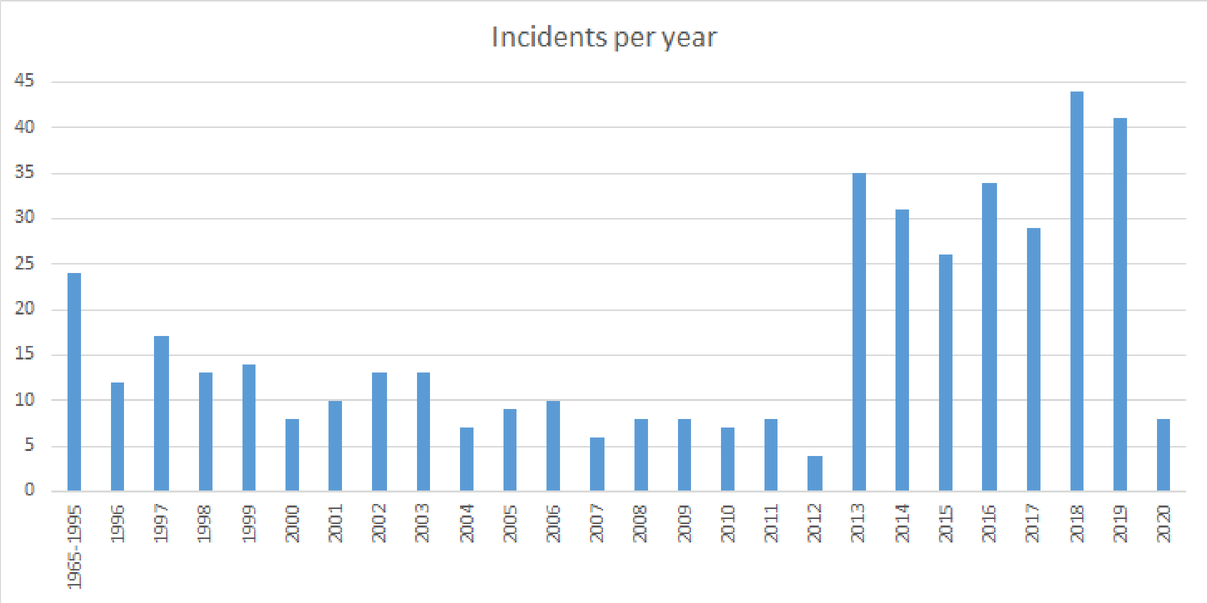


Figure 8. Number of incidents per year

One of the main gaps found during the compilation of the database is the fact that there is not a standard regarding how information for incidents should be reported and this results in a very heterogeneous set of attributes.

Moreover, each source of information has a specific set of attributes depending on their claims and functionalities and what is the purpose of this information (e.g. EMSA and insurance companies take advantage of information in many different ways).

Furthermore, there are common data such as *Date* but not all common attributes can be directly merged. For example, ship types may rely on categories that, again, depend on the institution, making the compilation process difficult. The LASH FIRE project has used the categorizations in SOLAS as basis.

Finally, attributes like *Severity*, have values that depend on a subjective assessment which may imply a certain level of bias in the results. In the maritime context, definitions exist of different severity levels but these definitions are more qualitative than quantitative.

The following sections contains information about the different sources including main figures and, optionally, a brief data analysis of the most relevant attributes (except for tunnels and parking spaces since this source is mainly used as complementary information, giving relevance to incidents occurred in ships).

6.2.1 FSI 21/5

The FSI 21/5 document (IMO, 2012a) provides a wide list of maritime accidents in ro-ro passenger ships from 1994 to 2011. This data includes the year of the incident, when it occurred (on passage, in port…), who extinguished the fire and a short description of the incident. However, the information provided by this source was not enough to fill all the fields of the database. Hence, other sources of information were used to compensate this lack of information.

Some of the incidents in this list did not fulfil the aforementioned conditions (some accidents did not originate in the cargo or occurred in the engine room) and were rejected.

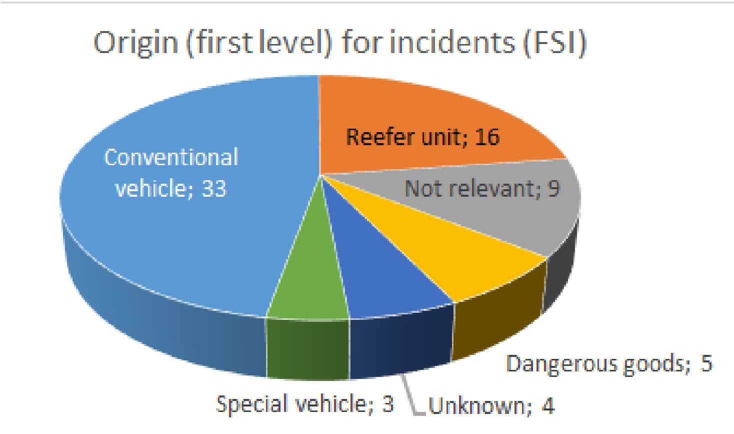


Figure 9. Origin (first level) for incidents gathered from FSI

As the next diagram Figure 10, shows, the type of ship is not available for almost half of the incidents. For the other half, the most usual type is Ro-Pax ships (39%) while ro-ro cargo ships and Vehicle Carriers are less common and both with the same order of magnitude.

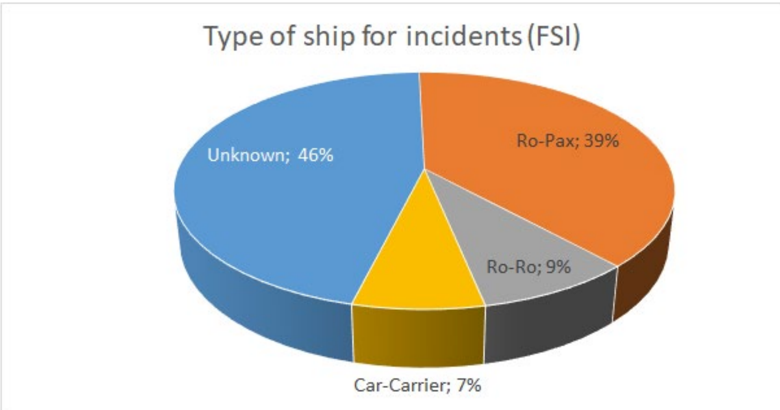


Figure 10. Type of ship for incidents gathered from FSI

Taking a look to the fire cause, what we notice is that about 35% of the incidents refer to an unknown cause and more or less the same percentage are due to an electrical fault (in cabin, engine compartment, in unit or in cable/connections). The other third remaining is associated to up to 11 causes with a low number of incidents, as the next diagram depicts:

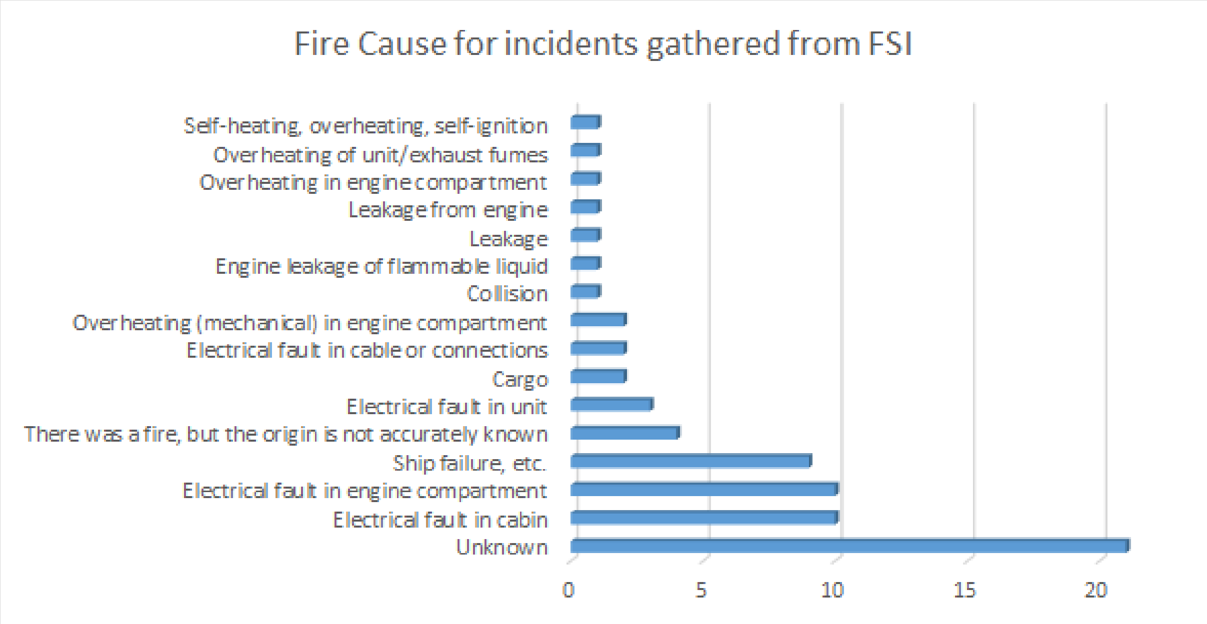


Figure 11. Fire causes for incidents compiled from FSI

These incidents have been reported between 1994 and 2011, both inclusive. During this period, there is almost an average of 4 incidents per year, finding in the interval 2005-2007 more than 25% of the total for FSI. The next chart shows the frequency of incidents in a yearly basis:

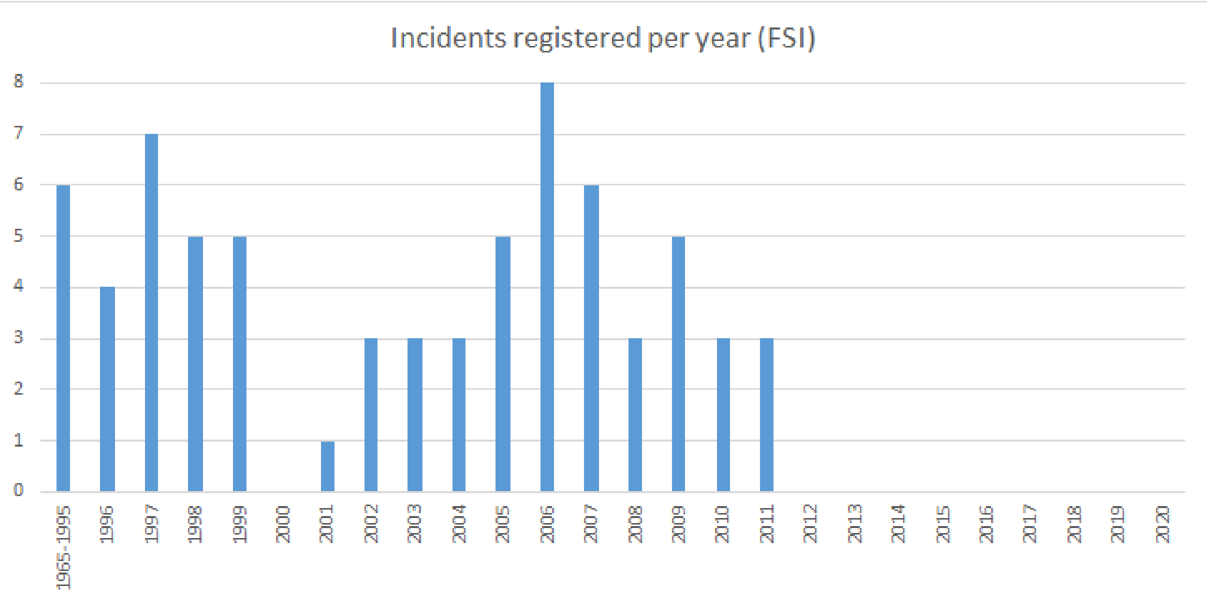


Figure 12. Fire causes for incidents compiled from FSI

6.2.2 GISIS

IMO provides an information system called GISIS (Global Integrated Shipping Information System). Among other services, GISIS has a data base that collects several marine casualties and incidents, which can be filtered applying certain conditions. In this case, the filters applied were the following:

- Initial event is a fire or explosion

- Type of ship is a passenger / general cargo ship, a passenger / ro-ro cargo ship, a refrigerated cargo ship or a ro-ro cargo ship
- Type of casualty is a fire or explosion

However, even with these filters some incidents were not added to the database. The origin of some of the fires was in the engine room and not in the ro-ro space, hence, these incidents were rejected. In the end, only 7 incidents were extracted from a total of 54.

6.2.2.1 LASH FIRE WP04 Workshop 2019

Several marine accidents in ro-ro spaces were gathered from the document D04.1, "*Review of accident causes and hazard identification workshop report*". Some of them were already covered by FSI 21/5 and GISIS, nevertheless, they facilitate a list of reports with some new relevant information for the database.

In the end, 17 incidents were included from a total of 21.

6.2.2.2 Ship Operators

Originally, there were a total of 108 events of fire or explosions in ro-ro spaces. Sorting these accidents into those that have been produced due to cargo, finally 67 incidents were extracted. The proportion of the different ignition origins of these records is very similar to FSI 21/5 with a slight increase of the conventional vehicle, representing now more than 65% of the total.

From the 45 incidents involving conventional vehicles, for 19 of them, the exact type of vehicle is unknown. For the rest, the most usual vehicles are trucks (16 occurrences) and cars (8). Finally, there are also two incidents involving buses.

The next chart shows this distribution:

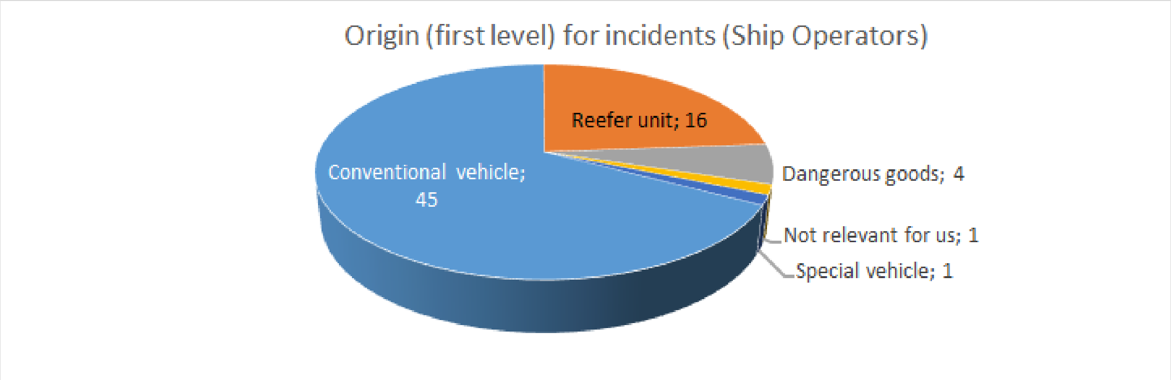


Figure 13.Origin for incidents gathered from ship operators

Looking to the type of ship where the incidents occurred, we notice that in two thirds of them the involved ship was a Ro-pax ships. In the meanwhile, just 6% of incidents occurred in a ro-ro cargo ship. Vehicle carriers comprise the rest of incidents reported by Ship Operators as the diagram shows:

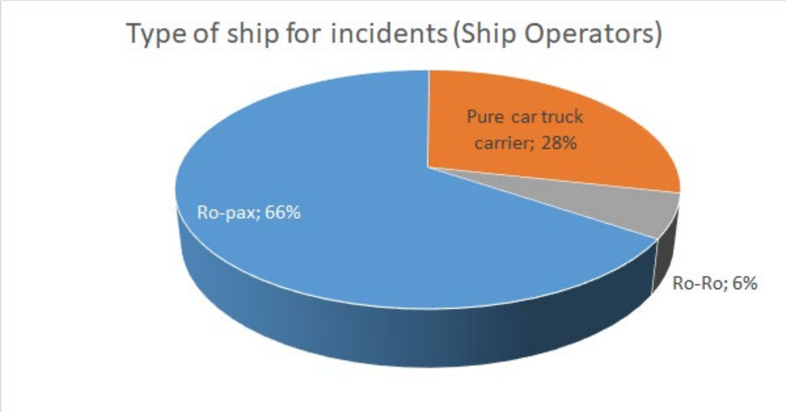


Figure 14.Type of ship involved in incidents (Ship Operators)

Compared with records from FSI, if we look to the main causes for the incidents from Ship Operators, we notice that the three most reported causes are the same, including unknown as the top one. These three categories represent more than 70% of the total. The other 28% is distributed along 7 different causes. The below diagram depicts this distribution:

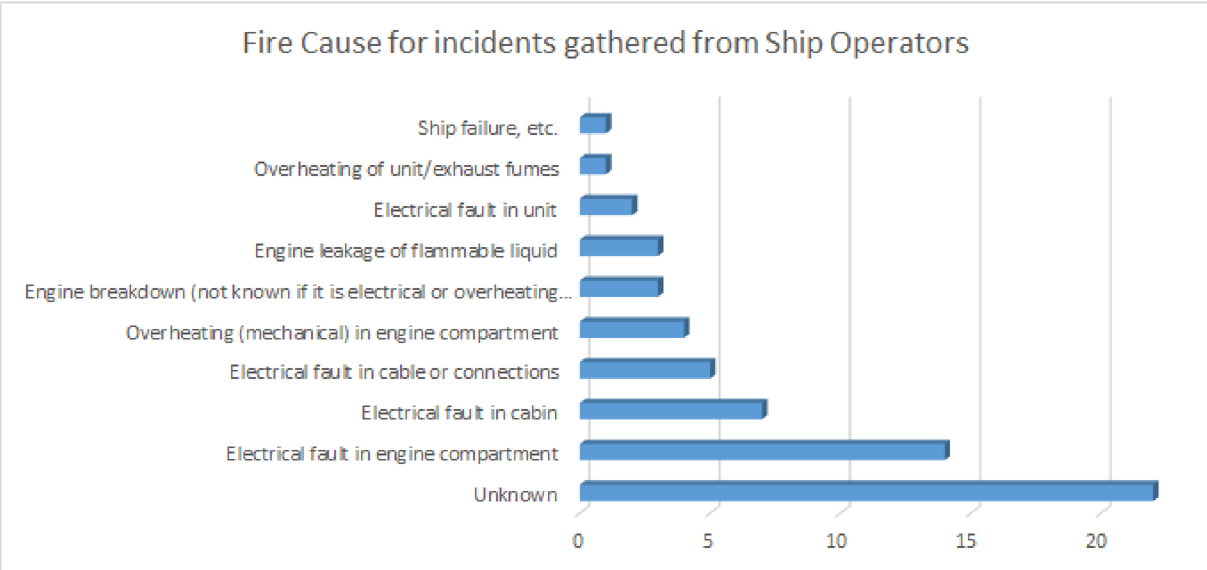


Figure 15.Main causes of fire detected in incidents from Ship Operators

Table 3 shows the causes of the incidents and the frequency depending on the type of ship. Although the sample is quite different, it seems that the behaviour is not the same for both types:

Table 3. Causes of fire for most common ship types in incidents reported from Ship Operators

Cause	**Incidents**	
	Ro-Pax	**Pure Car Truck Carrier**
Unknown	20	4
Electrical fault in engine compartment	6	8
Electrical fault in cabin	5	2

Electrical fault in cable or connections	5	
Electrical fault in unit	2	
Engine breakdown (not known if it is electrical or overheating problem)	2	1
Overheating (mechanical) in engine compartment	2	1
Overheating of unit/exhaust fumes	1	
Ship failure, etc.	1	
Engine leakage of flammable liquid		3

Finally, the histogram below shows the years when the incidents were reported (all of them from 2011 on). Note that for 3 incidents, there was no information about the year.

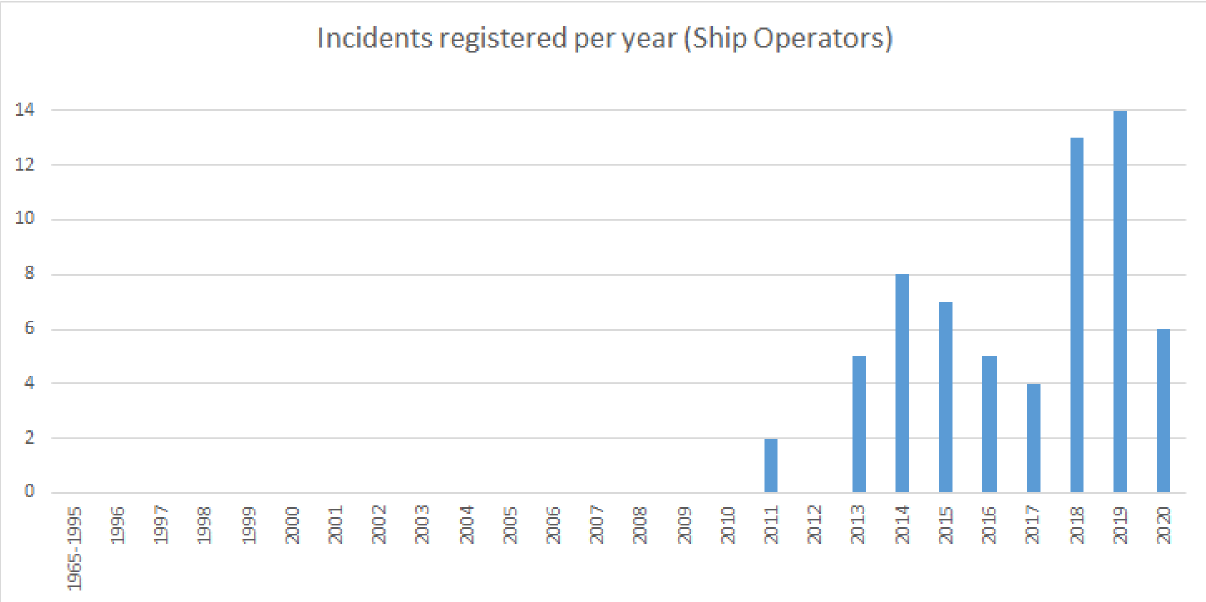


Figure 16.Frequency of incidents in a yearly basis (Ship Operators)

6.2.2.3 ForeSea

In addition, an extract from the ForeSea database was provided on 12 June 2020 by one of ForeSea contributors. The extract was consolidated and anonymised based on the template elaborated by Ship Operators.

As per ForeSea website, "ForeSea is an information system for accidents, incidents / "near misses" and non-conformities at sea. The system is designed and used of the shipping industry in Sweden and Finland."

This database collected 35 events. However, rejecting those incidents that were not originated by cargo, a total of 18 incidents were finally included in the database.

6.2.2.4 RISE

RISE Research Institutes of Sweden collected and summarized common vehicle fire origins from their internal vehicle fire investigations database. The investigations had mainly been conducted for fires in vehicles trafficking Swedish roads.

RISE has long experience in conducting vehicle fire cause investigations for different kind of customers. The most common customer are insurance companies, but it is also common that vehicle manufactory and industrial companies order a fire cause investigation. Mainly, RISE has investigated heavy vehicle fires, but they have also collaborated with the company "TS Utredningstjänst" [Eng: TS Investigation Service) which has investigated all kind of vehicles. Information from the fire cause investigations done by RISE and TS Utredningstjänst during the years 2013 to 2019 were included in the database. Data such as background information, description of the fire event and judged fire cause were extracted.

RISE has provided a total of 93 fire registers in Swedish roads, 57 (~60%) occurred in conventional vehicles and 36 in special vehicles (for further information about types of non-conventional vehicles please refer to the corresponding section of D04.1).

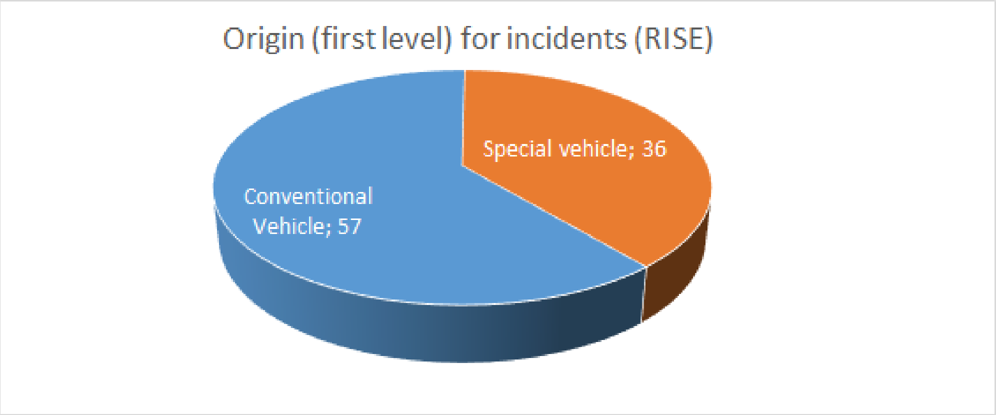


Figure 17. Origin (first level) for incidents reported by RISE

The distribution of the fires originated in conventional vehicles is homogeneous, so 19 registers occurred in trucks, 19 in buses and 19 in cars. On the other hand, there is a wide variety of special vehicles that have been reported as the following charts shows:

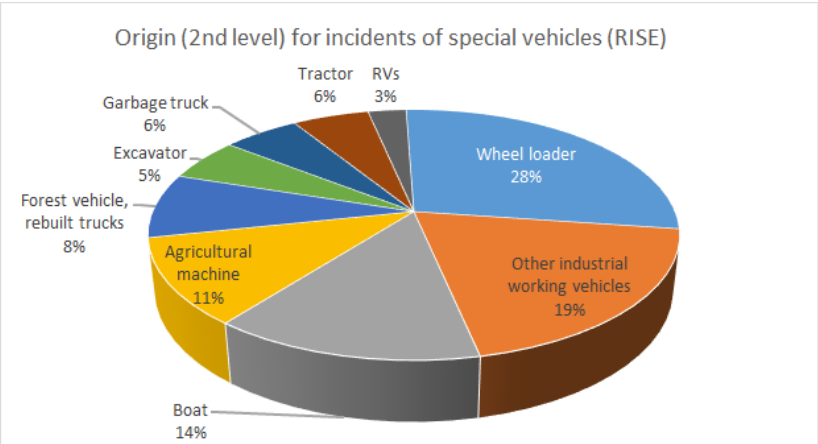


Figure 18. Origin (second level) for incidents reported by RISE where a special vehicle was the first origin

Regarding the causes of the fires, Table 4 shows, from more reported to less, the causes for both conventional and special vehicles without distinguishing what type of vehicle it was. It is important to remark that for both conventional and special vehicles, the two most reported causes are the same: electrical fault in the engine compartment or an engine leakage of flammable liquid, representing between the 60% and 85% of the total, approximately.

Table 4. Most common causes of the fire for incidents reported by RISE

Conventional vehicles		**Special vehicles**	
Cause	**#**	**Cause**	**#**
Electrical fault in engine compartment	24	Engine leakage of flammable liquid	18
Engine leakage of flammable liquid	11	Electrical fault in engine compartment	13
Leakage from engine	7	Component failure	2
Component failure	6	Overheating (mechanical) in engine compartment	2
Overheating (mechanical) in engine compartment	5	Leakage from parts on chassis	1
Overheated parts in chassis	2		
Overheating in engine compartment	2		

6.2.2.5 Official organizations in Mediterranean countries

With the previous sources, there was a lack of information of marine casualties in the Mediterranean Sea. Hence, further research was done in different official websites of the Mediterranean countries, to look for fire casualties in ro-ro cargo ships, ro-pax ships and vehicle carriers. Mediterranean countries were in this study defined as those that commercialise in the Mediterranean Sea or, exceptionally, in the Atlantic Ocean such as the connection from/to Canary Islands (Spain).

Several marine casualties' organizations were covered in this analysis, such as CIAIM, HBMCI or MTIP. A total of 7 incidents were found for ships from Spain, Greece, Italy and Malta from 2012 to 2019. It is to be noted that this range of years was not a deliberate filter, but fire casualties before 2012 were not found.

6.2.2.6 Fire casualties in parking spaces and tunnels

Fire casualties originated in vehicles that were driving through a tunnel or were parked in a parking space were also considered due to the similar conditions to the ones considered in the project.

Tunnel casualties were collected from Carvel and Beard's (2005) handbook and other numerous sources. Accidents from 1949 to 2017 were recorded in the database, including information about the place of the casualty, the type of vehicle where the fire was originated, the cause of the fire, the fire origin and what the vehicle was carrying.

Regarding fire casualties in parking spaces, it is important to remark that this information is less accessible than tunnel casualties. Information from three sources were added to the database: an analysis made in New Zealand's parking spaces between 1995 and 2003 by Li and Spearpoint (2007), several fire casualties on electric vehicles in 2018 by Sun, et. Al. (2020) and several parked Tesla fires gathered by the journal *The Drive.*

Counting all the registers gathered in the previous sources, 107 incidents were added to the database.

6.2.2.7 EMCIP

Operational starting from June 2011, the European Marine Casualty Information Platform (EMCIP) is a database and a data distribution system operated by EMSA, the European Commission and the EU/EEA Member States. EMCIP aims to deliver a range of potential benefits at national and European relevance by:

- Improving the information background about marine casualties and incidents
- Widening and deepening the analysis of the results of casualty investigations
- Providing at-a-glance information, enabling general risk identification and profiling
- Sharing lessons learned and safety issues detected in the course of safety investigations.

EMCIP is also connected to the Global Integrated Shipping Information System (GISIS) managed by the IMO.

Information about marine casualties and incidents is also made accessible to the public, such as the investigation reports published by the accident investigation bodies and “anonymized” data about casualties and incidents notified by Member States authorities.

From the extensive EMCIP database, a total of 43 records were selected. They were filtered by selecting those accidents produced by a fire or an explosion, and moreover the origin of these incidents must have occurred in a ro-ro space. When applying these filters, some EMCIP incidents were rejected since they were already covered by other sources, or due to the cause of the fire was not cargo (e.g. fire in an electric cabinet, fire caused by a fluorescent light, etc.). Furthermore, a few incidents were not selected since the vehicle type in which the fire originated was unknown.

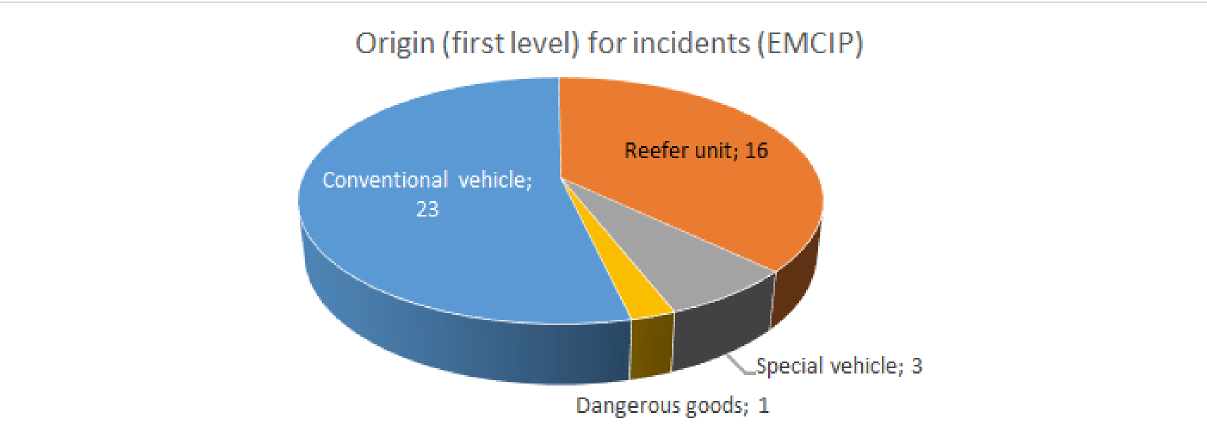


Figure 19. Origin (first level) for incidents registered from EMCIP

Respect to the type of ship, 41 incidents (95%) were occurred in Ro-Pax ships.

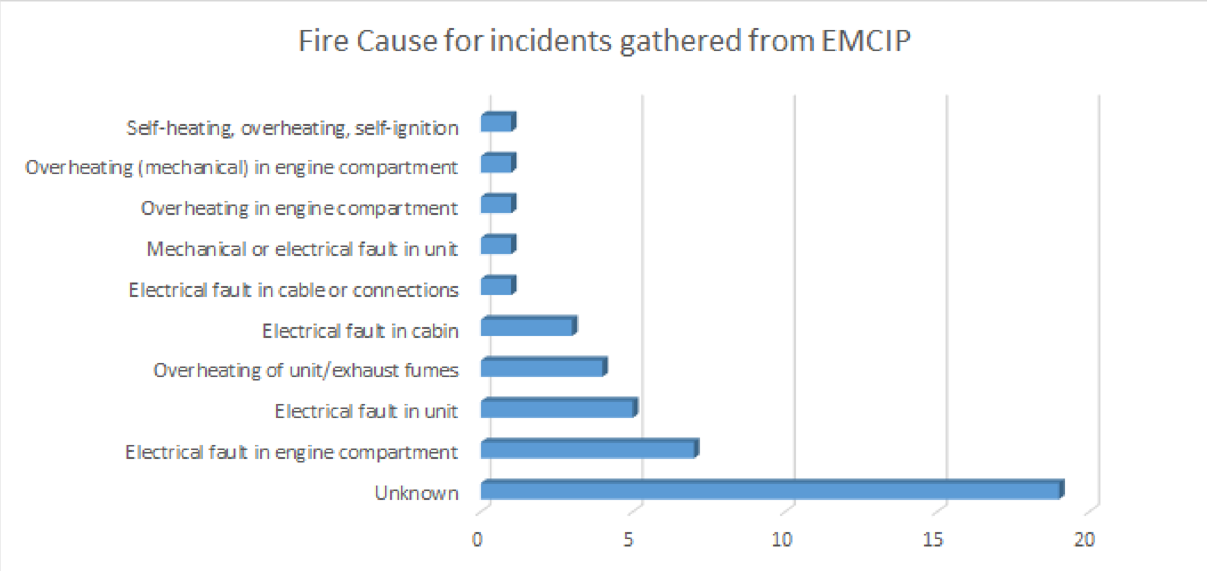


Figure 20. Fire cause for incidents registered from EMCIP

Regarding the year when the incidents were occurred, the result is similar to the one obtained from Ship Operators as all of them were reported from 2011 on as the histogram shows:

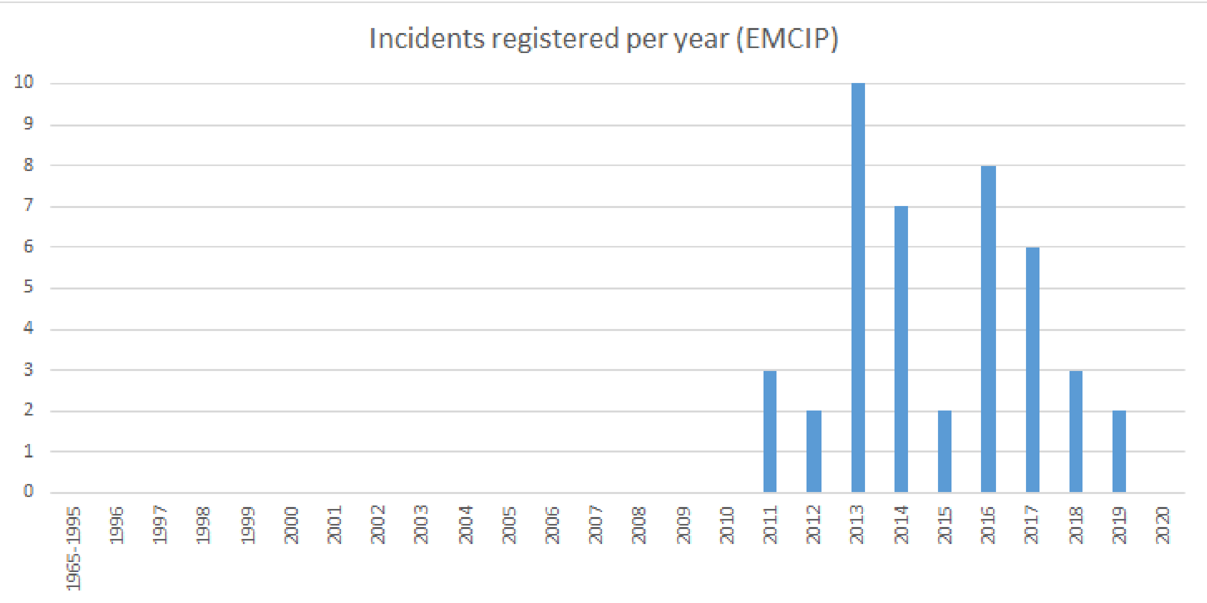


Figure 21. Frequency of incidents in a yearly basis (EMCIP)

6.2.2.8 Other sources

Apart from the sources shown above, numerous other sources, such as journals (e.g. Journal of Maritime Research) and private companies' reports have been used. The main purpose of the use of these sources was to complete unknown information from incidents already recorded.

In addition, these other sources were also used to look for more incidents, such as fires originated in parking spaces for electric vehicles or famous fires covered by newspapers (Liverpool fire, 31 December 2017 or Stavanger fire, 8 January 2020).

Furthermore, in addition to adding information to incidents already covered by other sources, these other sources increased the database size with 18 more incidents.

6.2.3 Implementation

This section describes which actions have been performed in order to create a database (in terms of computer sciences engineering) from the information compiled in the initial step. The whole process from the scratch is detailed, focusing in technical details rather than in the meaning of the data being processed.

6.2.3.1 Methodology

In order to build the database, a classical analysis of the gathered data was applied to convert the compiled data into a relational-based structure.

The methodology used to achieve this objective responds to the following steps:

1. Search of different sources with valuable and relevant information according to goals of the tasks involved in the creation of the ro-ro space cargo fire hazard database.
2. Only for maritime sources extraction of records related to incidents where fire started in the ro-ro spaces, discarding and filtering all unnecessary information.
3. Once different sets of data were gathered, a double process was performed:
    a. A mapping of the record to one of the categories defined during the *HAZID* Workshop held in the context of WP04 at RISE premises in December 10th-12th, 2019. These categories define the fire origin (two levels of accuracy) and the fire cause.
    b. For each record, about 20 attributes were recorded that will be used for different purposes during the exploitation phase (for example, specific attributes to distinguish if the incidents are a maritime sources or not). This step supports homogenization of all the sources

At this point, all the data was formatted in a user-friendly way (spreadsheet) and from here on, the steps were directed towards the transformation to a structured format oriented to speed up the access of the information by the SW components (machine-friendly).

4. Using a *macro* developed with *Visual Basic for Applications*, a new tab was filled with all the data in a tabular way. The objective was to prepare the data to be used to populate the DB.
5. A second *macro* exports the tab generated in the previous steps to a CSV file.
6. Finally, a *script* developed in *Python* dynamically creates the DB based on the corresponding relational model and populates it with the information in the CSV file.

The diagram below graphically depicts this methodology and shows which steps are interactive (requires user interaction) and which are not (just launch an automatic process):

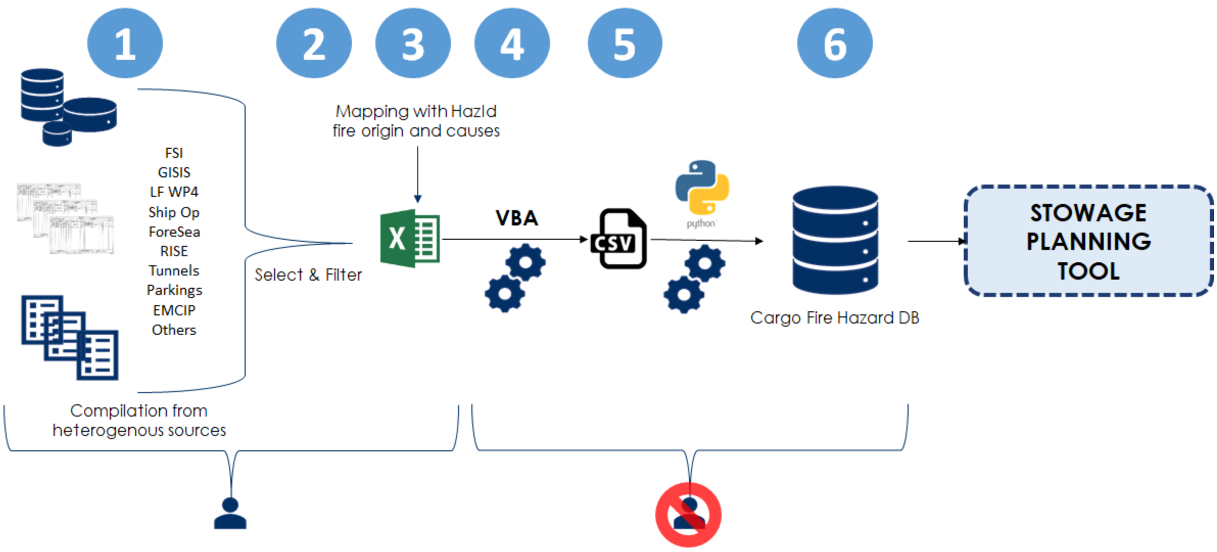


Figure 22. Workflow of the methodology

Table 5 shows what attributes are available after step 3. Note that certain fields are not used depending on where the incident occurred (e.g. IMO number is not applicable for tunnels).

Table 5 Full list of available attributes before migrating to a relational model

Attribute	Description
Fire origin 1	Where fire has been originated
Fire origin 2	More detailed information about the fire origin. For example, for conventional vehicles, it is specified if the incident occurred in a truck, bus or car
Fire cause	Which has been the cause of the fire: Electrical fault in the engine, overheating, leakage…
Ships/tunnel/parking/road	In which scenario the incident occurred
Ship/tunnel name	Which is the name of the ships (at the moment of the incident) or the name of the tunnel where the fire occurred
Month	Month when the incident occurred
Year	Year when the incident occurred
Failure	General description of the incident. This is the wider attribute, and relevant description of the incident is written here such as a more detailed information of the cause of the fire, or the list of events before and after the incident
Severity	Degree of severity of the incident. This information appears just in ships because for the other types of incidents this information was not available.

Type of ship	In which type of ship the incident occurred
Location	Where the incident occurred. If the incident occurred on passage, the name of the sea or ocean will appear. If the incident occurred in port, the name of the port will appear
Occurred when	In which process was the ship when the fire occurred: on passage, in port…
Deck where fire originated	In which deck the fire occurred. Weather deck, deck 1, deck2…
Closed or open	If the deck where the fire occurred was open or closed
More info. About deck location	Other relevant information about the location of the incident in the deck, such as in which zone of the deck the ignition originated
Goods in the fire origin	Which goods was carrying the vehicle where the fire originated
Goods close to the fire origin	Which goods were close to the fire origin, but that were not transported by the vehicle where the fire originated
More info. About close goods and other fuels' intervention	Other relevant information about goods close to the fire origin such as their tonnage, or special factors that could influence the ignition
Dangerous goods	If the good in the fire origin was classified as dangerous
Code dangerous good	In the case that the good is classified as dangerous, which is its code
Continent (for tunnels and parking spaces)	In which continent the fire occurred
Country (for tunnels and parking spaces)	In which country the fire occurred
Was charging?	Gives information about if they were charging or not at the moment of the incident
Number of incidents	How many incidents occurred for each record. Usually, this attribute has a value of "1". However, in some specific cases there was not information of each incident individually, and more than one incident was computed as a group or for a time interval.

Weight	It defines the credibility of the incident. In some cases, it was not possible to verify if a new incident was already in the data base or not due to a lack of information of the source. In these cases, a weight less than 1 but bigger than 0 was computed
Link	The link where the incident was found
Found in document	In which document the incident was found. In many cases, the incidents recorded in the database come from other data bases so the incidents are extracted from a document, not from a link
IMO Number	These 3 attributes are focused on tracking the identification numbers of the reports depending on the organization the incident comes from. Not all three columns are necessarily filled for a given record. They are used to manage duplicates during compilation but for privacy purposes they are not transferred to the SW database.
Casualty report nr.	
ForeSea ID	
SOURCE_DB	Indicates which is the source of the record

At the end of step 6, what is obtained is a relational model, which is described in the next sections. It is important to remark that this model gives support to the needs of the project action so far. It is expected to be extended in the future in order to give support to new features during the SW development phase. These modifications will not be changes but improvements based on the scalability of such kind of model: new relations between existing tables, perhaps a new attribute with new information or even new tables with information which is not needed now but it makes sense once the project has achieved a specific mature level.

For example, taking a further look into the relational model, it can be noted that *DangerousGoods1* and *DangerousGoods2* constitute tables without relation to other tables. This is because these tables will be used in the future, during the development of the optimization tool.

6.2.3.2 Relational Model

As mentioned above, the result is a relational database which is just a database based on the relational model of the data. As the name reveals, the relational model is based on the relations defined between the tables (logical units of information) and, to be more specific, based on the relations that exist between one or more attributes (featuring a relevant characteristic of the logical unit of information) of a table and one or more attributes of other/s table/s.

Attributes may have some constraints that influence what records can be stored in the table. As an example, these constraints refer to what values are allowed, if nulls are possible, if the values must be unique or if checks must be done before insertion.

Each relation not only defines an existing interaction in the real world but is also establishes a set of links between the information stored in the database. That way, queries can be performed against one or more tables, extracting a final set of records composed of information made by logical and mathematical operations between involved attributes. In other words, such this structure not only provides a better organization of the data but a way to speed up queries against the database in order to retrieve information that can be used for many purposes.

Finally, some attributes can be used to uniquely identify a specific record. The specific term for these attributes is “key”. Primary keys identify records in a table and foreign keys point to unique records in another table. By definition, it is not possible to have more than one record with the same value in its primary key attribute. It is important to remark that the primary key can be a relevant characteristic of the record (i.e. “number of the identification card” for people) but it also can be just a random identifier used to perform fast operations over the records (i.e. “auto incremental number” for transactions of a bank).

The model can be represented using an Entity-Relationship (ER) diagram where interrelated tables of interest in a specific domain of knowledge are depicted. In addition to databases, this type of diagrams is also often used in the specification of domain-specific ontologies.

There is no standard on how to exactly draw such a diagram. In our case, boxes represent a table, where the header is the name of the table and then we can find two sets of rows: the first one containing the primary key attributes and the second one including the rest of attributes.

Lines connecting two tables represent relationships between them; the side with the white square is the table containing the foreign key and the side with the black circle points to the table where is defined the primary key which is referenced. Note that lines are lines are drawn automatically and somewhere around the borders of the boxes and not necessarily near the involved attributes.

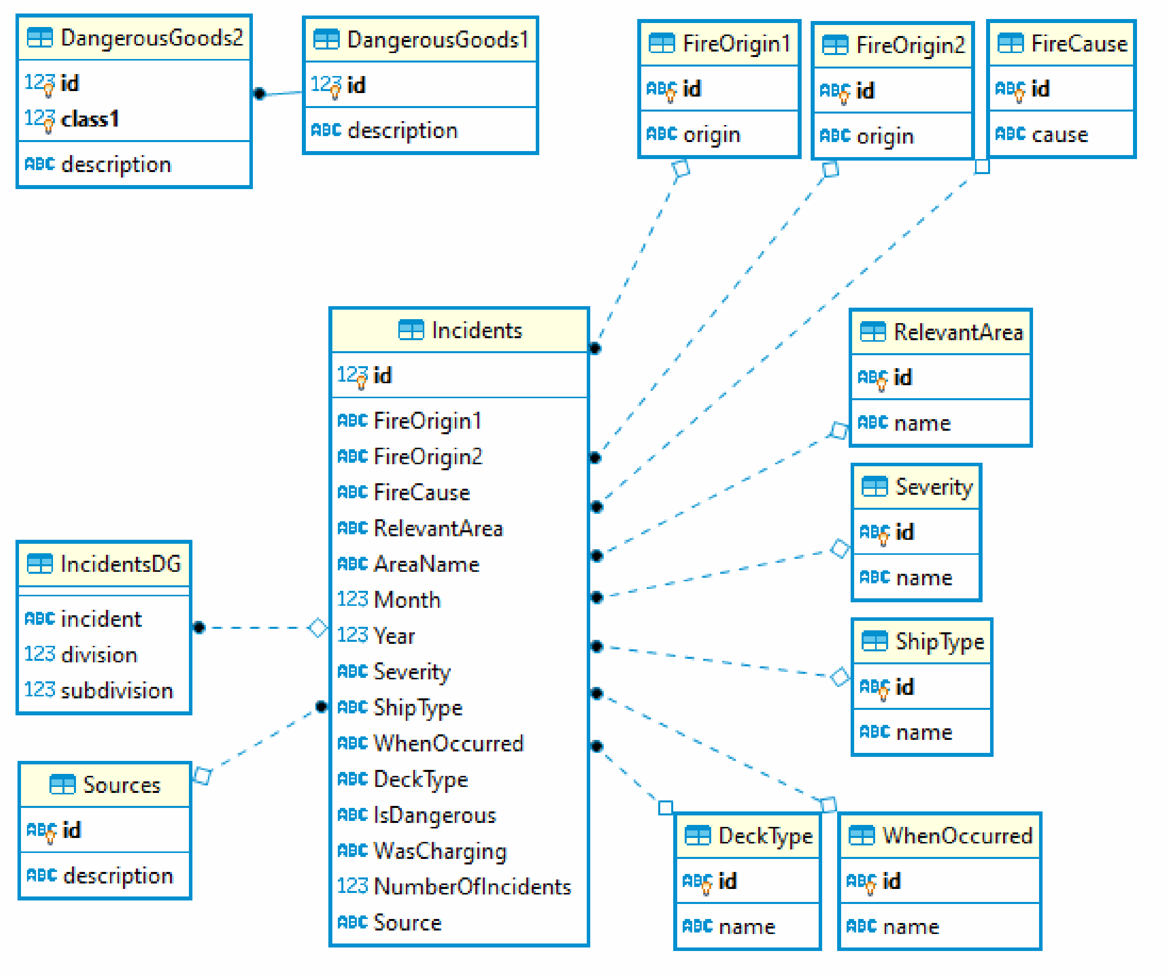


Figure 23. Fire Cargo Hazard DB Entity-Relation Diagram (generated with DBeaver)

6.2.3.3 Platform

In the same way as the solution for a problem can be faced using more than one design, many approaches can be used to implement one specific design.

Once the compilation made from many sources of information has been transformed to a relational model, the next step is to decide what implementation will be used in terms of selecting a database management system.

Using a relational model does not imply a unique implementation. There are lot of both free and commercial solutions that fit this requirement, each of them offering different options in terms of prices, licensing, portability, scalability, support and so on.

Strictly speaking, no benchmarking itself has been done in order to select a suitable platform for the implementation, for many reasons:

- In order to foster cooperation, find synergies and transfer knowledge between the teams involved in the different tasks associated to the Demonstration and Development work packages, a series of meetings are being arranged every six weeks using the official platform of the project, Microsoft Teams. One of the initial results of these meetings was an agreement on some guidelines to ease future integration of the SW components and to avoid incompatibilities. Concerning platforms, languages and protocols, the remark was to always use open-source or free applications and open standards (non-proprietary), if possible.
- Selected programming language is available in the most common operating systems and is very easy to install.
- Selected database management system (DBMS) eases deployment because does not require complex installations and all database features are embedded in a single file (and the corresponding library for the programming language).
- Selected tools and/or products ensure portability (available in many platforms) and speed up the deployment of the solution since they are easy to install.
- For future maintenance by staff not involved in the development, both products are fast to learn.

With these considerations and the previous experience of the team, the selected platform for development is composed of *Python* as programming language and *Sqlite* as *DBMS*.

Python is an interpreted, high-level, general-purpose object-oriented programming language emphasizing code readability for large-scale projects, including a comprehensive standard library. Since *Python 2.X* is officially discontinued all developments will use *Python 3.5.X* or later versions.

Sqlite is relational database management system (RDBMS) which, in contrast to many other DBMS is not a client-server-based engine. It implements most of the SQL standard and is ACID-compliant, which means that atomicity, consistency, isolation and durability properties of database transactions are guaranteed. Its source code is in the public domain and free of charge to everyone to use for any purpose.

Although *Sqlite* was selected, in case of extreme scalability needed or because migrating to a client-server architecture of the SW development, minor changes and low effort is required. The reason is that all of them share a common implementation of the SQL standard syntax. So, *MySQL* or *PostgreSQL,* for example, can be used in the future, if needed.

SQL is a database-specific language specially designed for the management and processing of data held in a RDBMS, that is, data incorporating relations between entities. One of the main advantages and most popular feature is the fact that it uses a human-readable syntax that allows developers to be quickly productive without the need of a previous long technical training.

The scope of the language includes a wide range of procedures and operations with the data: queries, manipulation (insert, update and delete), definition and modification of schemas and access control. In the next sections there are the SQL commands used to create all the tables of the relational model and to populate them with the information selected from the compilation from the different sources.

It is important to remark that even it is a base standard, there are lot of implementations with specific commands and/or operators or improvements; despite of this wide variety, migration of the database from one RDBMS to another is quite simple and depends on the features used for the source RDMBS.

In the case of LASH FIRE a simple design has been used, making it both scalable and portable as needed. How the database and its contents will be finally used by other incoming components will be deeply explained in deliverable D08.4 “Stowage planning optimization and visualization aid” where the current design will be fine-tuned to meet specific requirements of the software to be developed. To give an example, new tables including information about available sensors (both in the industry and among the ship’s equipment) will be added together with foreign keys linking the current information (risks of cargo) with the new one (prevention to a specific risk provided by sensors). That way, expected features of the software supporting placement recommendations will be possible. Deliverable D08.4 will also include the algorithms used to perform the risk assessment, detailing the steps and calculations implemented in the software.

6.2.4 Conclusions

The proposed methodology involves many steps that were oriented to achieve, develop and demonstrate a technical solution for automatic screening of cargo to identify fire hazards and develop, utilize and experimentally validate a digital logistics management tool featuring risk-based load planning.

The first step of the methodology, compilation of data from several sources, was not easy to complete. Relevant information was not easy to find or is not open access or free access, which is not compatible with the budget constraints that exist in a project funded by public taxes. In addition, much time discussing was spent with owners of the information about agreements to exploit the information. That resulted on an impact in time planning and final size of the sample. In the latter case, there is a relevant affectation in the risk analysis since suggestions made by the software are based on the database: the fewer records there are, the erroneous information can be given.

In addition to the abovementioned issue, lack of standard/homogenization of taxonomies or how qualitative attributes are managed between different sources difficult to make the process repeatable or fully automatic.

Despite of these disadvantages, a database has been successfully created as expected, making it available for exploitation in the context of the project.

Also, many automatisms and mechanisms have been developed to ease the process of creating and populating a database from the compiled data. They have been tested during the development and have been verified using real data. In fact, all the data analysis included in this document has been supported with real queries over a real DBMS, certifying that the methodology used was successfully completed.

Summarizing, in data-driven components results are poor if input information is not good enough. For this reason, during the coding of the above mechanisms and also during the design of the database, the scalability was a must.

If, during the development of the next tasks, new information is available, it can be converted to new records of the database without an impact on the time planning of the project because they will need small efforts thanks to the work performed in this task.

6.3 Cargo fire hazard listing

Main author of the chapter: África Marrero

The main objective of this section is to list the hazards found in the analysis of the accidents collected in the database.

The listed hazards should give us two perspectives for further analysis, in which cargos they occur and what are the causes of these hazards. Only in this way can general measures be taken when the same hazard is found in different loads or specific measures be taken when the cargo or cargo unit itself is a hazard.

In order to list the hazards included in the accident reports analysed, the cargo and cargo unit have been categorized in 5 categories (reefer unit, conventional vehicle, special vehicle, new energy cargo and dangerous goods). (LASH FIRE, 2020)These 5 categories are the main cargoes found on this type of ship.

The hazards identified in the maritime area and in other relevant areas such as accidents on roads, parking lots and tunnels have been analysed. The data collected from the other relevant areas will complement the results obtained in the maritime area. Hazards that have not yet manifested themselves on ships may be obtained and could help to prevent their occurrence.

Data from other relevant areas will help to know what accidents have occurred in these areas, to compare them with those in the maritime domain, to identify common accidents and accidents that have not yet occurred in the maritime domain, and to assess whether they could occur and take measures to prevent them.

Table 6 below shows the different categories of cargo analysed with the hazards found in each of them, both in the maritime area and on the road, in the parking lot and in the tunnel.

Table 6 Main fire causes in the cargo in ships and other relevant areas

	Ships	**Road/Parking/Tunnels**
Reefer unit	• Electrical fault in cable or connections • Electrical fault in unit • Mechanical or electrical fault in unit • Overheating of unit/exhaust fumes	

Conventional vehicle	• Electrical fault in engine compartment • Electrical fault in cabin • Overheated parts in chassis • Overheating (mechanical) in engine compartment • Engine leakage of flammable liquid • Cargo • Engine breakdown (not known if it is electrical or overheating problem) • Overheated drive system • Overheating in engine compartment • Leakage from engine • Leakage from drive system • Collision	• Engine breakdown (not known if it is electrical or overheating problem) • Electrical fault in engine compartment • Overheated parts in chassis • Overheating (mechanical) in engine compartment • Engine leakage of flammable liquid • Cargo • Component failure • Leakage from engine
Special vehicle	• Electrical fault in engine compartment • Electrical fault in cabin • Cargo • Electrical fault in engine compartment	• Electrical fault in engine compartment • Engine leakage of flammable liquid • Overheating (mechanical) in engine compartment • Leakage from parts on chassis • Engine breakdown (not known if it is electrical or overheating problem) • Component failure
New energy carrier	• Spontaneous ignition	• Spontaneous ignition
Dangerous goods	• Self-heating, overheating, self-ignition • Electrical fault in unit	• Mechanical failure • Self-heating, overheating, self-ignition

	• Leakage • Mechanical failure	

The risks identified have been classified into 5 main hazard areas: electrical hazards, overheating, leaks, load and other hazards; the latter will be analysed individually as they include specific risks. For each group of hazards, the main faults that have caused them have been listed as shown in Table 7.

Table 7 Main hazards areas and their failures

Hazard areas	Failure
Electrical	Damaged cable or cable becoming damaged during loading or other deck activity
	Poor quality cable
	Wrong kind of cable provided by driver
	Damaged connection
	Improper connection, coiled cables (cable rolls heating or reels not pulled out all the way)
	Poor maintenance of cables
	Missing protection lids
	Short circuit
	Wrong fuses
	Squeezed cables (isolation fault)
	Installation fault
	Movement of cargo
	Faulty reparation/installations
	Christmas trees, lights, fans, TV, laptop, cabin heater
	More vibration exposures
	Battery left on to remain heating
	Wrong electrical connection to ship grid
Overheating	Slipping V-belt (poor maintenance)
	Couplings failure
	Compressor failure
	Bearings failure
	Cooling failure of exhaust system
	Fuel heater failure

	Stop-engine fans and heaters failure
	Particle filter glowing
	Catalyst smouldering fire
	Regeneration in particle filter failure
Leakage	Leakage from tank, pipe, connections, gasket due to mechanical damage.
	Overloading of vehicle, overfilling of fuel (ramp tilt, sun, heel/trim…)
	Leakage fuel, wiper fluid, cooling liquid, AC gas
	Leakage brake fluid
	Mechanical failure
	Broken seals
Cargo	Self-ignition
	Insufficient lashing of cargo

6.3.1 Cargo fire hazard evaluation

Main author of the chapter: África Marrero

The assessment of the different hazards and failures causing them is based on the number of occurrence and the severity that each hazard has produced on the ship. Considering frequency of occurrence, the number of times that risk occurs in the period of time evaluated. Severity, on the other hand, will show the level of consequences that this failure has produced on the ship.

6.3.1.1 Frequency of occurrence of failures related to cargo and vehicles.

In order to analyse the main hazards involved in the different cargos and cargo units loaded on the ship, the different causes of accidents and their number of occurrence within the sample analysed have been analysed for each type of cargo.

The accident records have been evaluated by periods, since the overall sample is not constant over time and there are quite a few gaps in the information for the different years. Therefore, the total sample has been divided into three periods, taking into account the amount of data available in each of them. Recent figures could be considered closer to reality than older data. Therefore, for the purposes of the study, it seemed a conservative approach to consider only accidents from 1994 to 2020 for the calculation of the initial accident frequency.

These periods were established using the following criteria:

- Years of records from each data source, the periods covered by each source were considered.

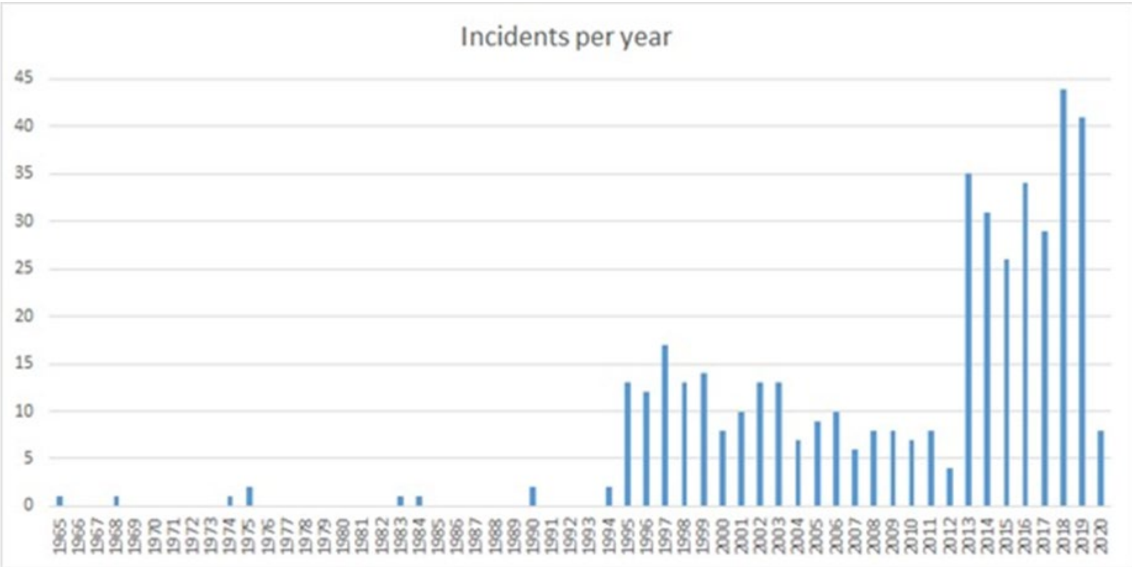


Figure 24 Incidents in maritime area per year

- It is assumed that safety measures for cargo and ships have become stricter over the years, therefore, accidents will be different due to safety measures and new cargo units.

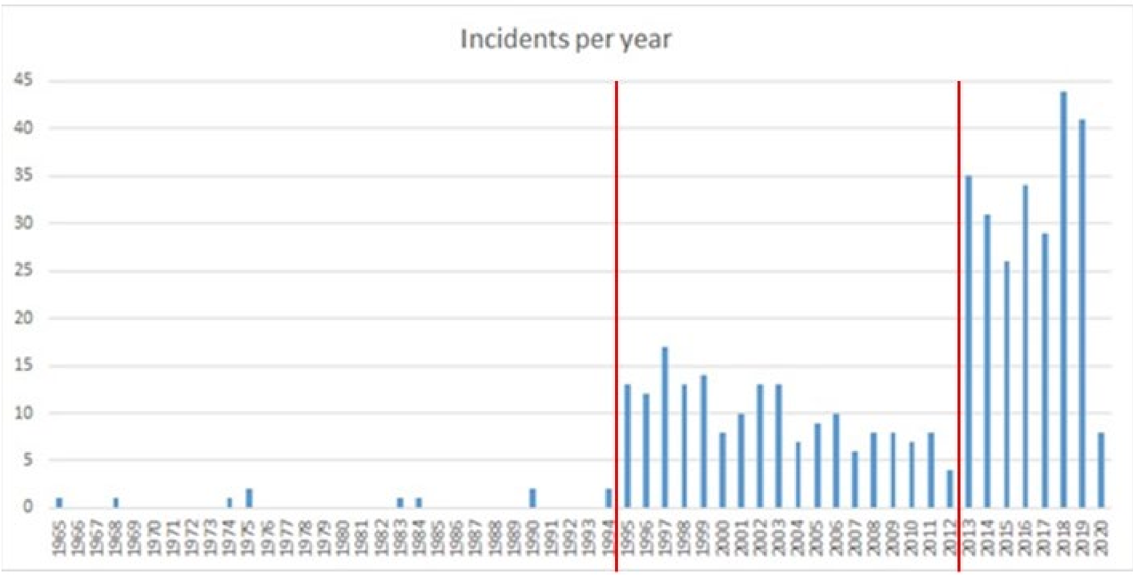


Figure 25 Incident per 3 periods

1. Period 1965-1994

The analysis of this period has been discarded due to the limited amount of data available. The overall assessment of the accidents is not binding as the sample is not significant.

2. Period 1995-2012

The records analysed by cargo typology (cargo typologies have been based on the categories agreed in the HAZID, these being: Reefer unit, conventional vehicle, special vehicle, new energy carrier and dangerous goods) and the causes that led to them are as follows between the years 1995-2012(Table 8):

Table 8 Fire origin and fire causes in the period 1995-2012

Fire origin	Fire cause	Records
Reefer unit	Electrical fault in cable or connections	4
	Electrical fault in unit	5
	Mechanical or electrical fault in unit	1
	Overheating of unit/exhaust fumes	2
	Unknown	11
Conventional vehicle	Electrical fault in engine compartment	14
	Electrical fault in cabin	11
	Overheated parts in chassis	1
	Overheating (mechanical) in engine compartment	3
	Engine leakage of flammable liquid	2
	Cargo	1
	Unknown	10
	Engine breakdown (not known if it is electrical or overheating problem)	1
	Overheated drive system	1
	Overheating in engine compartment	1
	Leakage from engine	1
	Collision	1
Special vehicle	Electrical fault in engine compartment	2
	Electrical fault in cabin	1
	Cargo	1

New energy carrier	Spontaneous ignition	1
Dangerous goods	Self-heating, overheating, self-ignition	2
	Leakage	3
	Mechanical failure	2
	Unknown	3
Not relevant		15

Analysing only the causes without taking into account the cargo where it occurs, the hazards can be classified into 4 groups: electrical, overheating, leakage and a category that includes hazards which occurs on an ad hoc basis and cannot be included in any major category, the data shown in Table 9

Table 9 Main hazards area and fire cause in the period 1995-2012

	Fire cause	**Records**
Electrical	Electrical fault in cable or connections	4
	Electrical fault in unit	5
	Electrical fault in engine compartment	16
	Electrical fault in cabin	12
Overheating	Overheating of unit/exhaust fumes	2
	Overheated parts in chassis	1
	Overheating (mechanical) in engine compartment	3
	Overheated drive system	1
	Overheating in engine compartment	1
Leakage	Leakage from engine	1
	Leakage	3
	Engine leakage of flammable liquid	2
Rest	Mechanical or electrical fault in unit	1
	Unknown	24
	Cargo	2
	Engine breakdown (not known if it is electrical or overheating problem)	1
	Spontaneous ignition	1
	Self-heating, overheating, self-ignition	2

	Mechanical failure	2
	There was a fire, but the origin is not accurately known	5

As shown in Figure 27, electrical risks are the main hazards is identified, followed by overheating and leaks. The "rest" category includes all the risks that have occurred to a lesser extent, and although their individual frequency of occurrence is low, they will be analysed with the aim of identifying them and subsequently reducing them through proper risk management.

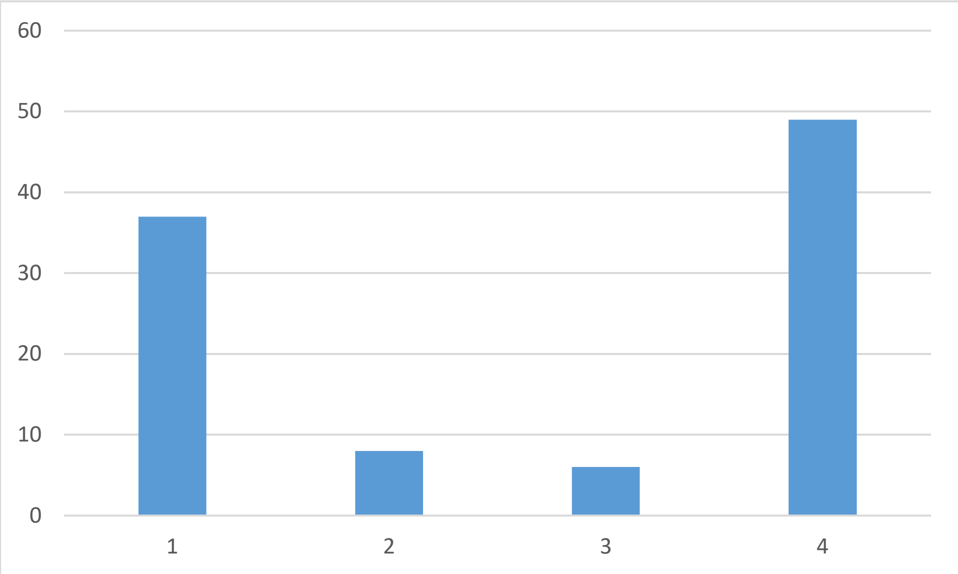


Figure 26 Number of accidents for each hazards group in the period 1995-2012

3. Period 2013-2020:

The records analysed by type of cargo in period 3 are shown in Table 10:

Table 10 Fire origin and fire causes in the period 2013-2020

Fire origin	Fire cause	Records
Reefer unit	Electrical fault in cable or connections	7
	Electrical fault in unit	7
	Mechanical or electrical fault in unit	1
	Overheating of unit/exhaust fumes	5
	Unknown	15
Conventional vehicle	Electrical fault in engine compartment	20
	Electrical fault in cabin	10
	Overheating (mechanical) in engine compartment	5
	Unknown	30

	Engine breakdown (not known if it is electrical or overheating problem)	3
	Overheating in engine compartment	2
	Leakage from drive system	1
	Engine leakage of flammable liquid	3
Special vehicle	Unknown	1
	Electrical fault in engine compartment	3
	Electrical fault in cabin	2
Dangerous goods	Electrical fault in unit	1
	Leakage	1
	Self-heating, overheating, self-ignition	1
	Unknown	3
Not relevant		4

Analysing only the causes without taking into account the cargo where it occurs, the hazards can be classified into 4 groups: electrical, overheating, leakage and a category that includes hazards which occurs on an ad hoc basis and cannot be included in any major category, the data shown in Table 11.

Table 11 Main hazards area and fire cause in the period 2013-2020

	Fire cause	**Records**
Electrical	Electrical fault in cable or connections	7
	Electrical fault in unit	8
	Electrical fault in engine compartment	23
	Electrical fault in cabin	12
Overheating	Overheating of unit/exhaust fumes	5
	Overheating (mechanical) in engine compartment	5
	Overheating in engine compartment	2
Leakage	Leakage from drive system	1
	Engine leakage of flammable liquid	3
	Leakage	1
Rest	Mechanical or electrical fault in unit	1
	Unknown	49

	Engine breakdown (not known if it is electrical or overheating problem)	3
	Self-heating, overheating, self-ignition	1
	There was a fire, but the origin is not accurately known	4
	Ship failure, etc.	1

As shown in Figure 28, electrical risks are the main risks identified as in period 2, followed by overheating, which in period 3 has a higher rate, followed by leaks. The data obtained in period 3 underline the importance of analysing electrical risks for their correct management and subsequent reduction.

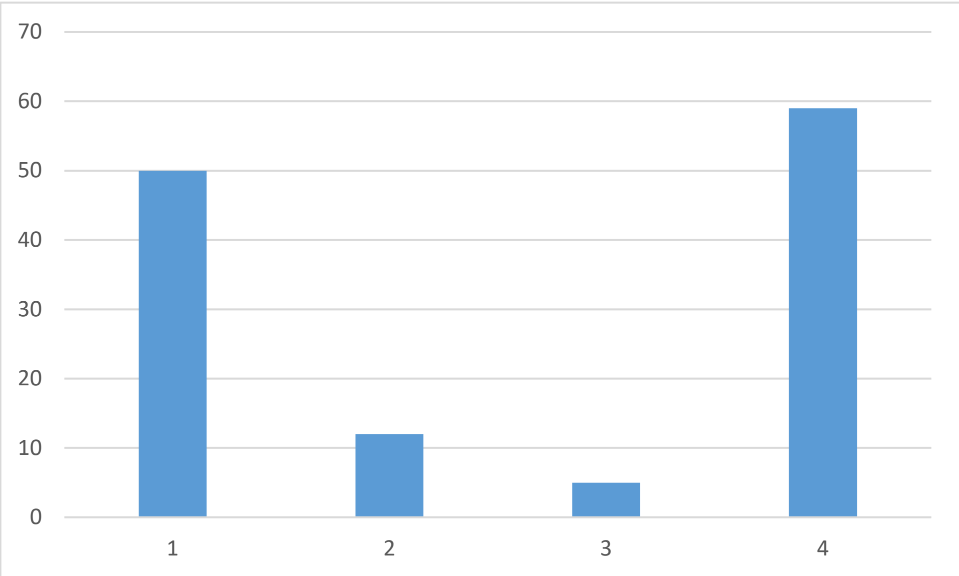


Figure 27 Number of accidents for each hazards group in the period 2013-2020

6.3.1.2 Severity

The following criteria are used to estimate the impacts of the fire along with the severity

- Type of ro-ro deck
- More info. about deck location
- Goods in the fire origin
- Goods close to the fire origin
- More info about adjacent goods and other fuel intervention
- Dangerous goods
- Was charging or plugged but not charging?

Together with the calculation of the severity, the above criteria provide guidance to make recommendations as to where the suitable location is for different cargos.

Severity was estimated from two perspectives. 1) The first was how the different data sources catalogued the severity of the accidents and 2) in those records where the level of severity was not collected, the descriptions of the accidents were analysed and a level of severity was assigned depending on the impact of the accident. This followed the same procedure used by the accident inspectors in their repots. The following explains how each severity level is designed according to IMO.

Since the risk is assigned depending on the sample (except for DG, which by default they have the maximum risk) for those types of cargo which have not been reported before, the risk was set to the minimum level. According to IMO definitions (IMO's "Casualty Investigation Code" in its updated version and IMO Circular MSC-MEPC.3/Circ.3), a marine accident is considered as any marine casualty or marine incident. An accident does not include a deliberate act or omission, with the intention to cause harm to the safety of a ship, an individual or the environment. Severity is classified into the following levels (IMO (. M., 2008):

- very serious marine casualties
- serious marine casualties
- less serious casualties
- marine incidents
- near miss

Marine casualty means an event, or a sequence of events, that has resulted in any of the following which has occurred directly about the operations of a ship (IMO (. M., 2008):

- the death of, or serious injury to, a person
- the loss of a person from a ship
- the loss, presumed loss or abandonment of a ship
- material damage to a ship
- the stranding or disabling of a ship, or the involvement of a ship in a collision
- material damage to marine infrastructure external to a ship, that could seriously endanger the safety of the ship, another ship or an individual
- severe damage to the environment, or the potential for severe damage to the environment, brought about by the damage of a ship or ships.

<u>Very serious</u> casualties means a marine casualty involving the total loss of the ship or a death or Severe Damage to the Environment

<u>Serious</u> casualties are casualties to ships which do not qualify as very serious casualties and which involve a fire, explosion, collision, grounding, contact, heavy weather damage, ice damage, hull cracking, or suspected hull defect, etc., resulting in:
- immobilization of main engines, extensive accommodation damage, severe structural damage, such as penetration of the hull under water, etc., rendering the ship unfit to proceed∗, or
- pollution (regardless of quantity); and/or
- a breakdown necessitating towage or shore assistance.

<u>Less serious</u> casualties are casualties to ships which do not qualify as very serious casualties or serious casualties.

<u>Marine incident</u> means an event, or sequence of events, other than a marine casualty, which has occurred directly in connection with the operations of a ship that endangered, or, if not corrected, would endanger the safety of the ship, its occupants or any other person or the environment.

Near miss is an unplanned event that did not result in injury or damage - but had the potential to do so.

Material damage in relation to a marine casualty means:

- damage that significantly affects the structural integrity, performance or operational characteristics of marine infrastructure or a ship; and requires major repair or replacement of a major component or components, or
- destruction of the marine infrastructure or ship.

Severe damage to the environment means damage to the environment which, as evaluated by the State(s) affected, or the flag State, as appropriate, produces a major deleterious effect upon the environment.

Serious injury means an injury which is sustained by a person, resulting in incapacitation where the person is unable to function normally for more than 72 hours, commencing within seven days from the date when the injury was suffered.

The proportion of accident severity could be biased by the reporting process depending on the database provider.

However, due to the obligations under Directive 2009/18/EU (EU, 2009), incidents are expected to be well represented in the different databases studied.

Therefore, the statistics based on the different databases from which 230 have been obtained in the maritime field and of which 142 have accident severity values give us the severity results in Figure 28

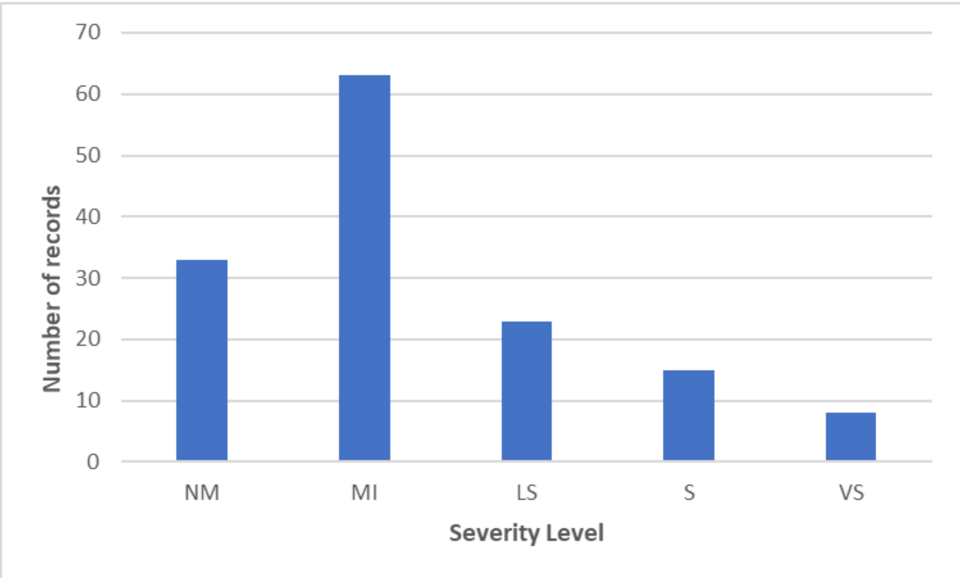


Figure 28 Number of records per type of severity

From which the level of severity does not come (88 data), but the report where the accident was analysed describes the accident that has happened, the IMO standard is considered to establish if the level of severity shown in Figure 29.

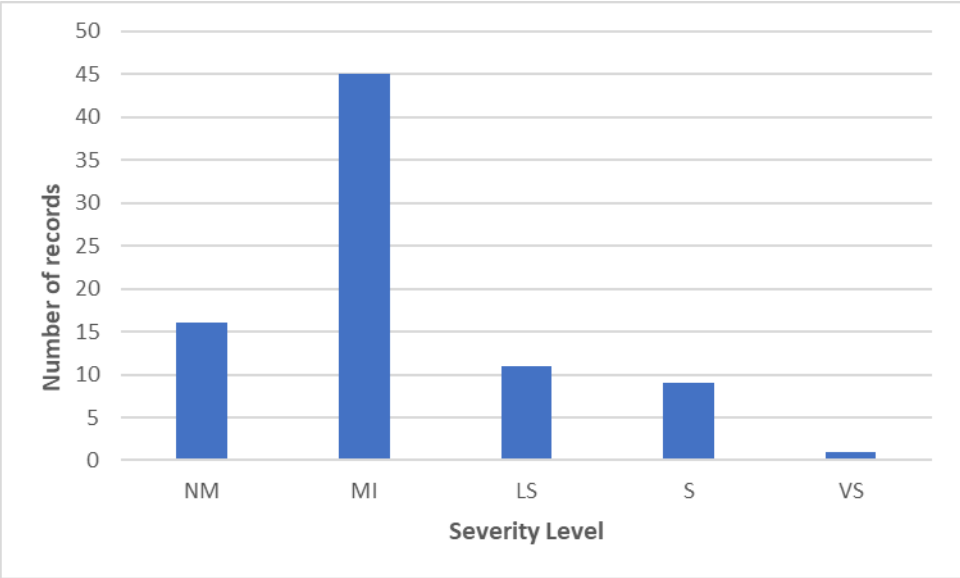


Figure 29 Number of records per type of severity II

6.3.1.3 Analysis of the main hazards

6.3.1.3.1 Electrical

Electrical hazards are considered to be all those that involve a danger derived from contact with electrical current and that may result in a danger to the integrity of the cargo, ship and people.

The electrical faults that have been found in the 230 accident reports evaluated in the maritime environment can be classified into the following 4 electrical faults (according to the location of the fault)

- Electrical fault in cabin
- Electrical fault in cable or connections
- Electrical fault in engine compartment
- Electrical fault in unit

The causes that led to each of them are shown below:

- Damaged cable or cable becoming damaged during loading or other deck activity
- Poor quality cable
- Wrong kind of cable provided by driver
- Damaged connection
- Improper connection, coiled cables (cable rolls heating or reels not pulled out all the way)
- Poor maintenance of cables
- Missing protection lids
- Short circuit
- Wrong fuses
- Squeezed cables (isolation fault)
- Installation fault
- Movement of cargo
- Faulty reparation/installations
- Christmas trees, lights, fans, TV, laptop, cabin heater
- More vibration exposures
- Battery left on to remain heating

- Wrong electrical connection to ship grid

The severity derived is shown in **Fel! Hittar inte referenskälla.** below:

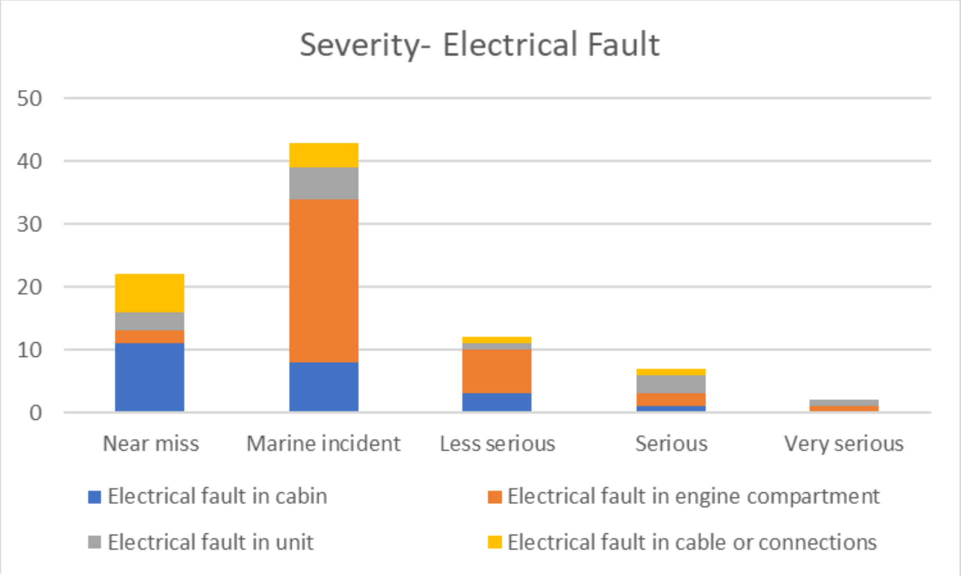


Figure 30 Severity-electrical fault

6.3.1.3.2 Overheating

Overheating hazards are considered to be all those that involve a hazard arising from an increase in temperature of any part of the cargo or vehicle resulting in damage to the cargo or vehicle leading to a fire.

The overheating failures that have been found in the 230 accident reports evaluated in the maritime environment can be classified in the following categories

- Overheating of unit/exhaust fumes
- Overheated parts in chassis
- Overheating (mechanical) in engine compartment
- Overheated drive system
- Overheating in engine compartment

The causes that led to each of them are shown below:

- Slipping V-belt (poor maintenance)
- Couplings failure
- Compressor failure
- Bearings failure
- Cooling failure of exhaust system
- Fuel heater failure
- Stop-engine fans and heaters failure
- Particle filter glowing
- Catalyst smouldering fire
- Regeneration in particle filter failure

Taking into account the 230 accidents in the maritime environment and the time periods in which they occur, we can say that 8.69% of the accidents encountered are caused by overheating.

The severity derived is shown in Figure 32

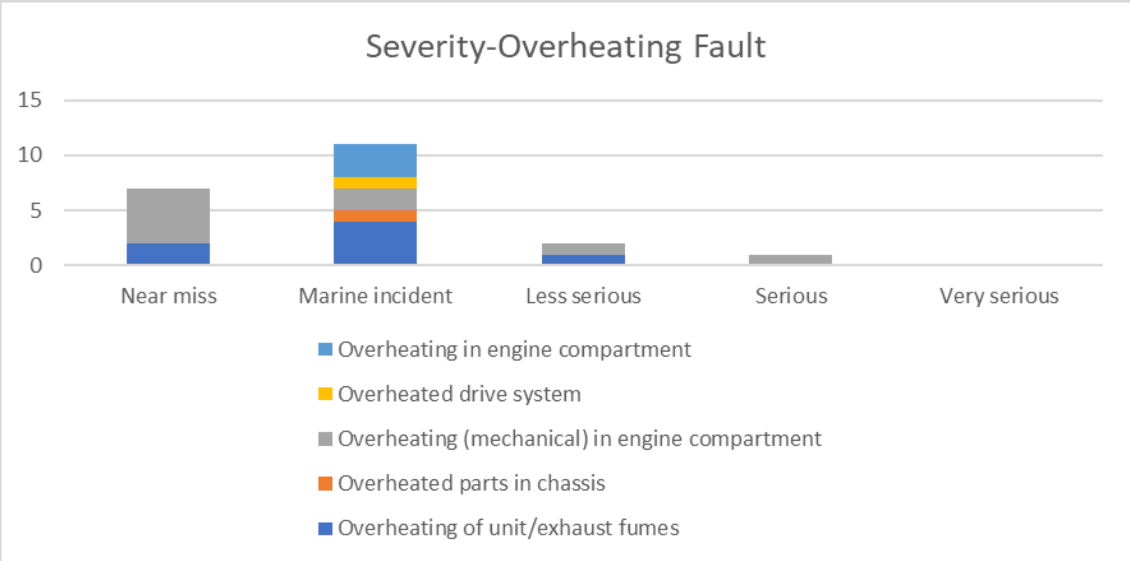


Figure 31 Severity-Overheating Fault

6.3.1.3.3 Leakage

Leakage hazards are considered to be all those that involve a hazard arising from the leakage of any liquid (flammable or not) from the cargo or vehicle resulting in damage to the cargo or vehicle leading to a fire.

The leakage failures that have been found in the 230 accident reports evaluated in the maritime environment can be classified into the following categories

- Leakage from engine
- Leakage
- Engine leakage of flammable liquid

The causes that led to each of them are shown below:

- Leakage from tank, pipe, connections, gasket due to mechanical damage.
- Overloading of vehicle, overfilling of fuel (ramp tilt, sun, heel/trim…)
- Leakage fuel, wiper fluid, cooling liquid, AC gas
- Leakage brake fluid
- Mechanical failure
- Broken seals

Taking into account the 230 accidents in the maritime environment and the periods of time in which they occur, we can say that 4.78% of the accidents encountered are caused by leaks of a liquid (flammable or non-flammable).

The severity derived is shown in Figure 33

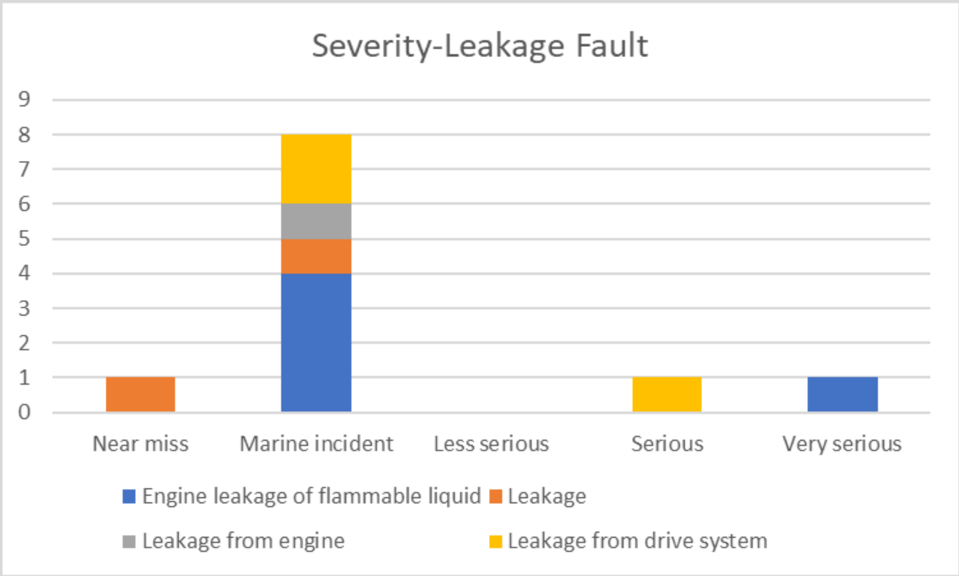


Figure 32 Severity-Leakage Fault

6.3.1.3.4 Other relevant hazards

Other relevant hazards have been categorized as all those that have occurred in the analysis of the 230 records analysed. Due to their specific occurrence, they should be considered when making recommendations and trying to reduce their occurrence or danger.

The risks that occur to a lesser extent and that will be analysed are the following:

- Unknown
- Cargo
- Engine breakdown (not known if it is electrical or overheating problem)
- Collision
- Spontaneous ignition
- Self-heating, overheating, self-ignition
- Mechanical failure
- There was a fire, but the origin is not accurately known
- Ship failure, etc.

The severity derived is shown in Figure 34 below:

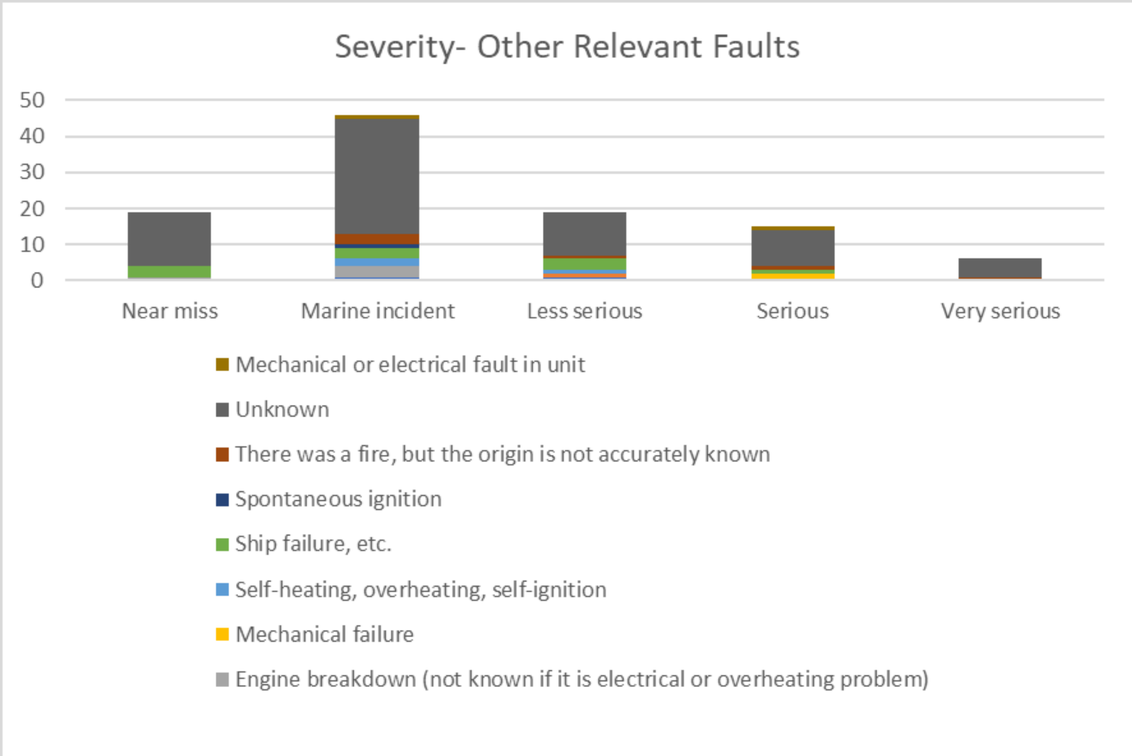


Figure 33 Severity - Other relevant faults

6.3.1.3.5 Other relevant areas (parking lots, roads and tunnels)

In total, 123 fires in parking lots, roads and tunnels were gathered. Most of them (101 incidents) occurred in conventional vehicles and in 17 incidents “New Energy Carrier” was the first origin of fire. These 17 incidents are significant for the DB because they represent 94% of the total of fires that occurred in a “New Energy Carrier”.

The following histogram (Figure 34) shows the frequency in a yearly basis for all the incidents from this source considering the interval of years from the first reported incident in the whole database to the last (this allows quick comparison between the same chart for different selections):

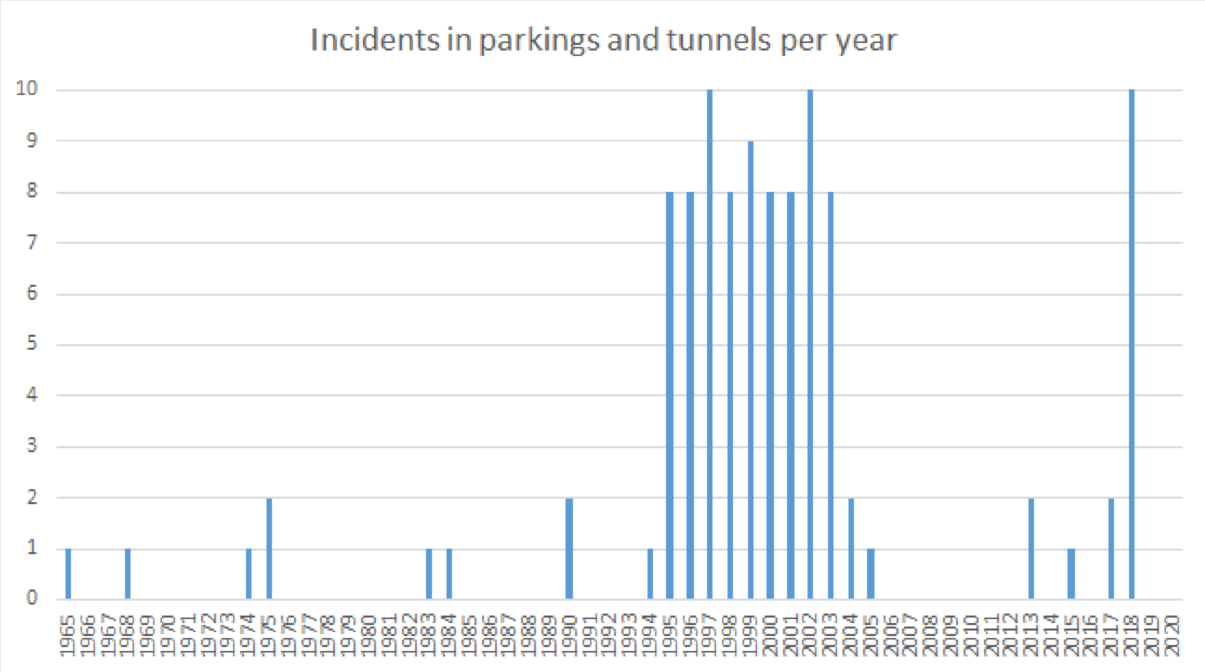


Figure 34 Registered incidents in tunnels and parking per year

Within the 123 analysed, the following causes have been identified for each fire origin (shown in Table 12)

Table 12 Fire origin and fire cause in road, parking lots and tunnels area

Fire Origin	Fire cause	Records
Conventional vehicle	Engine breakdown (not known if it is electrical or overheating problem)	9
	Electrical fault in engine compartment	51
	Overheated parts in chassis	4
	Overheating (mechanical) in engine compartment	7
	Engine leakage of flammable liquid	12
	Cargo	1
	Component failure	6
	Overheating in engine compartment	8
	Leakage from engine	18
	Other	33
	Unknown	9
Special vehicle	Electrical fault in engine compartment	13
	Engine leakage of flammable liquid	18

	Overheating (mechanical) in engine compartment	3
	Leakage from parts on chassis	2
	Engine breakdown (not known if it is electrical or overheating problem)	1
	Component failure	2
New energy carrier	Spontaneous ignition	17
Dangerous goods	Mechanical failure	1
	Self-heating, overheating, self-ignition	1

Independently of the cargo where the hazard occurs, the causes can be classified into the following categories as shown in Table 13 below.

Table 13 Fire cause in road, parking lot and tunnel area

	Fire cause	Records
Electrical	Electrical fault in engine compartment	64
Overheating	Overheated parts in chassis	4
	Overheating (mechanical) in engine compartment	10
	Overheating in engine compartment	8
Leakage	Engine leakage of flammable liquid	30
	Leakage from engine	18
	Leakage from parts on chassis	2
Rest	Cargo	1
	Component failure	8
	Engine breakdown (not known if it is electrical or overheating problem)	10
	Mechanical failure	1
	Other	33
	Self-heating, overheating, self-ignition	1
	Spontaneous ignition	17
	Unknown	9

As shown in Figure 36, the electrical hazard continues to outweigh the others significantly, however in the accidents collected on roads, parking lots and tunnels there is an increase in overheating and leakage hazards.

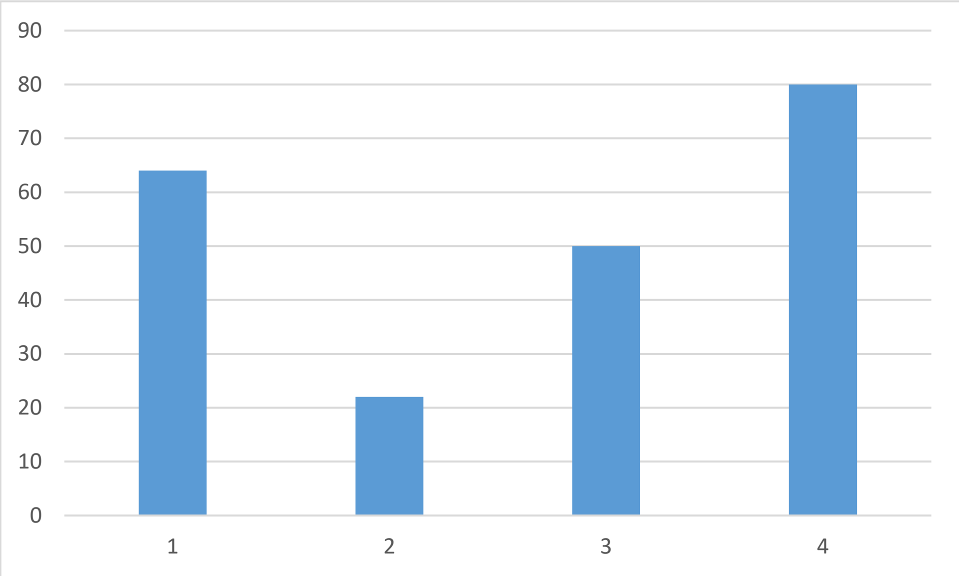


Figure 35 Number of accident per hazard group in other relevant areas

6.3.1.3.6 Conclusion of fire hazard evaluation

The most common ignition source is conventional vehicles as the type of vehicle is the most common type of cargo on the ships analysed. Analysing the main causes of fire in this type of vehicles, electrical failures in the engine compartment, engine leaks, overheating in the engine compartment or electrical failures in the cab of trucks stand out.

Making a brief study of cargo manifests, and which are the most common cargoes in this type of ships, especially in ro-pax ships and ro-ro cargo ships, where the cargo is usually more heterogeneous than in a car carrier, conventional vehicles are the most common type of cargo.

In the usual operation of ro-ro and ro-pax cargo ships, many of the loading trucks arrive at the port a few minutes before the cargo closes, as a strategy of the transport companies is to keep the truck at the port as short as possible and to plan the routes so that waiting times are as short as possible and thus reduce costs. This causes the truck or car entering the ship to have a high temperature in several parts of the vehicle, which, in conditions of poor ventilation, among others, can cause fires.

Apart from conventional vehicles, fires are also frequent in refrigerated units, special vehicles and vehicles classified as APV. In refrigerated units, fires caused by electrical faults in the unit or in the wiring and connections are by far the most common source of fire. For special vehicles, special attention should be paid to fires originating from electrical faults in the engine compartment or in the RV cabin. Finally, it should be noted that the main cause of fire in APVs is spontaneous ignition.

Another risk to highlight is the high risk of electrical failure in reefers, in many cases due to poorly maintained electrical connections both in the connector and in the reefer itself. The trend indicates that more and more ships are carrying reefer units, so more attention and maintenance is needed to reduce electrical fires in this type of cargo units. In addition, Report D04.1 (D04.1, 2020) states that "marine casualty data also show that electrical failures in reefer units are particularly dangerous, evidenced by the fact that four of the top five ro-ro passenger ship fires in recent years have been caused by electrical failures in reefer units."

Electric vehicles are currently booming and, in many cases, it is not known why their batteries ignite, so spontaneous ignition of these vehicles has a high risk because the behaviour of these vehicles cannot be predicted at present. The main causes of accidents with electric vehicles are due to technical defects (short circuits or local overheating of parts) and incorrect charging of electric vehicles, either through the use of unsuitable cables or improper plug connections.

Electric vehicles or systems with lithium-ion batteries tend to burn more than other batteries. This does not mean that they are more likely to catch fire, but it does mean that they are more difficult to extinguish. It has been found that the more the battery is charged, the more energy is released in the event of a fire. Securius and Kähler (Securius, 2013) highlight the importance of focusing on accidents caused by charging damaged cells and batteries on ro-ro and ro-pax ships.

7 Definition and parametrization of ships

Main Author: Blandine Vicard, BV

All systems developed in WP08 must relate to different aspects of the design and physical layout of the ship, it affects rules for stowage and segregation as well as operational aspects for sensors, drones and protection from environmental aspects demands on the electrical installations.

7.1 Definitions of ro-ro space, vehicle space and special category space

As per SOLAS II-2/3:

- "*Vehicle spaces are cargo spaces intended for carriage of motor vehicles with fuel in their tanks for their own propulsion.*"
- *"Ro-ro spaces are spaces not normally subdivided in any way and normally extending to either a substantial length or the entire length of the ship in which motor vehicles with fuel in their tanks for their own propulsion and/or goods (packaged or in bulk, in or on rail or road cars, vehicles (including road or rail tankers), trailers, containers, pallets, demountable tanks or in or on similar stowage units or other receptacles) can be loaded and unloaded normally in a horizontal direction."*[1]
- *"Special category spaces are those enclosed vehicle spaces above and below the bulkhead deck, into and from which vehicles can be driven and to which passengers have access. Special category spaces may be accommodated on more than one deck provided that the total overall clear height for vehicles does not exceed 10 m."*

  Special category spaces are ro-ro spaces to which passengers have access, possibly during the voyage. Special category spaces are the most frequent type of closed ro-ro spaces on ro-ro passenger ships.

  It is to be noted that open ro-ro spaces are not considered as special category spaces.

7.2 Closed, open and weather deck

As per SOLAS II-2/3:

- A "*weather deck is a deck which is completely exposed to the weather from above and from at least two sides.*"

  IACS UI SC 86 additionally details that: "For the purposes of Reg. II-2/19 a ro-ro space fully open above and with full openings in both ends may be treated as a weather deck."

  For practical purposes, drencher fire-extinguishing system cannot be fitted on weather decks due to the absence of deckhead. This criterion is often used for a practical definition of weather decks.
- An open vehicle or ro-ro space is "*either open at both ends or [has] an opening at one end and [is] provided with adequate natural ventilation effective over [its] entire length through permanent openings distributed in the side plating or deckhead or from above, having a total area of at least 10% of the total area of the space sides.*"
- A closed vehicle or ro-ro space is any vehicle or ro-ro space which is neither open nor a weather deck.

As a reference criterion, it can be considered that a vehicle space that needs mechanical ventilation is a closed vehicle space.

[1] In other words, ro-ro spaces are vehicle spaces into which vehicles can be driven. It is to be noted however that, for the purpose of the application of SOLAS II-2/19, the following interpretation can be found in MSC.1/Circ.1120 and IACS UI SC 85: "Ro-ro spaces include special category spaces and vehicle spaces"

8 Remote identification methodologies

Main author: Robert Rylander, RISE

Automation and digitalisation tools for both increased safety and efficiency in daily operations. In WP08 the goal is a technology transfer from other domains such as tunnel safety and drone technology with the goal to raise safety from gate to gate by the introduction of remote sensing. All ships, ports, terminals, and flow of cargo/vehicles are unique due to many factors, global and local. Due to this, a single methodology that works in one location might not work at another location. It can be so that the physical layout of the terminal in the different ports, differs so much that a solution that works in port A does not work in port B.
The following chapters of the report start with a general description of the situation on conditions that needs to be considered but not limited to that both will and might affect a future choice of solution. A system for automatic screening must consider all various scenarios of possible deck arrangements.

8.1 Operational context

In this project, the challenges are grouped into external and internal challenges. External are those that humans cannot control e.g. meteorological, such as rain, snow, water spray. Internal are those that are man-made or imposed, such as design of ship or concerns of insurance claims.

Physical contact between drivers/stevedores/ship crew and the cargo/vehicles are considered a high priority, all types of contact imposed extra costs and adds a risk for insurance claims. All systems must be scrutinised in a life cycle analysis perspective, for example a system using "tags" must consider aspects of reusability and disposal of these. At first, a ferry connection might look simple and straight forward, but the fact that the cargo/vehicle or even the ship, might seldom or never come back to that specific port/terminal, limits the feasible solutions. Some of the ships roam the world and makes port calls in different nations along their routes.

Systems could either be based on the ship and travel the world, or port/terminal and line specific. If the system is shipborne or parts of it, the system must be able to operate in all nations and considerations must be taken on use of radio frequencies, integrity of passengers and personnel working at the terminal/ports. If the system is shore based, it is probably simpler but the values of having such system is limited to the pre-loading phase and will not raise the safety onboard the ship after the last point of sensor, neither can it support the crew on the ship during the sea passage.

To tackle the challenges, combinations of different hardware e.g. sensors and software techniques is needed. Other industries/domains have similar challenges, production plants, logistic centres, airports and lessons learned from them are brought in to LASH FIRE to address the challenges, but so far, no other public transportation domain has the same width of challenges as the shipping companies and terminal operators.

8.1.1 The air conditioning unit on a reefer trailer

The basic concept of a reefer unit is an air conditioning (AC) unit illustrated below in Figure 36 that can sustain a given temperature by the usage of added energy. The added energy is either fuel, most common is diesel to an internal combustion engine (ICE) or electricity

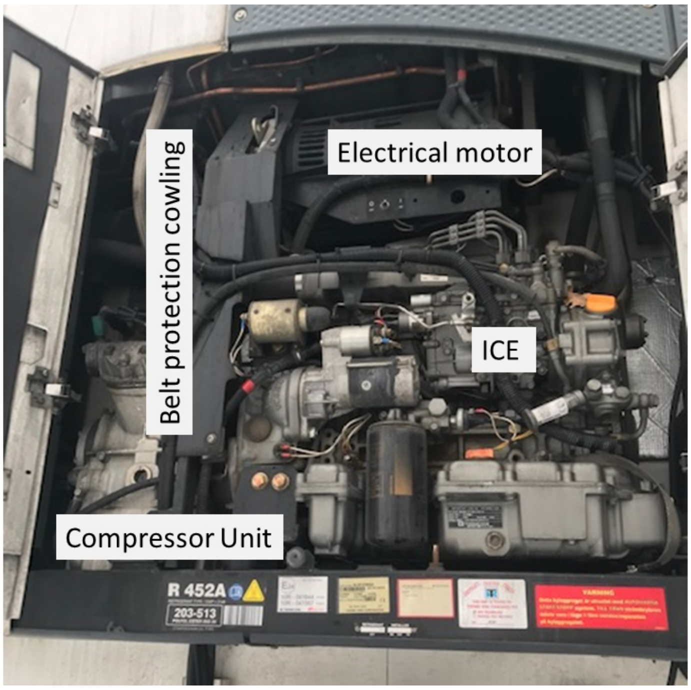


Figure 36 Air conditioning unit on a reefer trailer (source Anders Efraimsson, RISE)

Both these motors are connected to a compressor unit via belts and other support systems e.g. generators on the ICE to produce electrical power to fans, battery charger(s) etc.

These AC units can provide heat and/or cooled or heated air flow into the cargo area of the trailer. The system is usually only capable of keeping a temperature, not cooling down or heating up larger amounts of cargo. And they are self-sufficient of power for longer periods running on the ICE. A new trend is to fit these reefer trailers with solar panels and a larger battery bank, allowing minimum or no use of ICE at all.

Figure 37 Belts inside an AC reefer unit (source Anders Efraimsson, RISE)

If the unit is to be connected to an electrical grid ashore or on the ship, a standard 400V 32 Ampere connection is provided. As illustrated below in Figure 39 by a red socket. Also visible is a diagnostic port in black.

Figure 38 An 400V, 32 Ampere IP44 socket on a reefer unit (source Anders Efraimsson, RISE)

8.2 Flow of cargo/vehicles

As illustrated in chapter 3.3 in Figure 2 the sea voyage can be seen as a continuation of the road, as a bridge or link. At some strategic point in the port, at the terminal and/or at the ship, good use of sensor technology will allow for an enriched situational awareness of the status cargo/vehicles entering the terminal and then onboard the ship. Adding sensors could also monitor the terminal as well as assisting with yard management and even security related issues such as trespassing. But there are challenges of different kinds along the cargo/vehicles path in port, at the terminal, entering and onboard the ship.

Usage of remote sensing technologies can enhance the current fire safety routines and systems around the handling of cargo/vehicles. The growing number of alternative powered vehicles (APV) will make the situation onboard the ship more complex than it is today, both in regard to the fire safety in general and especially in regards to dangerous goods. Ship's stability will also be affected , since battery electric vehicle are heavier than the majority of today's vehicles with internal combustion engines (ICE) and is already a concern for vehicle carriers. The mixture of hazards that will make it more complicated to extinguish a fire, since the means of controlling and extinguish the fire might need combinations of solutions and techniques.

This chapter is considered an overview of what an automatic system could provide, concerns related to automatic screening of cargo and the scope for the activities that was defined by the HAZID that was held in December 2019 at RISE in Borås Sweden (LASH FIRE, 2020)

8.3 Challenges for usage of remote sensing for detecting heat anomalies

The work package has two overarching tracks that meet up in a common system of systems approach, with the LASH FIRE cargo fire hazard database a foundation for risk reducing in the planning phase and usage sensors as the cargo/vehicles enters the premises and is carried onboard the ships. It also makes the proposed solution flexible and robust e.g. one system can operate and contribute to higher level of safety independent of the other system. And together they will enrich each other and improve the safety of the passenger, crew, cargo and ships.

SICK's Vehicle Hotspot Detection system (VHD) is a state of the art and will be the base line technology for scanning objects at fixed installation, the gate that cargo/vehicle enters the terminal, and also a demonstration of a novel concept for automatic screening of cargo and vehicles onboard, will be conducted in the project at demonstrators.

LASH FIRE will add the new hazards identified at the HAZID, e.g. issues with malfunction of reefer motor/compressor and a novel approach to address the new challenges alternative powered vehicles (APV) possess in a planning and loading of units to the already cargo/objects addressed in the IMDG code. This work package focuses on early detection methods and other sensors are covered in other work packages in LASH FIRE, but in a future system they all contribute with their sensors and data to a more rigid system of systems, mitigating the risks onboard the ships.

All systems are subject to their environment, to design an automated system such as the Vehicle Hot spot Detection (VHD) described in 8.5.7 and drones in chapter 9, some of the factors must be addressed and dealt with. The robustness of the system has to be considered, so that it can handle all these challenges and a solution designed with procedures that can rectify errors or loss of data from an automated system or a fail over solution designed.

8.3.1 External challenges

Non-controllable factors that must be taken into consideration and mitigated if possible. One good thing is that the push for autonomous vehicles that will operate in similar conditions, is driving the technology forward and the prices are dropping, or the performance is increasing.

8.3.1.1 Meteorological

Most cargo operations in terminals are conducted in open areas, where the cargo/vehicles are exposed to all types of weather. The local temperature differences inside the ship's hull compared to the ambient temperature and relative humidity, adds challenges to remote sensing such as condensation on hull, on sensors as well as on cargo/vehicles. And precipitation such as snow, sleet and rain, but also mist/fog is challenging environment for remote sensing and provides problems for automated drones using visual navigation.

Water droplets or water in more solid forms, can also effectively dampen radio signals. On weather decks the strong wind with rain/hail can also damage sensors, cargo and drones by e.g. impairing the manoeuvring of the later.

8.3.1.2 Dirt on cargo/vehicles

Particles, dust and dirt from travelling on roads is also a challenge for the use of cameras to read signs and it dampens signals.

8.3.1.3 Spray of salt water

In ports and terminals, the wind can carry spray of sea water, and the salt has good adherence on surfaces and is a challenge both to the placement of sensors as well as keeping them clean enough for continuous operation. It can also put constraints on the materials used in a solution due to the corrosive nature of the salt water.

8.3.1.4 Light condition

Depending on what type of sensors that can be used, the local light needs to be considered. Strong sun light, glare, reflections or precipitation will possess challenges. Also, the lack of light or blocking by smoke can pose problems when using e.g. RGB cameras.

8.3.2 Internal challenges

As assumed in this report, the Internal challenges are those that are man-made or imposed by humans, could be by rules and regulation or tradition.

8.3.2.1 Insurance and liability

If the cargo/vehicle is damaged under the care of the shipping company, there is a risk of claims if the ship's crew or something belonging to the ship hits the cargo/vehicle. Therefore, other than direct safety or cargo securing/lashing related operation, as little or no physical contact with the cargo/vehicle as possible is preferable. In general, the lower the value of the cargo/object the more physical contact is accepted. On the other end is high valued cargo such as new vehicles transported on ships, where ship crew should avoid contact to an uttermost extent to avoid insurance claims. Any automized solution is required to be able to detect and avoid obstacles for the safety of both crew and cargo.

8.3.2.2 Human error

There are also the aspects of human error both in the sense of mistakes e.g. incorrect labelling or placement of equipment and malicious acts, which could e.g. be sabotage or theft. An automated system must allow easy manual corrections/support.

8.3.2.3 Radio inference

Different types of transmitters both on land on from other ships risk interfering with the ones on the ship or the terminal. These can e.g. be radio inference or radar inference.

8.3.2.4 Radio frequencies

Different nations have different public or open frequencies, for a ship that roams the world, it might need three different transceivers to be able to operate and also transponders will have to work on different frequencies.

8.3.2.5 Design of terminal

The physical layout of ports and terminals varies all over the world. On some locations it can be hard to place a stationary system, or the cost will go up since a higher number of sensors might be needed to cover a whole truck and trailer. Also, if the cargo/vehicle can pass underneath a canopy/roof where controlled ambient environment is possible or not, is a factor to consider when designing these types of systems.

8.3.2.6 Design of cargo/vehicle ramp(s)

The cargo/vehicle ramp between ship and shore, differs from type of ship and terminal. Most Ro-Ro-pax/ro-ro cargo ships/Vehicle carriers have one ramp on the ship, some have multiple. Some ships have the ramp in the stern, usually allows a wider ramp, others have opening to cargo/vehicles in the bow of the ship.

Some ports/terminal allows parallel loading/unloading operations. Some ship has side openings with ramps as illustrated below with a ramp available for the use of cargo operations through a side door at the Stena Line Denmark terminal in Gothenburg. Others need shore facilitated infrastructure of ramp(s).

Figure 40 Vehicle/cargo ramps leading up to the ships side (Photo Robert Rylander, RISE)

In some cases, the ship is fully dependent on the infrastructure in the port/terminal as illustrated below with Stena Carisma unique solution for mooring and cargo ramp, or vice versa where the terminal has just a flat area for the ship to lower and land their ramps on. Often the solution for vehicle carriers, hence, the unique design of stern and side ramps.

Figure 41 Linkspan and external cargo ramp for HSS Stena Carisma (Photo Robert Rylander, RISE)

And even two ships on the same trade could differ in terminal interface. All these aspects make an installation close or on the ship a challenge.

8.3.2.7 Design of ship openings

The openings in the ship is also usually the maximum size of cargo/vehicles that can be carried onboard as shown in Figure 39. Openings in the aft, often allows one wide ramp or parallel ramps. Some ship can load directly to weather deck using shore-based ramps. This could allow higher types of cargo, but usually lower weight than cargo that is loaded on lower holds in the ship on main deck.

8.3.2.8 Design of cargo deck

All ships are different, even sister ships in the same series have differences. It can be changes in selection of materials, deck gear to larger differences such as re-designing structural items in the hull such as lay out of decks, openings and type of ramps. All this makes retrofit of a system more expensive and it is expected that one of the most time-consuming items will be routing of cables for sensor signals and power. It is also a driver for systems that can move freely, since they have a larger market/uptake than systems that are ship specific.

8.3.2.9 Beams and pillars

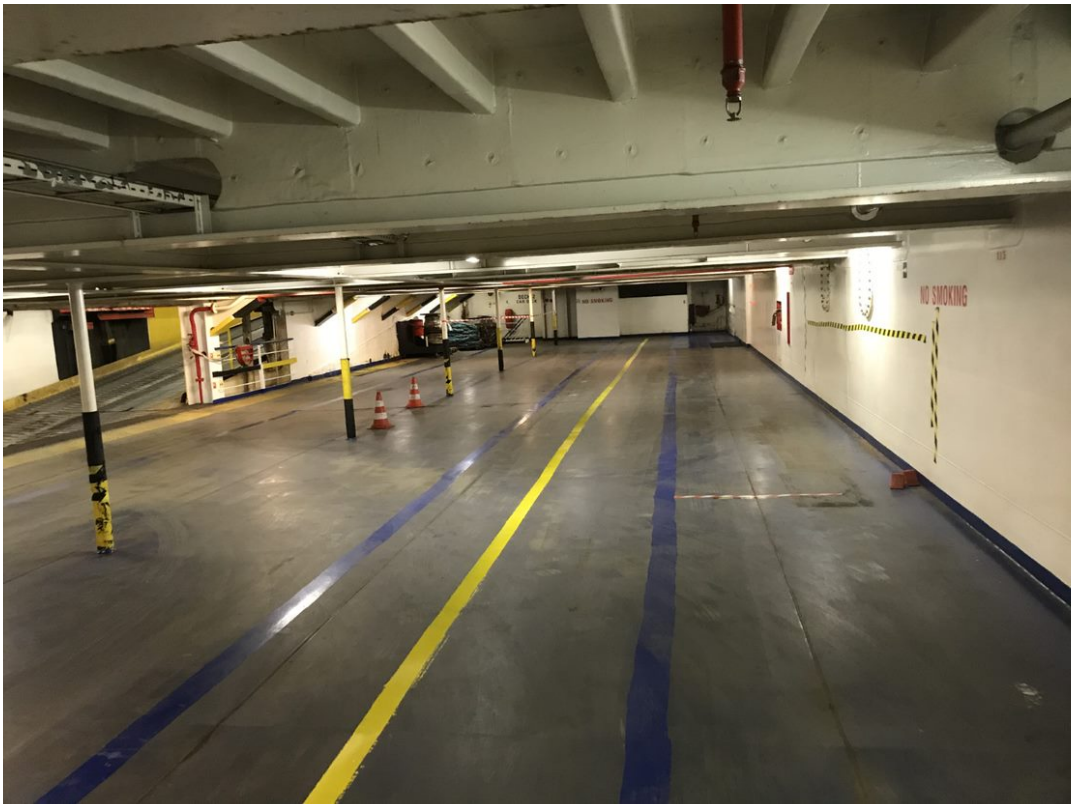
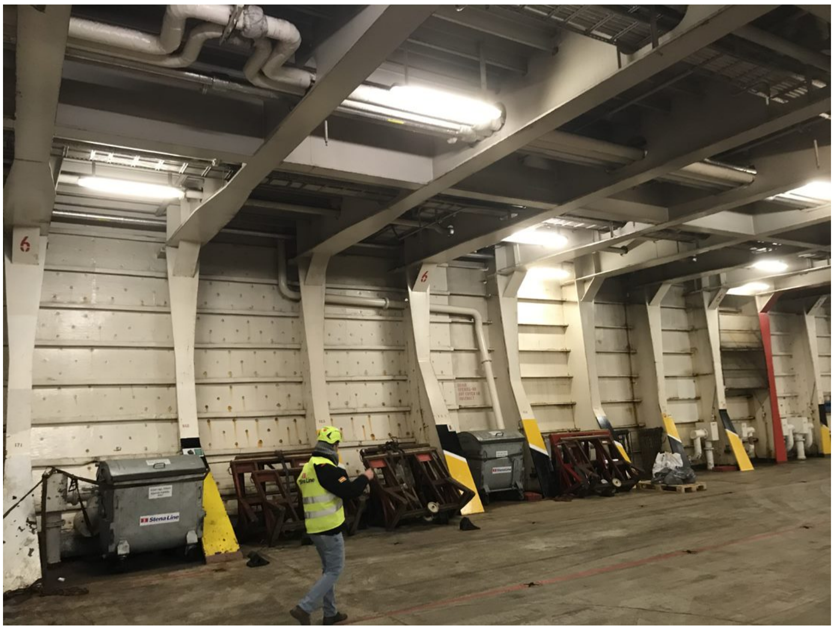


Figure 42 Beams and supporting pillars in a lower ro-ro cargo ship cargo hold a.k.a Tank top (Photo Lena Brandt DFDS)

Steel is used in the beams, it is possible to take out openings for cable and sensors, but it is a costly procedure when routing cables between watertight and fire and explosive secured decks. In the future, when designing new ships, it is not a large cost to prepare for more installations of sensor-based systems and the needed cable routing.

Pillars supporting the horizonal beams are also something that must be taken into consideration when designing a screening system. They can support sensors, but they also block areas for most types of sensors.

8.3.2.10 Bulkheads



The recesses between vertical beams are often used for storage of deck gear and lashing or storage.

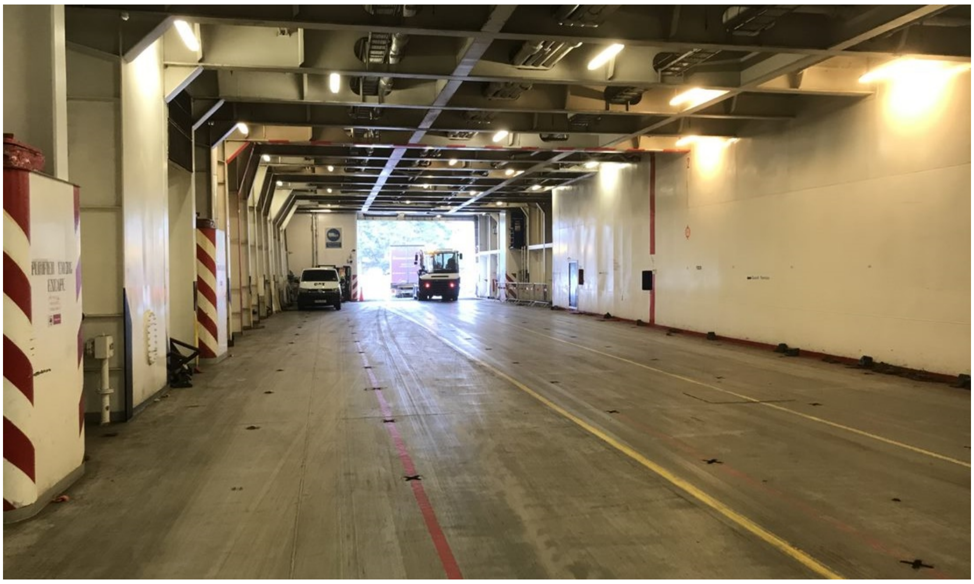


Figure 44 Rows of lashing points in the deck (Photo Martin Carlsson Stena Line)

The vertical beams on the outer hull side, to the left in the picture above, are used for various purposes and can be an access point for electrical power to reefers or emergency exits that should not be blocked at any time.

8.3.2.11 Cargo deck watertight doors

Decks or compartments/segments of decks are often sealed off by a water and gas tight door. Therefore, there is a need of a system, which can handle each of these compartments/segments separately.

8.3.2.12 Flood control doors

After the Estonia tragedy the issue with free water surface on large open car decks was addressed by sectioning of the deck into smaller surfaces (volumes). It is done in different ways; some ship have watertight doors that completely section off the deck. Other have partial closures like “barricades” that are partly dividing the free surface area of deck into sections.

8.3.2.13 Deck

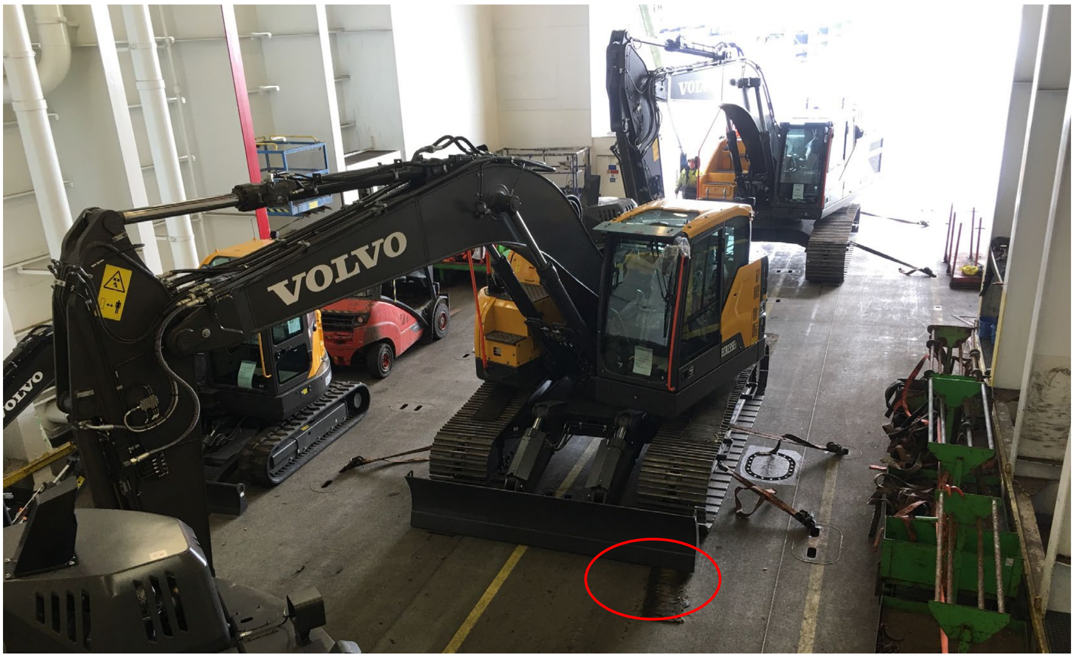


Figure 45 Rubber mats (encircled) used to protect the deck (Photo Lena Brandt DFDS)

The deck itself are as obstacle free as possible, but some have recesses, pads or holes for lashing points. They are occasionally trafficked by heavy machinery and the use of so called MAFIS or flatbeds that carries cargo can be placed all over the deck. To protect the deck and to prevent metal surfaces from being directly connected slabs of rubber mats are placed between the carrier and the deck as illustrated in Figure 8. Worth noting in Figure 45, there is also a sharp contrast in the light condition between indoor and outside of the ship.

8.3.2.14 Lashing equipment

Lashing the cargo and vehicles is crucial to the safety of ships and cargo. The lashing equipment should both be safe to operate and though enough to secure the cargo in rough weather and even hold the cargo in place in the rare case of a ship capsize. Materials can be synthetic fibres to chains or wires. They can be operated with one hand or require power tools or steel bars to get leverage/torque. They are usually fastened in specific spots in the floor or the steel beams of the ships structure. The lashings present a challenge for drones and other mobile units both in regard to size and the overall mobility.

To speed up the stowage of trailer various types of systems have been invented and below there is one version of a so called "dolly". After the trailer is resting on the dolly, it is lashed to the deck.

Figure 47 One type of "Dolly" used to simplify the securing of trailers (Photo Lena Brandt DFDS)

Figure 48 below, shows cargo that is first secured to a rig called roll trailer, flatbed or MAFI, then the rig is secured to the ship using lashings.

Figure 48 Flatbeds lashed to the deck (Photo Lena Brandt DFDS)

8.3.2.15 Hostable/Raiseable/Liftable decks

Many ro-ro cargo/Ro-pax ships and vehicle carriers have flexible solutions for their cargo decks, one is the possibility to lower down “hanging” decks from the ceiling as illustrated below with red high visibility markings showing the corners and lowest vertical clearance.

Figure 49 Hoistable decks onboard Stena Danica (Photo Martin Carlsson STL)

Some ships even have multiple layers of these types of decks as illustrated below from a vehicle carrier.

Some ships have the possibility to raise/lower these decks in small sections to accommodate as much cargo space for so called high and heavy cargo and at the same time facilitate as much deck area for other cargo, usually smaller vehicles/cargo.

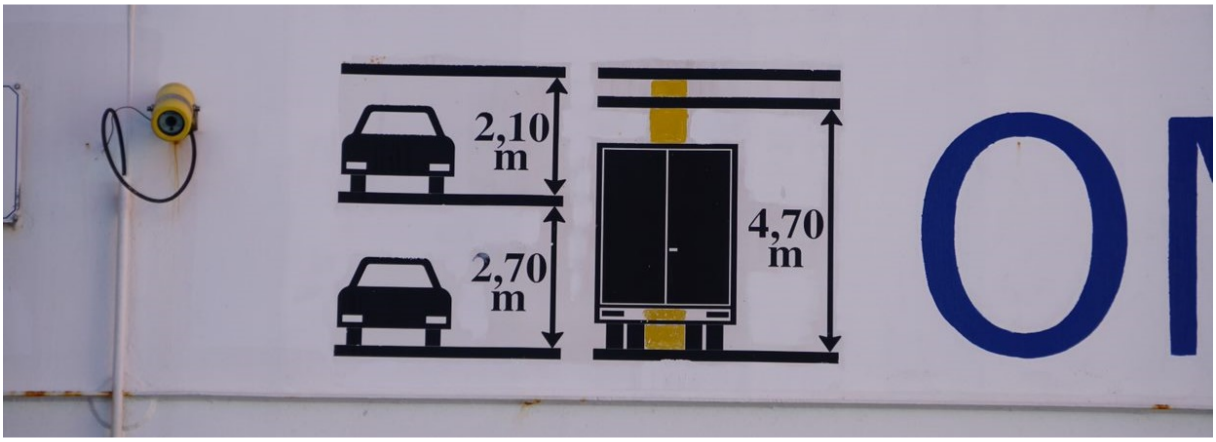


Figure 51 Flexible configuration using hoistable deck on Stena Danica (Photo Martin Carlsson Stena Line)

A system for automatic screening must consider all various scenarios of possible deck arrangements. It will also create constraints on the size of the solution as the space between the cargo and the ceiling can become very small, e.g. less than 10 cm.

8.3.2.16 Design of internal ramps

There are many different types of ramps, static and movable. They differ in shape and size between the ships. Some are part of the water and fire integrity, as water and gas tight barriers between decks, both horizontal as illustrated below or vertical as ports/doors.

Figure 52 Internal ramps of ro-ro cargo ship (Photo LASH-FIRE)

This is a challenge for many types of sensors, since it can block line of sight or aid a system since it enables wireless communication between decks when it is open.
The picture below shows static internal ramps of a vehicle carrier. The lane at the right also has an open watertight door up to decks higher than the upper one on the left.

Figure 53 Static internal ramps on vehicle carrier (Photo Robert Rylander RISE)

Also note the lashing points in the ramps allow cargo to be stored on the ramps to maximize the usage of square meters of deck area.

8.3.2.17 Ventilation

Ventilation inside the ship on cargo decks are usually mechanical using fans sucking air from the weather deck above or on the sides of the ship, pushing out exhaust through openings during loading/unloading the ship. During longer sea voyages, decks are ventilated to prevent humidity to build up inside the ship that could harm the cargo. Passive ventilation systems exist but are usually ineffective and therefore rare on modern ships. Most ventilation shafts have some kind of dampers that can be operated locally or remote, allowing air exchange or in case of a fire, shut off the air inlet to the stricken section or prevent inertial gases like CO_2 gas from leaking out.

8.3.2.18 Radio telemetry/GNSS

One common navigation solution for drones is to use GNSS coordinates when operating on open air spaces. The accuracy of such methods is, however, a challenge. More than the imperfect accuracy of the methods itself the coordinates also needs to be in reference to the ship and for some applications measured inside the ship, where the walls decreases accuracy further and, in the end, makes the system unreliable.

8.3.2.19 Explosive area (EX/ATEX)

All electrical equipment onboard merchant e.g. SOLAS ships must be compliant with IACS E10 Req. 1991/Rev.7 2018 (ICAS & ICAS ltd 2021, 2021) some ships have also an explosive atmosphere (EX or ATEX (European Commission DIRECTIVE 2014/34/EU , 2021)) rating on some decks. Zone 0 has the strictest restrictions and Zone 2 the lowest.

Zone 0: An area in which an explosive gas atmosphere is present continuously or for long periods.

Zone 1: An area in which an explosive gas atmosphere is likely to occur in normal operation.

Zone 2: An area in which an explosive gas atmosphere is not likely to occur in normal operation and, if it occurs, will only exist for a short time.

In general, ro-ro -cargo/ro-pax -ships and vehicle carriers, has a hull design that allows for decks and hold be classified as EX-zones. And many are built to have Explosive Zone 1 classification, on their different types of cargo decks. Depending on the classification of the zone, ventilation etc. different types of technical solutions is possible. If there is an EX/ATEX zone, this will affect the design and usage of fixed sensors such as cameras, LiDAR and the design of the drone, it sensors, charging and communication infrastructure. One example is, if a electrical system is installed less than 45cm up from the deck level it will have different safety criteria's to be full filled, compared to electrical equipment installed above 45cm in the same cargo hold. A system on weather deck will have more exposure to rain than a system in a more protected cargo hold and can require a higher Ingress Protection (IP) rating (International Electrotechnical Commission, 2021). Designing a system for operations in an EX zone will be the greatest challenge.

8.4 Concept of scanning cargo and vehicles

Main authors of the chapter: Robert Rylander, Martin Torstensson RISE

The concept of scanning rolling cargo for different types of questions is not new, it is done in an automated fashion in many domains. Given the many application areas, there is a drive for better sensors and the price of systems. Accessibility to such systems and services has become mature and global.

Scanning of rolling vehicles can today be found at road tolls, entering/leaving facilities for payment/tax, control of logistics, but also for safety. Such preventive action is becoming more common, such as scanning the vehicle before it is allowed to enter a tunnel. The information that can be gained varies from system to system covering among others cargo volume, X-ray inspections and heat detections. Even though the focus in this report will be on the heat aspects and potential ignition hazards other similar systems are also to be taken into consideration to grasp the current situation of stationary automatic screening of vehicles.

8.4.1 Volumetric scanning

One example is automatic collection of volumetric data in the forest industries. Where accurate measures traditionally are done manually by a surveyor, but now these tasks can be automated and is safer for the personnel involved.

8.4.2 Hazardous cargo in containers

There are several examples of cases where X-rays have been implemented for the scanning of transport vehicles to detect potential dangerous or illegal goods. There has been a project with this in focus called ACXIS (ACXIS, 2021). In the project analysis tools for the X-ray images were tested to find a method where objects such as cigarettes could be detected inside of a cargo truck. There are also products on the market performing automatic X-ray scanning of vehicles passing through a sensor system, such as gantry inspection system manufactured by Smith Detection (Smiths Detection, 2021). Such methods can be useful to find cargo inside of a container without necessarily opening it. The manufacturers claims to be able to have 23 trucks passing through in an hour. For such a solution to work when loading a ship there would, therefore, probably require several parallel gates for the vehicles to pass though within a reasonable timeframe.

8.4.3 Vehicle undercarriage inspection systems

In an era of increasing need of inspections of the undercarriage of vehicles due to threats such as bombs or smuggling of illegal substances as well as automates inspections in the automotive industry, there a growing market for robust solutions with high resolution of images. One supplier is UVEYE (Uveye, 2021) that uses camera technology to scan the body of a car and algorithms to detect anomalies. As illustrated well in their material, these types of operations benefit from a controlled environment e.g. local light condition. Cameras can be combined with other types of sensors to detect leakage of fuel, magnetic anomalies etc.

8.5 Vehicle Hot Spot Detector (VHD)

In LASH FIRE, a system originally used for increased tunnel safety called Vehicle Hot Spot Detector (VHD) will be the starting point for the field tests.

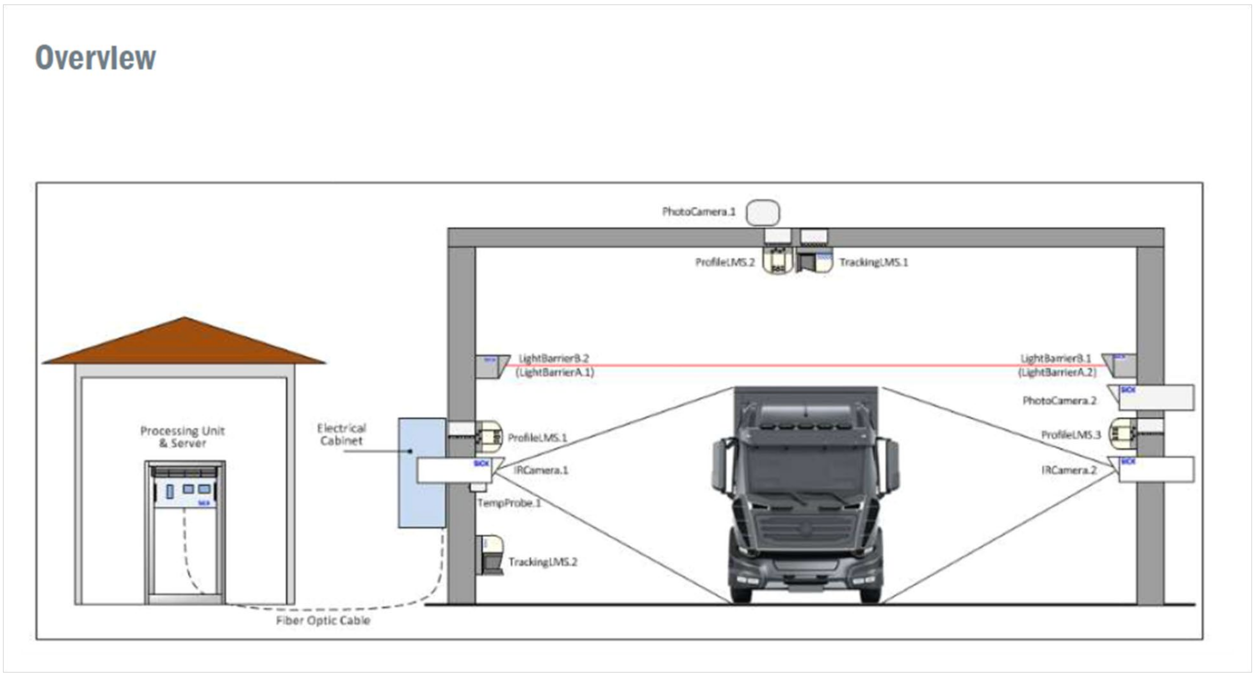


Figure 54 Example of a stationary screening system (SICK AG)

Based on this system LASH FIRE project will explore the possibilities to detect malfunctioning reefer units and other added values regarding the safety of the passengers, crew, other cargo and the ship. This could be the possibility to detect anomalies on the cargo carried on the trailer, detectable by same or complementary sensors on the VHD system. Better volumetric resolution on the cargo but exploratory work will be done to see if the system can be used to categorize APV from ICE vehicles.

8.5.1 Challenges

As mentioned earlier there are many challenges involved, depending on where it is placed illustrated earlier in Figure 3 as well as on a drone system. The available space prior and after the control zone as well as available height is some constrains for the sensors. Also the impact of rain/snow on the object as well as between the object and the sensors if they are placed in the open air, also need to be taken in to account. It can severely block the sensors or degrade the sensors optical capability, also fine particles such as soot/dust degrade performance but are easy to clean. To keep the sensors clean various systems are available, vipers to barriers by air flow.

Some types of sensors might need additional light or specific spectra of light to perform optimally. The following illustration is from a portal for returned rental cars at an airport. The vehicles are filmed/photographed as they roll by. Automatic documentation of the body status of the vehicle. The documentation is used if any damage is detected, to support any claims.

Note the amount of extra lights to set the light to optimal conditions for cameras as well as the number of cameras needed to cover all angles of half of the object.

Figure 55 One half of a portal for scanning returned rental cars (Photo Robert Rylander, RISE)

Today's solutions from other domains as well as systems installed at terminals today, have a high level of maturity and sensors are exposed to severe weather and can still operate at high service level. Many terminals/ports have designated gates and yards for ro-ro cargo that is suitable for high level of screening of cargo entering/leaving.

8.5.2 Constrains regarding scanning of rolling cargo

There are several aspects of constrains regarding when and where to scan the vehicle/cargo, some have been described earlier in this report (see section 8.3). The following chapter is focusing on the system constraints regarding sensors and the specific use case of scanning cargo/vehicles in a port or on a ship.

8.5.2.1 Hot spots

If the system is designed to look for heat or hot spots with temperature outside the normal heat signature for normal state of the vehicle/cargo or the specific operations, the scanning should be as close as possible to the ship to be able to detect anomalies before loading, or where the parked/stowed cargo possess the highest risk to the ship when stowed/parked onboard.

Scanning for anomalies on cargo/vehicle requires not only knowledge of the actual heat sources, it also requires a good dataset of different types of reefer cooler/heater units, different types of placing on the units/cargo and also what is the normal heat spots and when is it deemed to be unsafe e.g. when should the cargo/truck/vehicle trigger an alarm and when should it be stopped.

The earlier the cargo is stopped the better out of simple handling, the trailer/cargo can easily be turned back to the yard. But on the other hand, for detections of critical hot spots, the scanning procedure should be as close to the doors/ramps of the ship as possible, this is critical for the scanning of reefer units and late arriving rolling cargo that might have clamped brakes that has heated up the tires to such degree that the rubber can start to burn.

Another aspect is if the scanning equipment should be mounted on the ship or if it should be mounted ashore at the terminal. If mounted on the ship, there will probably be physical constrains of possible mounting locations. The sensors should be as flushed as possible with the bulkheads and bars, to protect them from being damaged by cargo loading/unloading. Raiseable/hoistable decks will also set constrains and other ship/deck arrangements such as design of ramps and doors. When mounted ashore, on the other hand, there are other aspects of importance, such as, the weather and availability for the transport to turn around.

Finally, components cannot block equipment used for firefighting such as drenchers etc. It is also a question of who is responsible for making sure that a malfunctioning vehicle or unit with overheated components do not board the ship? If it is the responsibility of the ship's owner, then it can be considered safer to have such equipment onboard to ensure the standard and availability of such systems.

8.5.3 Principle of sensor positioning

In general, there are three ways of positioning the sensors and it is all dependent on the type of sensors and what type of cargo is to be scanned. Placed vertically, placed from the sides or a combination of vertically and sides.

8.5.4 Truck and Semi-Trailer

As illustrates below, the cooling/heating unit (indicated in red colour) is the commonly placed in the front of the trailer.

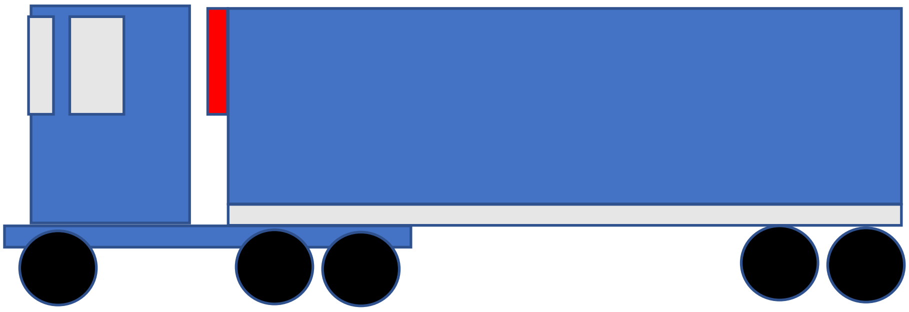


Figure 56 Truck and semi-trailer with highlight red AC-unit (Robert Rylander, RISE)

The small gap between the trucks cabin the AC-unit, highlighted in red, makes scanning of the whole AC unit challenging.

8.5.5 Tractor and Semi-trailer

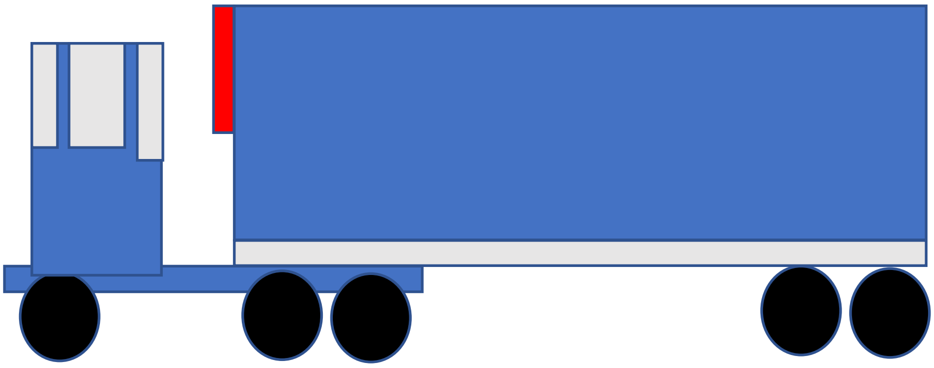


Figure 57 Harbour tractor and reefer unit (red) (Robert Rylander, RISE)

In port, the use of tractors/tugs (illustrated in Figure 42) makes scanning a bit easier since the clearance between the tractor and the trailer is larger. In general, the tractors cabin is also usually smaller than a regular trucks cabin.

8.5.6 Vertical placement of sensors

Below is an example of a vertical solution, with cameras/sensors placed vertically. When the coverage or field of view is horizontal the system can be more compact but at a cost of more sensors needed.

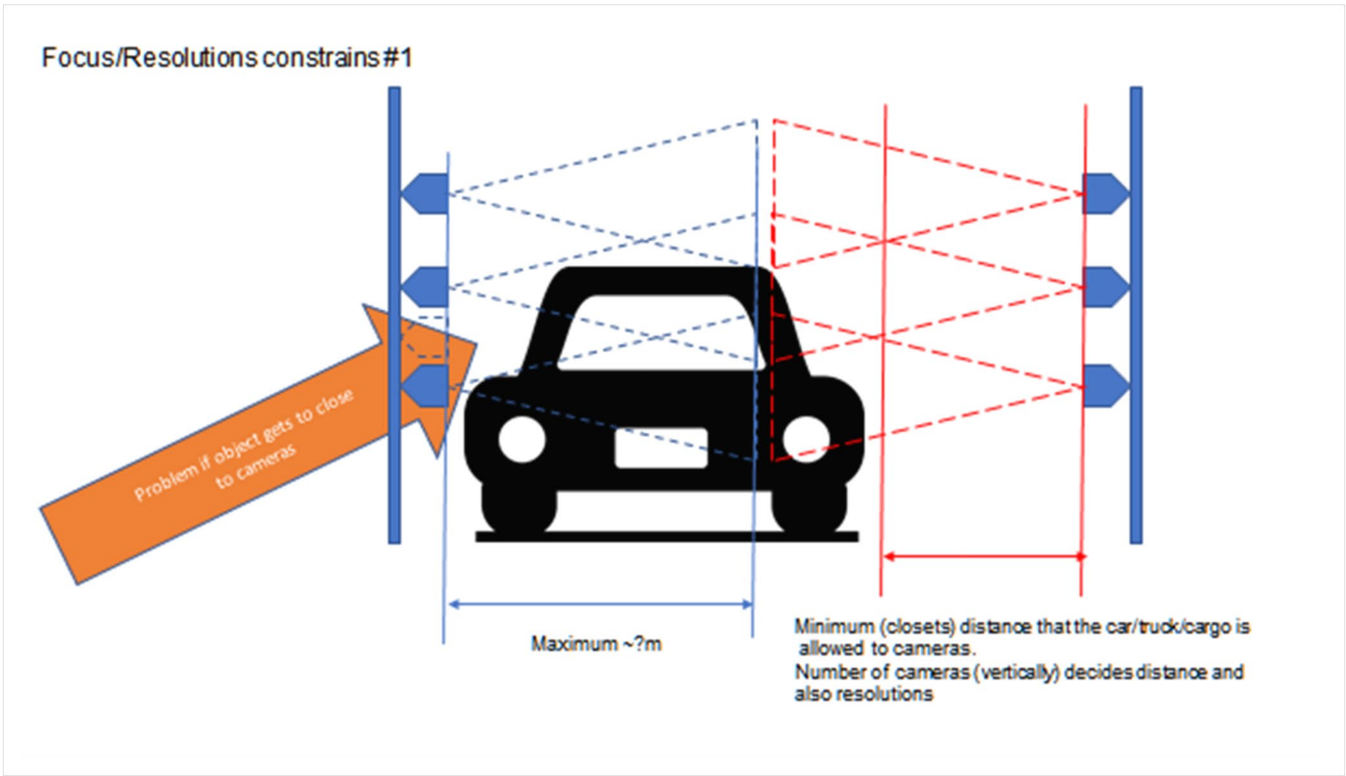


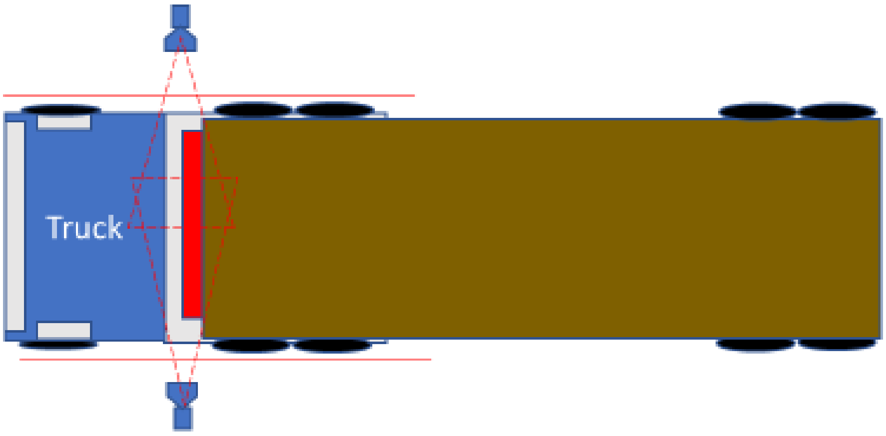
Figure 58 Vertical array of sensors and min/max distance to sensors (Robert Rylander, RISE)

This solution is easy to install and maintain, most sensors would probably be reachable for access by a technician standing on the ground/deck.

Drawbacks are that the object cannot be too close to the cameras or too far away, this is due to the lens openings of the sensors illustrated by dotted lines. This can to some extent be less of a problem using auto zooming lenses, but the costs rise with such solutions.

Truck and trailer

Vertically placed sensor array might have difficulties to capture the reefer motor/compressor unit (in bright red colour) below, due to the narrow gap between the trucks cabin and trailer.



Harbour tractor and trailer

The situation is probably better for unaccompanied trailers that are towed onboard by harbour truck a.k.a. Tugmaster, the gap between the tug and trailer is usually larger.

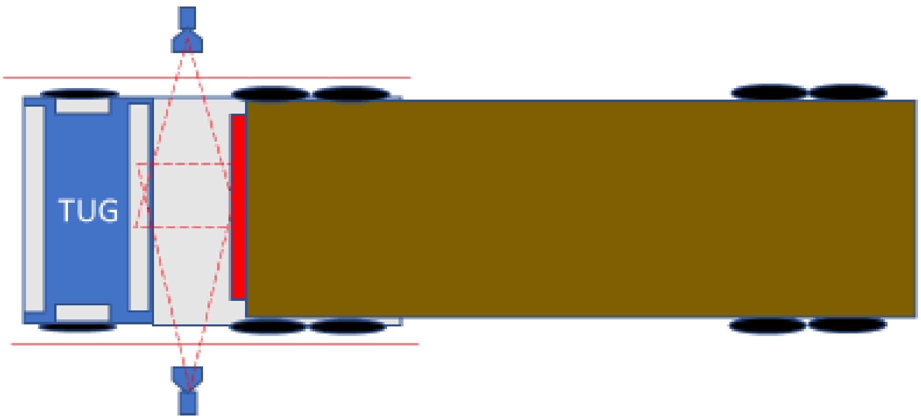


Figure 60 Illustrating tug and trailer and motor/compressor in bright red (Robert Rylander, RISE)

This makes it easier to screen the AC-unit on the trailer.

8.5.6.1 Horizontal placement of sensors

If the sensors are placed above looking downwards, the gap/void between the cabin and the trailer would look something like below. The challenge is to get a free field of view for the sensors/cameras:

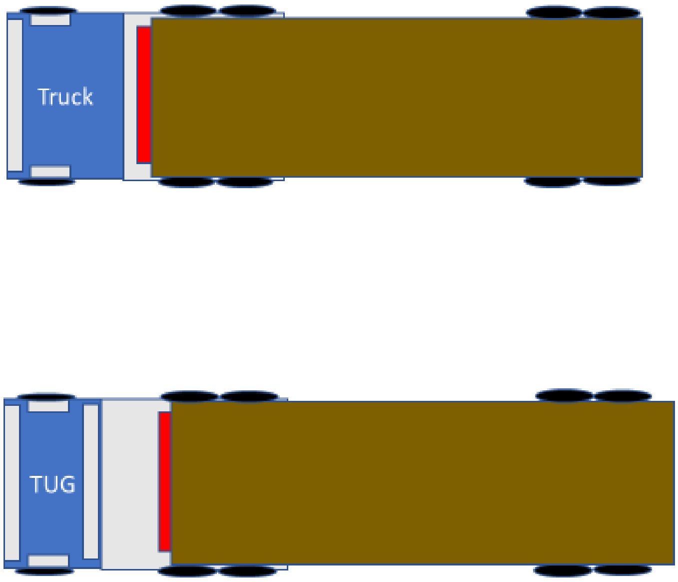


Figure 62 Bird view of Tug and trailer (Robert Rylander, RISE)

Below there is a sketch of an array of sensors looking downwards, it could be placed on shore or onboard the ship. In the figure below some focus aspects are illustrated and some approximate height measurements from some rear doors on ships indicates a maximum air draft of 5-6m.

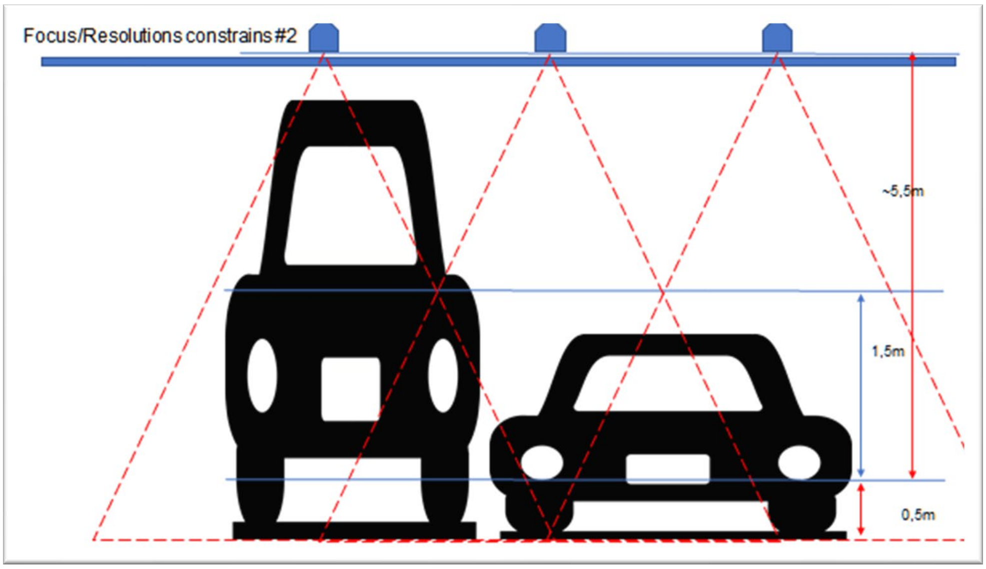
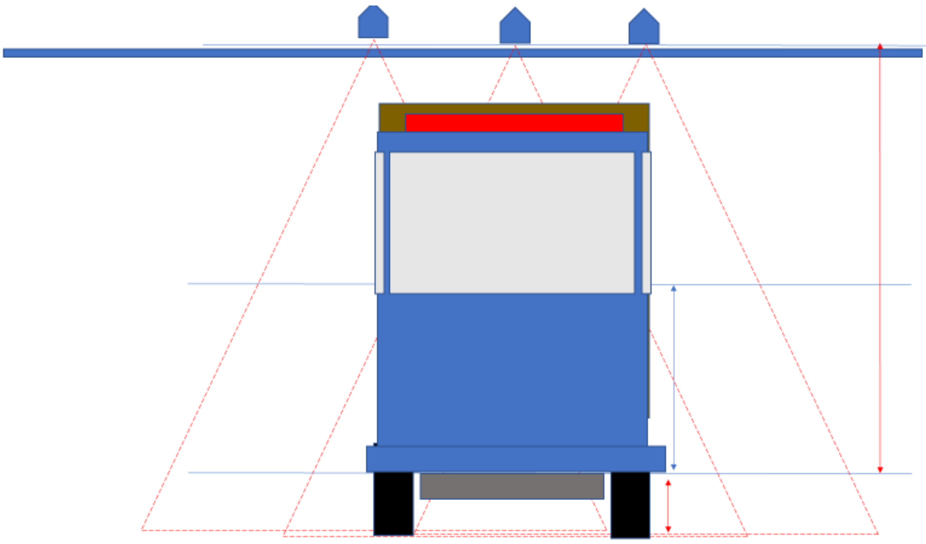


Figure 63 Array of downward looking sensors (Robert Rylander, RISE)

As illustrated, different height of “objects” causes problems for optics focal point, it also creates blind spots between the sensors (upper right corner of the high vehicle).



8.5.6.2 "Slanting" the sensors

As the illustration below exemplifies, a kind of optimisation of the position and number of sensors can be achieved by tilting/slanting the sensors.

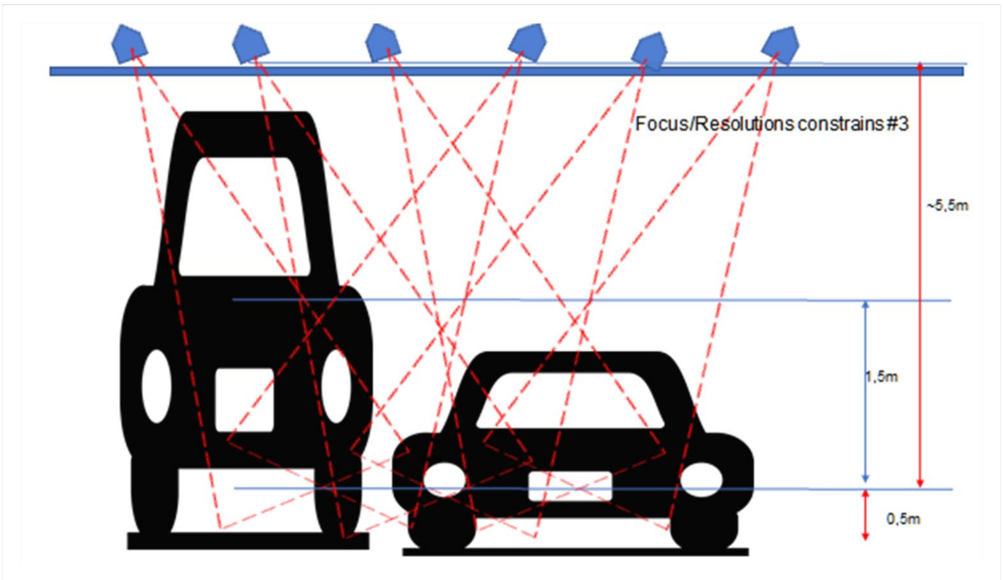


Figure 65 Slanting of sensors (Robert Rylander, RISE)

This technique can also be applied to vertical placements of the sensors. There is, however, a drawback in that the captured image is skewed (closer to sensor in one end and further away in the other). The effect can be corrected by post processing, but it will also lead to higher pixel density in the nearer area than the parts of the object that are further away.

8.5.6.3 Combination of vertical and horizontal

A combination of vertical and horizontal looking sensors is probably the way forward.

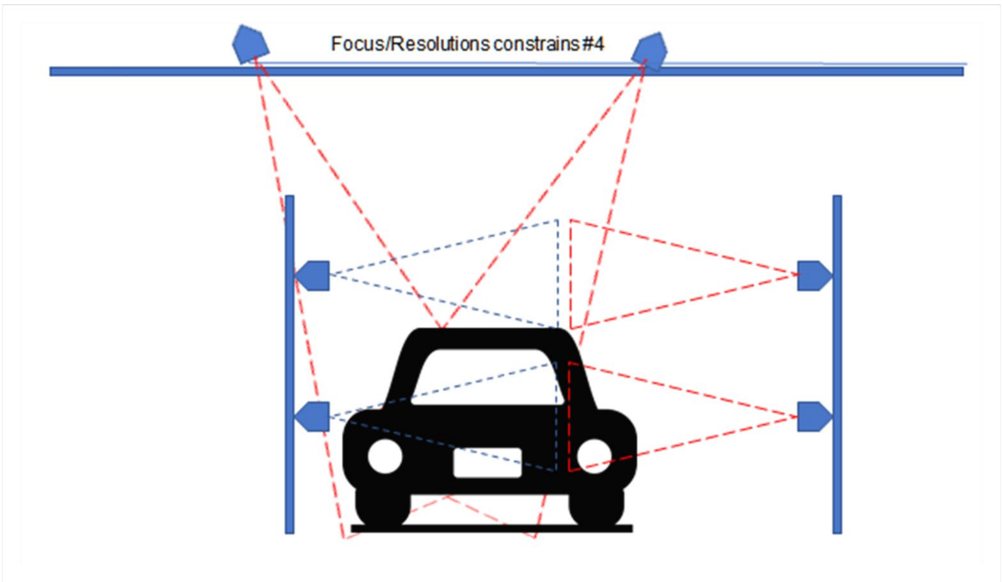


Figure 66 Combination of sensors (Robert Rylander, RISE)

It makes the system more forgiving but will require a more sophisticated implementation and, therefore, more costly.

8.5.6.4 Parallel cargo operations

In many ports/terminal parallel cargo operations is the standard, it could be loading on one deck and unloading at another. It can also be several lines of cargo that rolls onboard in parallel lanes.

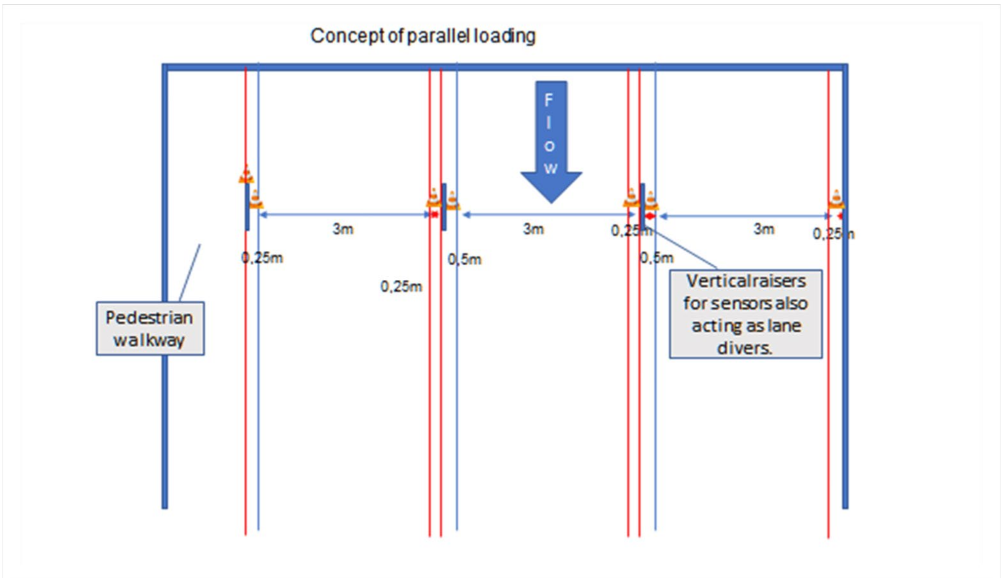


Figure 67 Multiple lanes for parallel cargo operations (Robert Rylander, RISE)

The vertical risers for sensors will have sensors looking both ways as illustrated below.

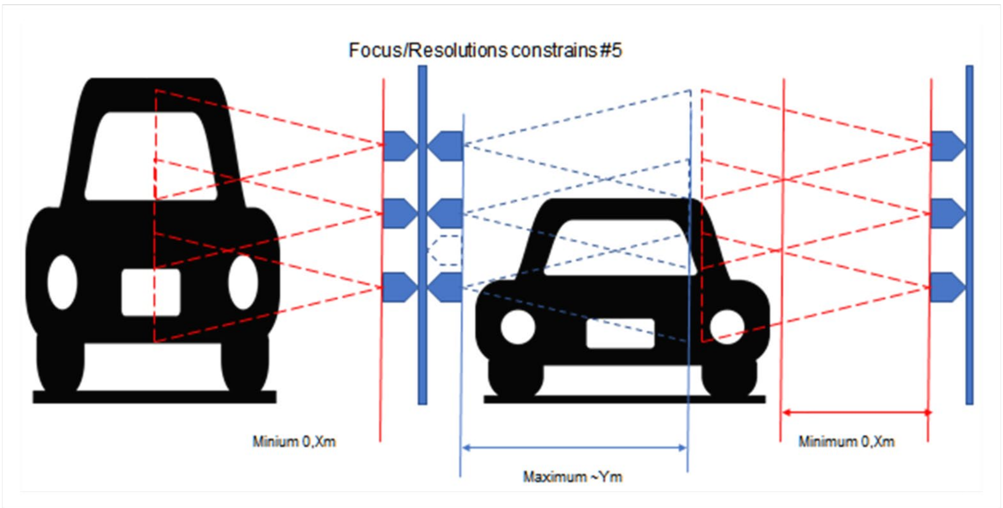


Figure 68 Alignment of cargo/vehicles to get correct focus for cameras (Robert Rylander, RISE)

8.5.7 VHD system implementation

The VHD system (SICK AG, 2021) is a combination of different sensors, a software that can segment out different types of vehicles and section/zones of the vehicle that are of interest and an infrastructure for safe storage and communication of data. The following sections describe the combination of hardware and software used, modified and tested in a new context in the coming demonstration in this project at Stena Line Majnabbe terminal in Gothenburg. The goal with the tests is to be able to scan the trailers and cargo and especially focus is the reefer units. A future VHD system can then be used to survey incoming goods and vehicles , detect temperature anomalies and raise an alarm to the staff at the terminal.

8.5.7.1 VHD Sensors

In Figure 69 below, the portal and arrangement of sensors is illustrated.

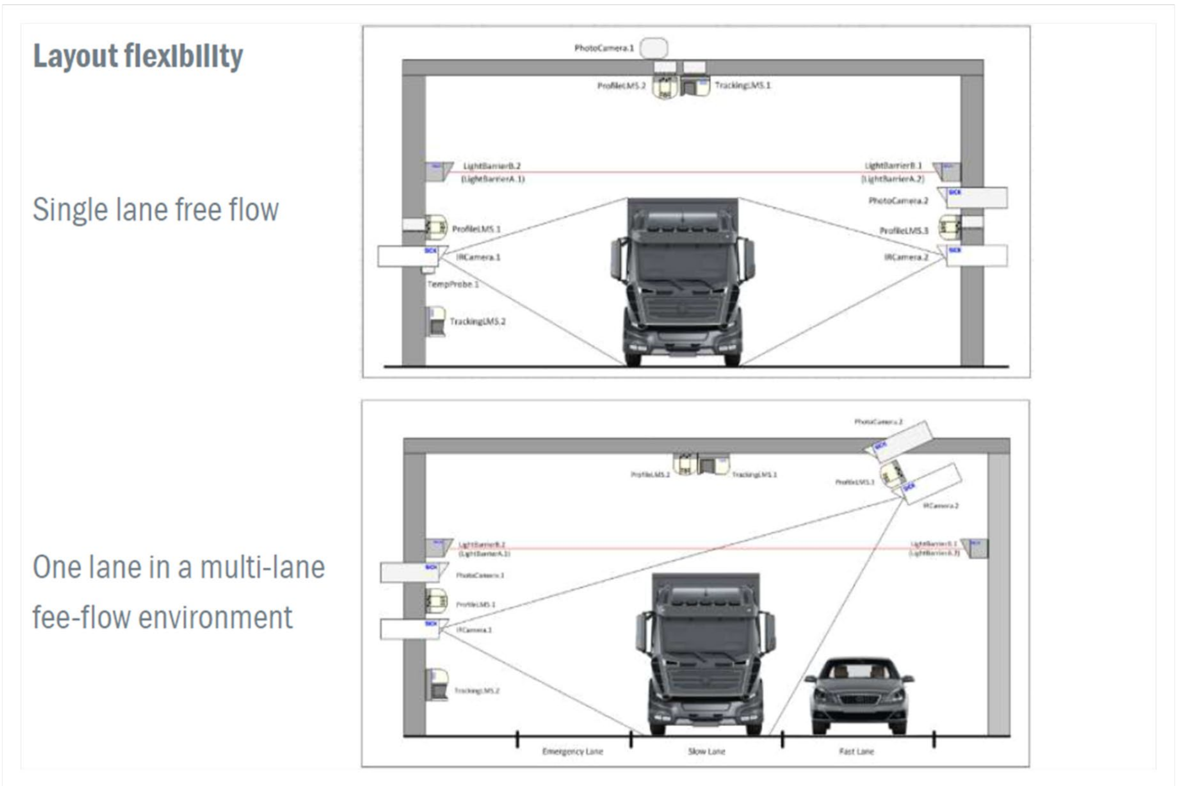
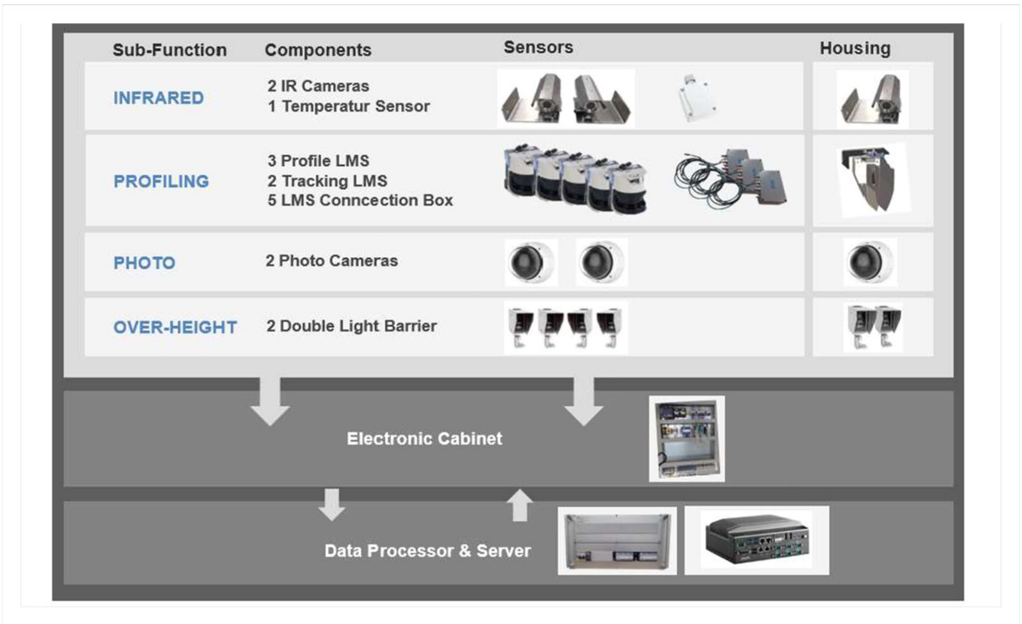


Figure 69 Example of sensor placement single and multi-lane constellation (SICK AG)

The system combines different sensors, and they are all the type that do not need a physical access to the vehicle/cargo that passes by. Depending on the physical space and the possibility of obstructed visual line of sight make every installation unique. This arrangement works for high-speed passage of vehicles on roads and is expected to work well in this type of application since maximum speed for cargo handling and vehicles should be below 30km/h in ports and terminals.

In LASH FIRE a single lane approach will be tested, the challenge is the physical space available for placing the sensors for maximum coverage.

The VHD system uses multiple sensors, Infrared (IR) cameras, Light Detection and Ranging (LiDAR) for profiling length, width, depth and volumetric measurements. It also uses cameras for registration plate recognition as well as capture “as is” photos and video of the object. The VHD system also has Light barriers, for indication if the object is too high (air draft) and possess a danger to infrastructure.



On the data processor unit, different software applications are running. Depending on the use case, computing of data can occur here, on the edge or more centralised using safe communication links.

8.5.7.2 Profiling of object

The profiling or outline of the object is done by an array of LIDARs, the 2D images are then stitched together using software to a 3D representation of the object.

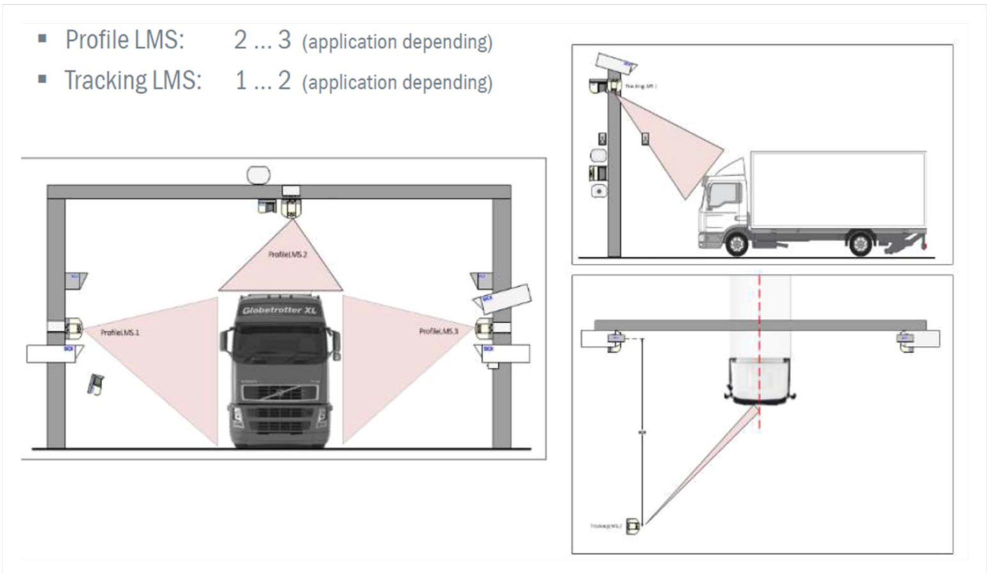


Figure 71 Example of vehicle detection and measurement (SICK AG)

The motion of the object is tracked by a LiDAR placed in line, prior or after the portal, with the flow of objects as illustrated in the low right corner in Figure 71 above.

A 3D presentation also referred to as point cloud, will look like the bottom section of the next Figure 72 below.

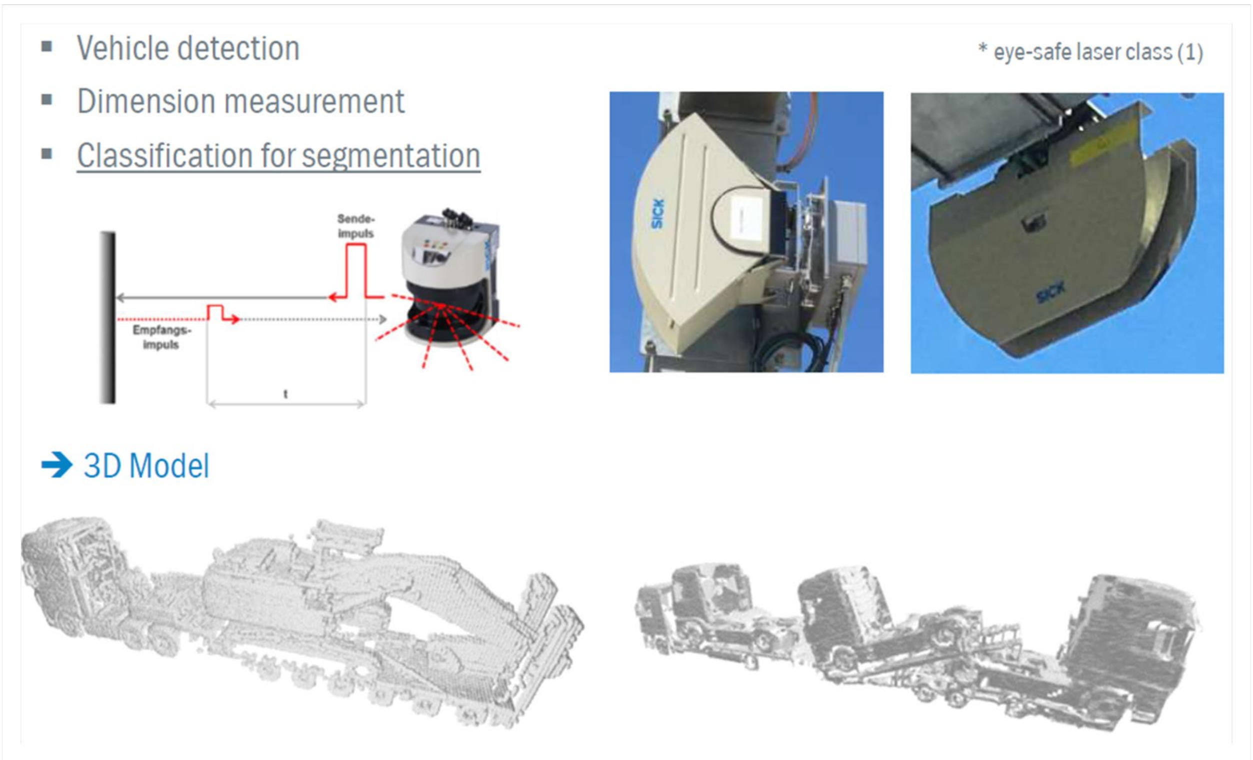


Figure 72 Example of 2D LiDAR data converted to 3D representation (SICK AG)

The richness of the 3D depends on how many beams that is sent and reflected back, at higher speed a sparser model can be built, at lower speeds a much denser point cloud is collected, and it gives a more detailed 3D model.

8.5.7.3 Segmentation and use

A combination of the 3D model and the data collected with the IR camera can be used to create a representation of the object and segment out the areas of interest or specific components. In VHD system vehicle specific segments, or objects like wheels, parts of the drive train such as turbo and exhausts, can be subject to other software algorithms that can use pre-defined values or historical data to determine anomalies such as overheated breaks on a set of wheels, as illustrated in Figure 73.

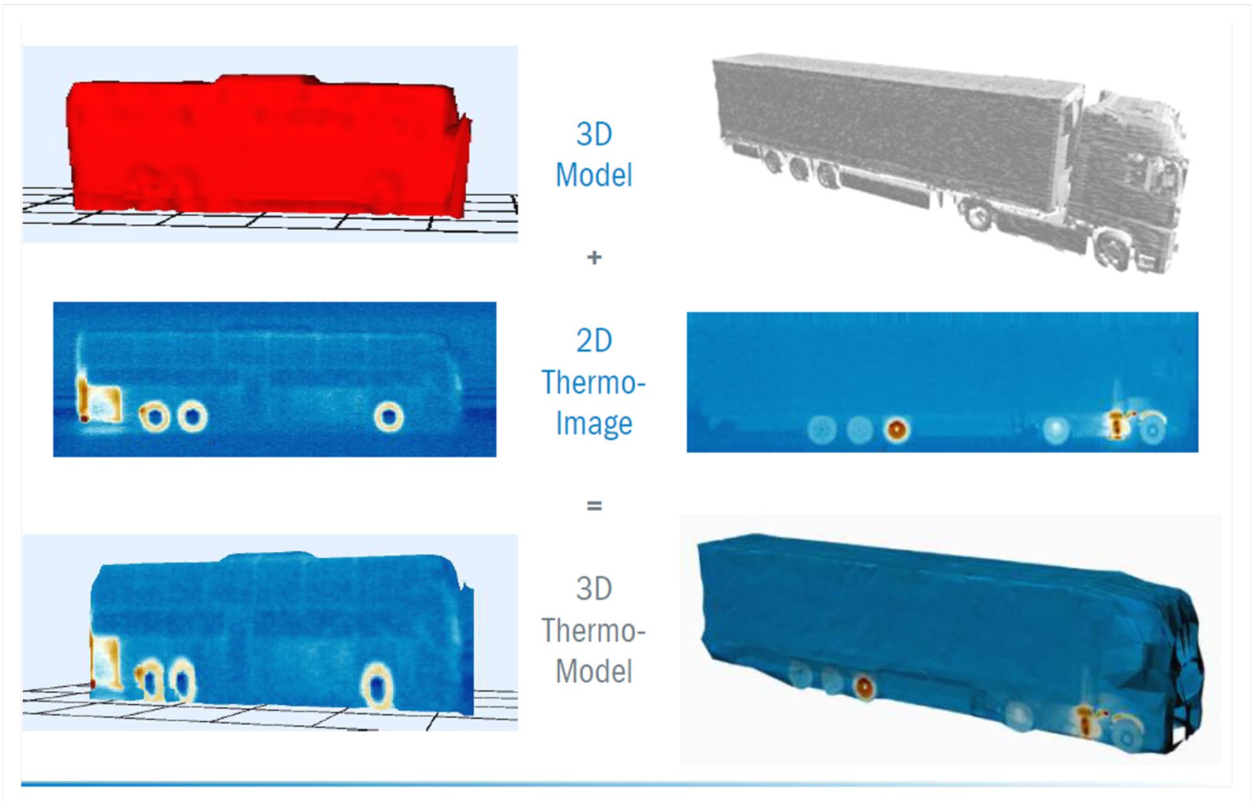


Figure 73 Example of 2D to 3D conversion and IR sensor fusion of sensor data (SICK AG)

The visualization in Figure 74 creates a good representation of the thermal image in combination with the 3D model that is easily understood by the viewer. The VHD also uses software to create segmentations of 28 different vehicle types, thermo image classes such as truck, bus, van, car and bike. Depending on the use case these classes and categories can also be extended.

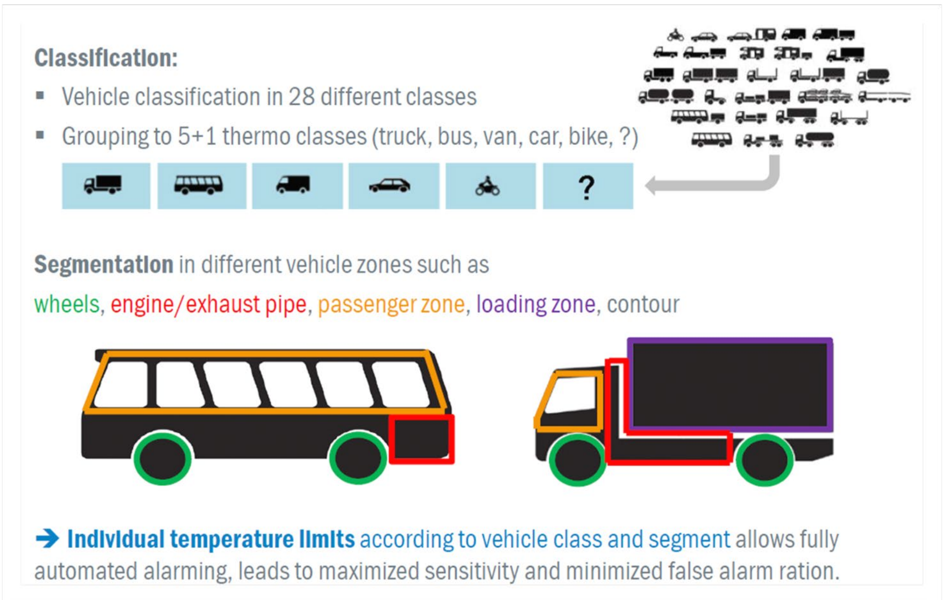


Figure 74 Example of segmentation of objects into specific areas of interest (SICK AG)

In the illustration in Figure 75 below the software can also be used to segment out the different compartments of the vehicle such as engine, passenger compartment, cargo hold and areas. Below is an illustration of how the sensors data and how algorithms maps (dotted) different sections of the object and presented in a user-friendly HMI.

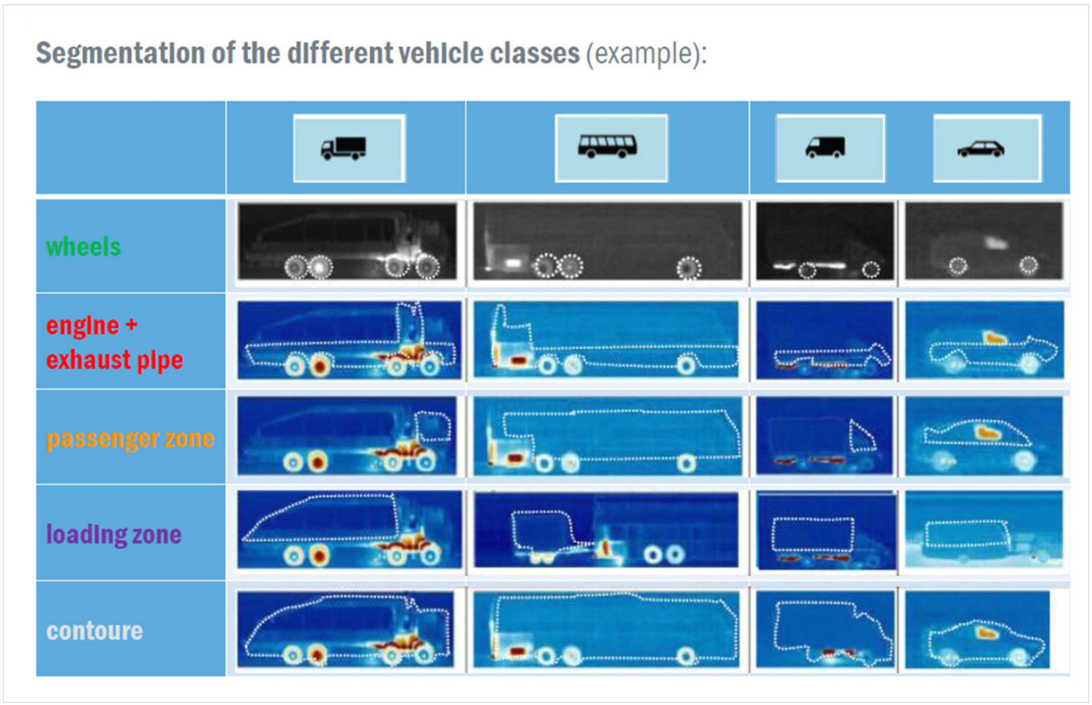


Figure 75 Example of sensors and software in a user-friendly HMI (SICK AG)

Building on all this, WP08 investigates how much can be understood about the status of the AC-unit on the reefer trailer and if it is within the operational limits regarding to its heat-signature. Preferred, this should be conducted as close to the ship to be able to detect anomalies just prior to loading. But for a test and demonstration, this system will be installed at the entrance to the terminal.

8.6 Reefer hot spot detection with the VHD system

With the VHD system and its project modifications there are several steps that will be taken to set up the system, collect data and configure the system for the new task, to segment out areas where reefers are located and also collect what is to be considered normal and what could be an alarming temperature deviation.

Figure 76 Description of procedure from collection of data to validation. (Robert Rylander, RISE)

8.6.1 Test site

The goal in WP08 is to build on the VHD system described above, place it at the terminal at Majnabbe. The route Gothenburg – Kiel has about 40 000 units, accompanied and unaccompanied trailers each year. Collection of data is done after the vehicle has passed the security check-in and is inside terminal premises. As unit moves through an already existing infrastructure for capturing the external status of the unit, the VHD system is mounted in parallel and there by the sensors are limited to the confined areas inside the structure and Majnabbe facilities.

8.6.1.1 Cargo profiling and hazard detection

The VHD system will also be used for screening the cargo area as described above. There are several incidents where something is activated in/on the cargo, it can be a chemical reaction such as oxidation, it could be due to the vibrations from the road trip or from the ships that causes a loose electrical wire etc.

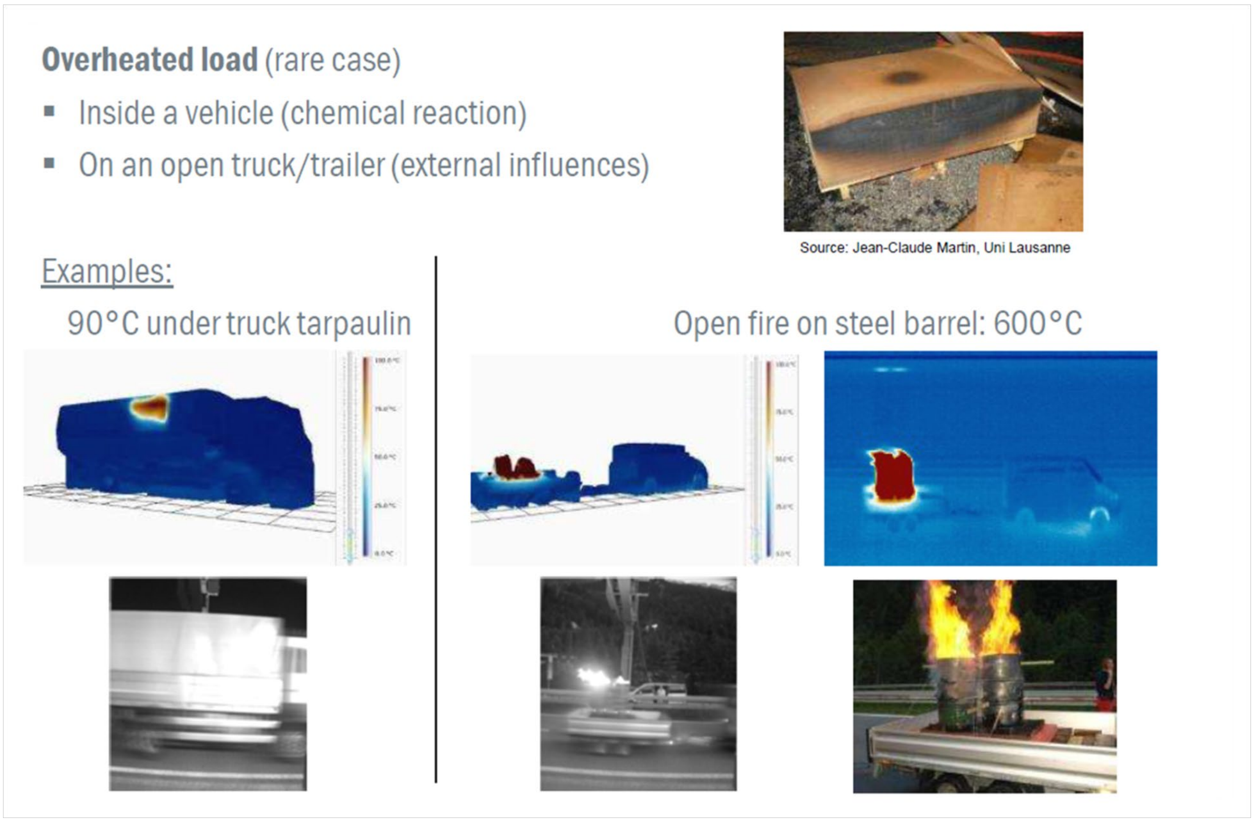


Figure 77 Example of system that can detect hotspots and anomalies on the cargo (SICK AG)

As illustrated above, the VHD system is capable of detecting not just open fires, as with the barrels, but also heat that spreads to the canopy of the trailer. This will be very useful to assist the crew onboard the ships and/or stevedores in the terminal, to get a clear picture of the status of cargo/compartments/area, that they are about to load or have onboard. If the same type of sensors are placed onboard the ship this will add an extra layer of safety since machine parts that has lost the cooling form the movement could have a raising temperature even if the unit has been standing still for a short while at the terminal or chemical reactions such as oxidation could benefit from more humid air that the proximity to water brings to the air, can accelerate the process.

Figure 78 Ship side installation of a VHD system (Source SICK AG)

8.6.2 Vehicle dangerous Goods Detection

During the project reading of different placards such as IMDG/ADR will be conducted using SICK Vehicle dangerous Goods Detection (VDG). The information can be used to verify the visual markings of the cargo compared to a what a normal heat signature should be for that type of cargo. At the same time a look-up service could enrich the signs used with more relevant data on the cargo as illustrated below in Figure 81. In the future it could be verified against what type of cargo/vehicle is booked and, all available data and supplemental data will be available directly to the user.

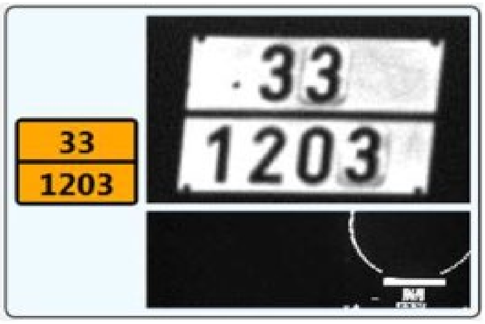


Figure 79 Hazard placard recognition (source SICK AG)

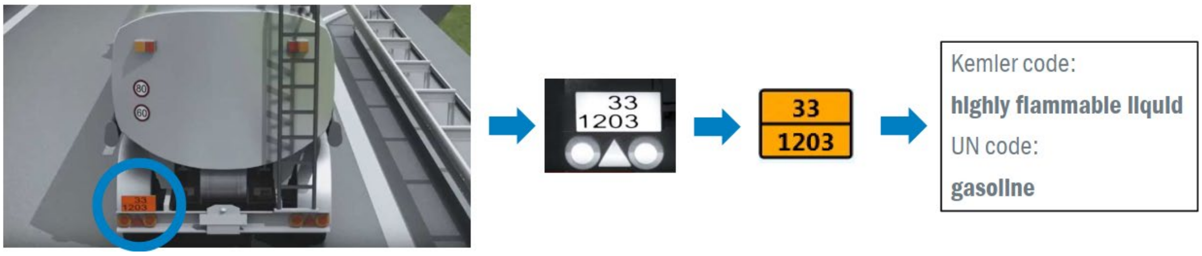


Figure 80 Look up service based on identified placard (source SICK AG)

At the moment this is considered a LASH FIRE standalone feature of the project, since the project system might not be available at all times during test periods. Also a reverse feature could be a service that checks the cargo that the stipulated placards are visible, and that the unit has the correct placards and thereby adds extra safety, but the fact that vehicles and trailers are exposed to dirt from the road trip as mentioned earlier, make these types of solutions a challenge to solve.

8.6.3 Vehicle and trailer registration plate reading

LASH FIRE VHD/VDG system is not equipped with license plate reader. Tracking and positioning of cargo/vehicles onboard ship

8.7 Identification

Identification of the object is a complex task since there is no standard in place. A mixture of techniques is one potential way forward to tackle the challenges describe below. Some of which are; that all vehicles do not have a license plate, neither does all cargo have clear markings, furthermore, there are problems with dirt, snow, rain, etc. With these aspects in mind the system still needs to allow for fast cargo/loading/unloading operations without having crew or stevedores physically interact with the cargo/vehicles.

Possible solutions could be:

- License plate reading technology for truck and trailer
- Barcodes or QR marking
- RFID tags or similar transponder technology
- Ultra Wide Band (UWB) solutions are coming to the market and are already used in the logistic supply chains around the world. It is also a transponder and base station technology. It is more costly than RFID but has more capabilities for data exchange and positioning. It

also has the same challenges as RFID when it comes to reusability and recycling of transponders.

- The combination of portals of sensors and smart algorithms using machine learning to segment out the uniqueness of each cargo/vehicle.
- Signals of opportunities, a lot of vehicles nowadays have RFID tags from the production line of the car, the combination of these might make them unique.
- A smart solution for the stevedores or crew to use smart tools as handheld devices and to fill in the blanks where the fixed system fails. The handheld device could use sensors such as barcode, sign, RFID reader to help the stevedore or crewman capture and identify the object.
- Drones, airborne or deck (floor) based could actively patrol the decks as the cargo/vehicle is filling up the deck using the same sensor technology as the crew/stevedores have in the handheld devices.

As mentioned earlier, there is today none identified solutions at the moment, for identification of all types of cargo/vehicles. In LASHFIRE an attempt scan all truck and trailers arriving at the road side to a terminal to segment out the reefer unit and analyse it for heat anomalies. The system will also search for other data such as dangerous good placards as well as trailer and vehicle heat signature anomalies.
A future system will be a combination of techniques and there will always be a need for smart manual updates to the system to fill the blanks for an automated system.

8.7.1 Tracking

Tracking of objects can provide the ability to know where different cargo and vehicles end up in the ship. This information could be combined with the ship stowage planning system to see whether it has been correctly followed and if there are specific areas containing cargo or vehicles requiring specific attention. For the tracking to work some fundamental components are needed, they differ depending on choice of techniques and goal with the tracking. Many new vehicles are connected vehicles, but there is still a gap between what the vehicle can and will communicate. In the future where the technology called Collaborative Intelligent Transportation System (European Comssion, 2021) C-ITS, a collaboration between the vehicle and a logistic supplier like a ferry operator could be established. But for now, it is impossible to build a system based on data shared from the vehicle since all suppliers/manufacturers are using proprietary solutions.

8.7.2 Cameras

Using cameras to track objects as they pass the cameras field of view, requires good light conditions. And by good light condition normal ambient light usually enough but it can be hard to maintain at all times onboard a ship. As illustrated below on a normal day for loading with good natural light visible in frame A on main deck, quickly changes on sections of the path the object moves on internal ramps up inside the ship. These variations can be rectified with installation of sources of light. Another problem was head light from the cars and glare from other light sources. Early findings in the project proved that it was relatively easy to set up a chain of cameras and follow an object all the way from A to E, in this case from main deck up four decks.

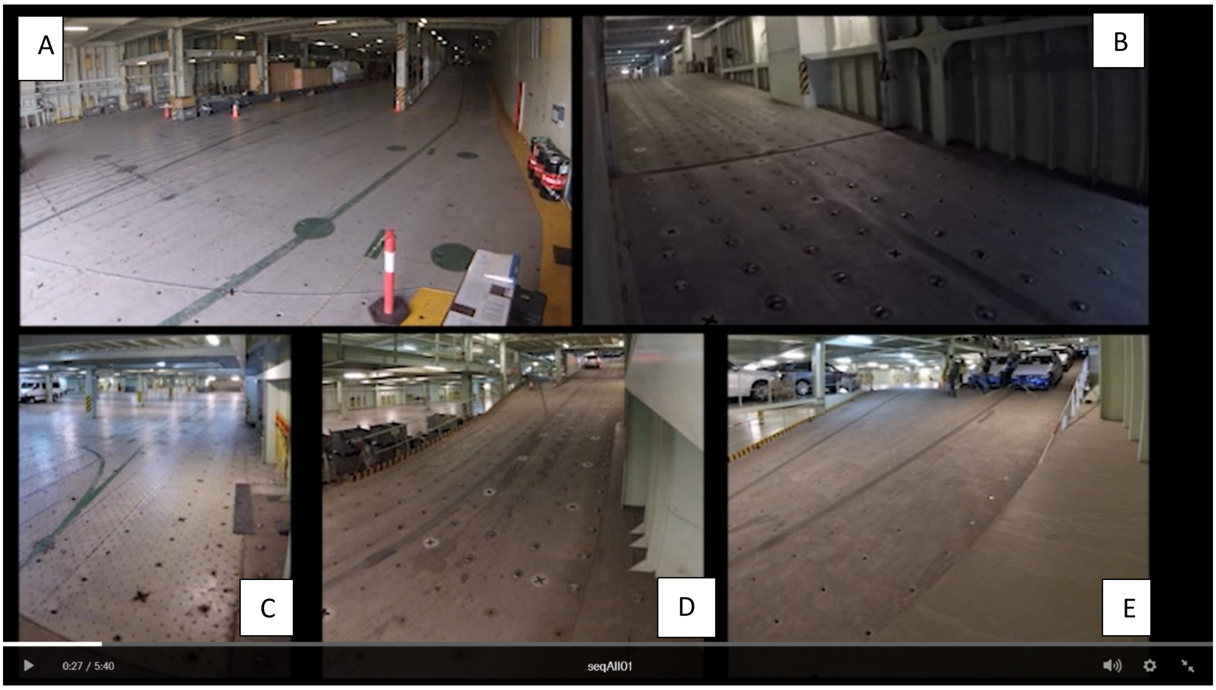


Figure 81 From Lighthouse project showing a chain of cameras that allows tracking over several decks up in a vehicle carrier (Boris Durán, Lighthouse/RISE)

As illustrated in Figure 42with vertical pillars and in Figure 52, internal ramps, that block the field of view. Also, as the decks fill up it will be crucial that the placing of cameras is done correct. Some of the issues with blocked field of view, can be compensated by smart algorithms in the tracking software, using the physical outline of the decks and logics such as if object is entering a dead end/blocked area, it is most probably still there even if it is currently out of sight. Modern tracking software can also make good use of overlap between cameras to easily track object as they disappear and comes back in to frame again. One crucial aspect that must be in place is time synchronisation, so a software can compare two images from two (or more cameras) with high precision of time stamping in each frame. The more distributed the system is, the more crucial time stamping, and synchronisation becomes even more critical.

Positive

- Good sensor chips for cameras are now relative cheap
- Costs for optics for cameras has come down
- Worldwide market e.g. spare parts/replacement can be found all around the world
- Easy to combine different camera technologies at the same node
- Minimum or no physical interaction with object
- Multiple benefits of having live camera feeds from all decks, at all times
- Similar output at all times provides benefits when processing data

Challenges

- Light conditions

- Clear field of view
- Head light, glare
- Retrofit of a system-based cameras inside a ship, includes high installation costs for routing cables for signals and power supply.
- Dust, water, condensation on lenses
- Lay out of cargo deck with beams and pillars, but they sometimes also offer excellent fastening positions for cameras.
- The number of cameras that might be needed
- It can be hard to identify individual objects. (Sometimes on a vehicle carrier there several identical objects moving in the same camera frame) additional marking (stickers, barcodes or sophisticated algorithms could probably mitigate some of the challenges).
- Objects that are covered with snow, or that are wet or dirty
- Many blind spots due to stowage density
- Must be designed separately for each ship
- High maintenance cost with many spread-out cameras

Added values

- Continuous live feed of the ongoing operation
- Live coverage in case of any incidents
- Documentation as statement of facts
- Possibility to track unwanted persons, stowaways or other intruders
- Combination of camera techniques for example IR would give a highly favourable feature for early detection of heat changes/hot spots and coverage in case of smoke filling up the cargo hold.

There are possibly more challenges and added values, but these are some of the most challenging/awarding ones.

8.7.3 Radio-frequency identification

Radio-frequency identification (RFID) uses small tags with a passive transponder, that as they pass RFID transmitter(s), the tag gets activated and sends out its pre-programmed ID and optionally other data. It is a promising technique and can probably be very useful in many applications. The RFID transmitters, if they are fitted with multiple antennas, can also tell what direction the tag passed the station e.g. in a cargo opening it can say if the object was going in or out of the cargo hold.

Positive

- RFID tags can easily be deployed
- Costs for tags has dropped
- Simple solution to implement

Challenges

- All tags must be presented, placed or handed out to the object.
- Tags must be placed outside of the vehicle; many new vehicles have heated windows and that wire mesh effectively blocks radio waves.
- RFID tags can be re-programmed remotely by anyone with off the shelf equipment (
- How well such system performs in parallel operations and over large openings such a rear ramp of a vehicle carrier must be further investigated
- Different nations use different radio frequencies for the RFID base stations e.g. the tag and base station must support all, if the ship roams the globe.
- In the production of new vehicles today, RFID is widely used to track the vehicle and components in the production. That means there will be a lot of RFID tags that needs to be filtered out. A sophisticated system could also use this as signal or opportunity, to distinguish individual vehicles.
- Low precision other than direction
- Radio waves inside a steel hull is still a challenge
- Reuse of tags, how to collect them or use them in a life cycle analysis perspective. The object and tag might never come back into the system.

8.8 Positioning

To obtain a relevant precision in the positioning, the physical layout of the cargo hold must be known to less than five centimetres accuracy, this is important if a positioning system will use smart software to fill in the blank/obscured spots or interpolate/extrapolate a position on insufficient data.

8.8.1 LASH FIRE system for positioning

A system for a grid or dimensions in all three, X Y Z -axels must be defined, so sensor data that is captured can be transferred to the ships 3D grid, and since cargo/vehicles can and will be parked/stowed in ramps, the system must handle all dimensions.

8.8.1.1 LASH FIRE reference for positioning

Illustrated below is a proposed standardisation for exchange of positioning data. All systems of LASH FIRE should follow a reference standard, this will enable simple data exchange between all work packages as well as systems created during LASH FIRE project.

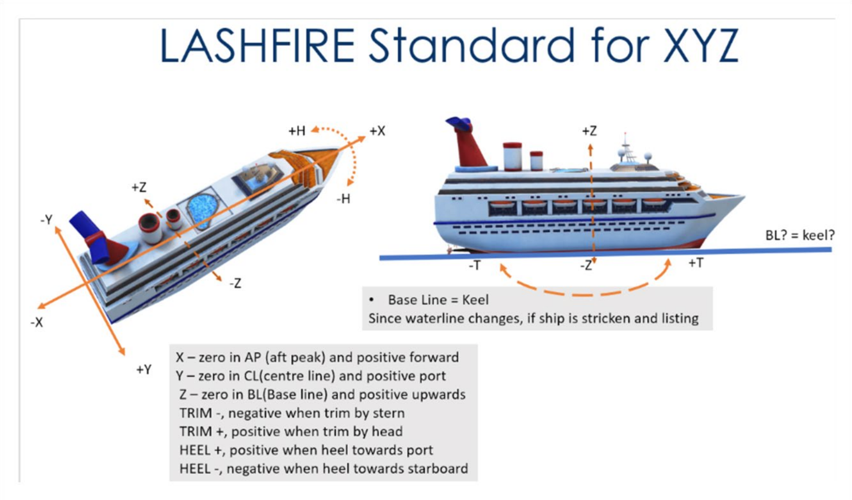


Figure 82 From WP08 proposed LASH FIRE reference for exchange of positioning data

This enable interoperability with other reference systems if it should be necessary via conversion of data/grids, and a tool would only have to be developed once for all WPs in LASH FIRE.

8.8.2 Time synchronisation

If the system will use fusion of sensor data, the timestamping of data is also relevant, one can say that an automated screening system is a 4-dimensional system (4D) using the time domain to enhance data or eliminate missing data. A system could use well established protocols such as Network Time Protocol NTP or Precision Time Protocol PTP, if time stamping can be done at the sensor it is preferable for use in application based on machine learning and future AI.

8.8.3 Fixed and mobile systems

There will probably be two types of sensor installations/usage, static ones fixed to the ship's hull or mobile such as handheld, mounted on movable parts or free flying/driving on the deck.

8.8.3.1 Fixed system

Using the hull/cargo hold structures a structure of sensors can be fitted to cover most of the deck areas. Depending on the resolution of the positioning of the object, it will set the number of sensors needed. This type of system is relatively easy to map up and get good precision in the position of the sensors in XYZ and the sensors direction.

8.8.3.2 Mobile system

This group can be divided in to two, guided or free moving. Guided is the one that travel in a fixed path, going up/down with a hoistable deck, ramp, doors etc or they could be mounted on rails/wires (similar to systems that are used at sport and large arena events) that allow the sensor to traverse a larger area in a fixed or controlled path. With a guided system, it is fairly easy to get high accuracy and direction of the sensor at all times. Free moving e.g. handheld or placed on some type of drone, requires good understanding of the sensors current position and direction at all times, otherwise the collected data needs to be rectified by post processing or it might have to be discarded in the automatic system. Even though an automated system might not be able to use the unstructured/scrambled data as human operator, that is able to apply a context based experience on the data. This is a domain where, in the future techniques like machine learning and future AI, might be able to fill the gap between traditional automation and "smarter" systems.

8.9 Technologies for indoor positioning

The inside of a steel hull is a challenging environment for radio wave-based systems, therefor a combination of different technologies will probably be needed.

8.9.1 Cameras

Fixed systems are relatively easy to set up, the cameras sensors, as mentioned earlier, must be positioned itself, then the cameras need initial calibration and re-calibration if moved or replaced. The type of calibration depends on the type of camera. Calibration has been a tedious work, but today may different automated techniques have been developed. Usually, the first calibration will have to be with high precision, then if the sensor is misaligned or replaced, todays software can use different techniques to self-calibrate the system, it could use known shapes in the hull like contours of steel beams or aided with a special sticker or markings, that is placed on a strategic spot in the view of the camera.

Mobile systems use the same techniques as the fixed system but require more sophisticated fusion of sensor data to be self-calibrating, e.g. a partly spin around its own axle to find know structures/stickers/markings, reference data from an onboard or Microelectromechanical systems (MEMS), the rotation on the wheels etc. Another solution could be a fixture that device/drone is positioned in and facing a known structure/shape for calibration.

SICK has sophisticated sensors, some of which will be used for the fixed test installation and at time of writing this report, it is being investigated if they can be small/light enough for mobile applications onboard a hostile environment such as an exposed ro-ro deck. Another example of an experimental platform is Intel´s different Intel Real Sense (Intel , 2021) platforms that are available on the market, they are not industrial grade but could be a starting point for testing the concept and future development.

8.9.2 Radio Frequency Identification

At the time of writing this report, precise positioning of RFID inside a steel hull appears to be too big of a challenge to get a high-resolution position. This might change in the future.

8.9.3 Ultra Wide Band

The use of techniques for triangulation of UWB transponders are increasing. Still the cost for a UWB transponder is relatively high compared to RFID, UWB techniques will probably work well for mobile devices and drones, how good it will perform inside a steel hull and with a full deck needs further investigation and research. But if it is used at strategic places inside the hull for initializing of mobile system it could probably work well.

8.9.4 LiDAR

Similar to cameras, LiDAR system can be used as fixed system and mobile system. The extreme high resolutions that a LiDAR system can measure distance and bearing, makes it very useful for either positioning of the object or the sensor. Mobile system could have known contours to calibrate on, base for a drone or a fixture for a handheld device pointing the LiDAR on a known object/shape.

8.9.5 Odometer/Tachometer

Knowing the outer diameter of a wheel, distance, speed and the rotation of a body can be measured, if there is no slip. Using odometers/tachometers on rotation of axels/wheels, is a fairly robust and cheap system, and with recalibration errors of dead reckoning navigation can be kept low.

9 Drones techniques for surveying cargo/vehicles

Main author of the chapter: Robert Rylander, RISE

In LASH FIRE WP08, exploring tests and demos will be conducted that can give valuable insights for a future development for use of drones for inspection and survey of cargo and vehicles onboard ships. The scope in WP08 is different compared to the drone activities that will be conducted in WP09 where the aerial drone will operate on the outside of the ships structure, but if information regarding hot spots, cargo/vehicles is detected, their positions in XYZ should correspond with all other activities in LASH FIRE, hence the importance of a common reference system for ship and positioning of cargo/vehicles discussed in chapter 8.8.1.1 a LASH FIRE reference system for positioning.

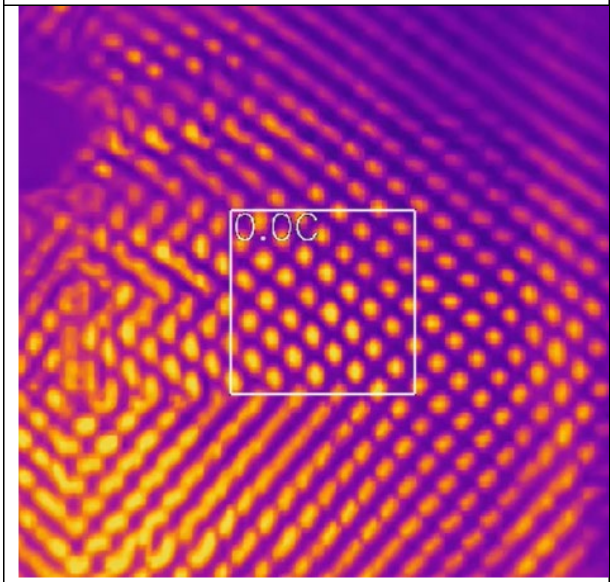
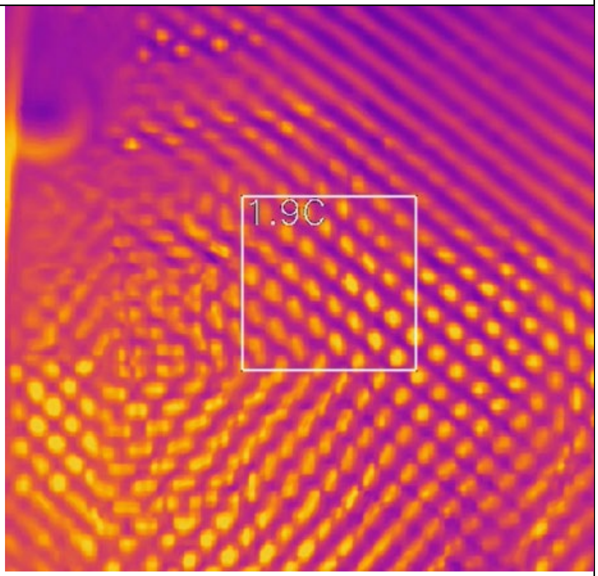
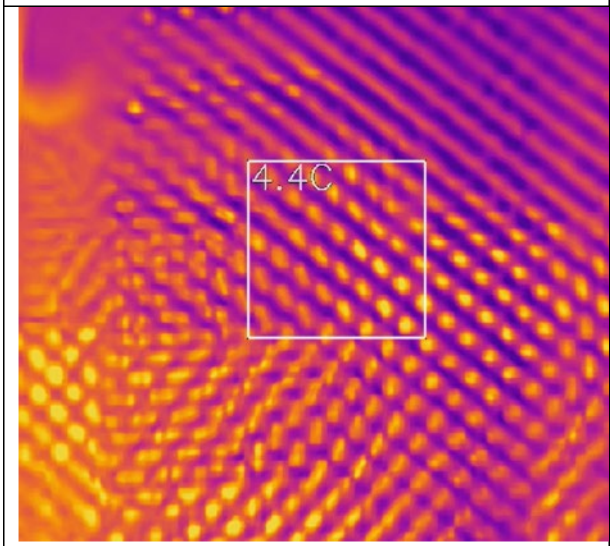
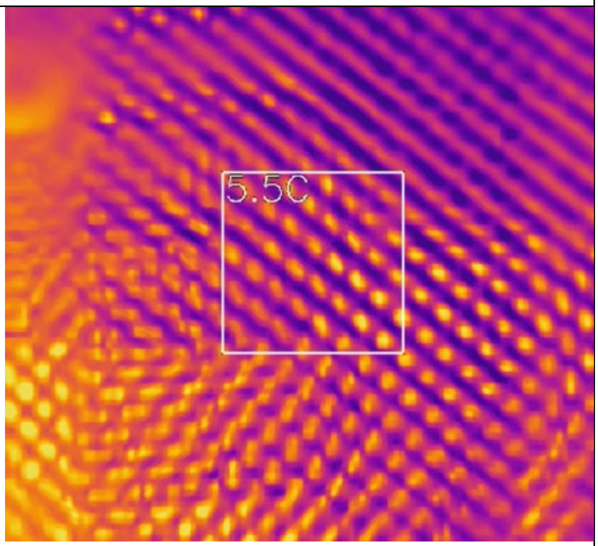
Figure 83 Roaming drone for cargo deck that scans for anomalies on the objects (Boris Duran, RISE)

In WP08 we foresee two types of drones that could be used, aerial or ground (deck) based. Both have challenges that need to be solved, but as technology evolves for example surveyors and classifications societies like Bureau Veritas (Bureau Veritas, 2021) now uses aerial drones to conduct inspections of ships hulls during such certification and classification works that is illustrated below. So far, these types of inspections have been in empty cargo holds and voids, ships at anchor or in dry docks. Flying on a fully loaded cargo deck is more challenging when it comes to automated positioning of the drone. Technology and the use of sensor fusion and computational power on the edge e.g. the drones are increasing every year, so we think that in a near future, a competent system can come to the market capable of handling most of the challenges.

9.1.1 Initial test of IR sensors for undercarriage survey

To verify that usage of IR sensors could detect heat signature from the undercarriage of a vehicle, test where conducted under different types of vehicles.

Illustrated below is a time series of approximately 4 minutes, the undercarriage of the Toyota C-HR Hybrid Electric Vehicle (HEV) and ambient temperature is zero degrees Celsius, the IR sensor is facing upwards directly towards the encapsulated and protected lithium-ion battery pack, approximately situated underneath the seats in the back of the car. The battery bank was stressed to power the car air-conditioning unit when the vehicle was parked and no ICE motor running. A Toyota C-HR has a ground clearance of approximately 140mm unloaded, many electric powered vehicles have low ground clearance.

Start, system temp is zero degrees Celsius	
	
After two minutes +4.4C	After three minutes +5.5C
	
After four minutes +6.1C	

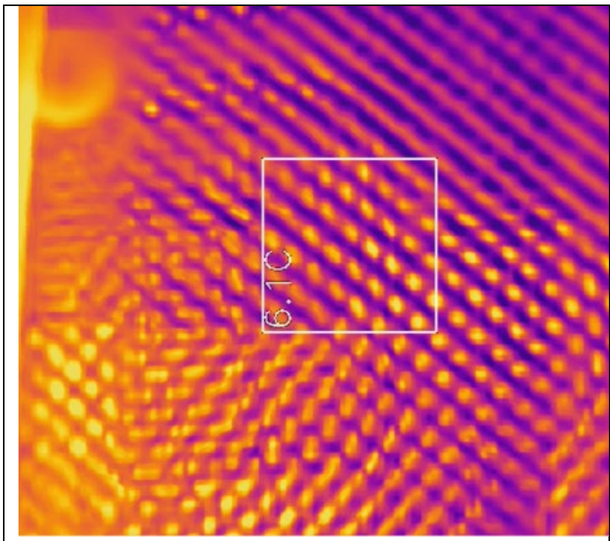
	(Intentionally left blank)

Table 14 Thermal sensor reading from the undercarriage of Toyota C-HR (source Boris Duran, RISE)

The project will use thermal sensors, since it is a proven and reliable technology, but a future solution could make use of several sensor technologies.

9.2 Drones at work

One of the major points with using a drone instead of a fixed or railed camera system is the difference in installation and maintenance. When using free moving drones, it would be possible to have one or a few in each enclosed space, which only requires one area for charging and does not t require installing a large set of cameras.

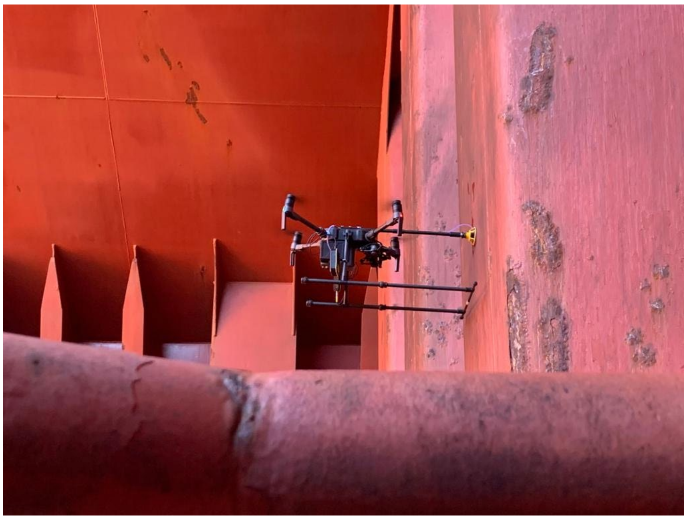


Figure 84 BV using aerial drones for sophisticated inspections of ships (Photo Vincenzo Paolillo)

The installation of the cameras cannot be made in a standard way due to the dissimilarities across ships, while an autonomous drone can be made to handle the differences itself. On the other hand, a mobile system also requires both a way of avoiding objects and a way to navigate in the area. These tasks are not straight forward as it is supposed to work in many different environments with their own challenges, such as small margins in between cargo and the ceiling or straps on the ground. The drones also need to be constructed with these things in mind as there are some aspects that are required for it to function, such as a small enough size to manoeuvre. A balancing is needed due to how other aspects such as, battery time and number of sensors increases the size and weight of the drones.

Positive

- Installation/maintenance cost
- Can cover varying size and architecture on area
- Constantly evolving technology
- A large market is lowering prices
- Few necessary changes in retrofit or new productions
- Removal of dirt/water/snow is easy due to low number of drones

Aerial drone

- Less obstructions e.g. few or no lashing
- Can cover a whole vertical side of trailer if free flight path is ensured
- Ships movement in the sea will impact the free space in the flight path
- On weather deck, the combined ships speed and current wind speed can excess the drones speed through air e.g. the drone cannot keep up with the ship.
- The cost for an automated system is still relative high, but is predicted to continue to drop

Ground drone

- Reduced collision risk
- Can carry larger or heavier payload

Challenges

- Need to balance battery time and size required to install necessary sensors
- Mobile units have a larger risk of collisions
- Needs to move under or above the vehicles to get close enough for many sensors
- Requires navigation software with high accuracy even in a moving enclosed ship
- Requires collision avoidance software
- Malfunctions in one unit have a large impact on area covered
- Needs to be able to withstand saltwater/snow/rain etc
- Communication networks either constant communication or with regular intervals

Aerial drone

- Sensitive to wind in open areas
- Smoke will hamper visual aids
- Sprinkler or drencher systems will limit operability in case of a fire

- Tight stowage of trailer and trucks
- Liabilities if a malfunction causes a drone to crash into a cargo/vehicle

Ground drone

- Little sensor information without a “camera arm” that can be extended
- Sensitive to water or other liquids on deck
- Cargo lashings will be a challenge
- Cargo decks with hoistable decks could require a AGV for each deck
- Potentially needs to be EX approved?

In WP08 the choice was made to use a ground-based drone, since it will allow thoroughly scanning of the undercarriage of vehicles e.g. monitoring of BEVs under charging during a sea voyage.

9.3 Operational context for an AGV drone

An operational context has been formed for the demonstration case of a ground-based drone to patrol a cargo deck. Data on different types of BEV that is on the market:

Function

- A light activated when an anomaly is identified, making it easier to localise AGV visually
- Normal route would be lane by lane
- Learning by experience most efficient route for 2nd round
- Able to cover fully loaded cargo deck (approximately 2000 m travel distance) in 30 minutes first round, 20 minutes 2nd round and onward
- If detecting emerging thermal runaway situation, send alarm with information to ship system, stay on site for monitoring
- Battery capacity to be able to supply sensors and functions for 30 minutes scanning/patrolling plus 30 minutes active monitoring
- Battery charging max 30 min
- Ability to separate disturbing CO sources such as remaining gases in combustion engine exhaust systems

Geometry

- Max height of unit 130 mm above deck to pass under most vehicles. Probably a production unit would need be as low as 100mm to be able to pass under the majority of BEVs (See 15.1 Annex B)
- Max length, width, wheel angles to secure minimum turning radius, maybe crawler type is best
- Able to pass lashing points and weld seems

Manoeuvre

- Traction system to handle steel deck with water and oil

- Max water depth 20 mm
- Sensors and control system to avoid hitting wheels or other low parts of vehicles (wheel suspension linkage)
- Ability to back out if facing obstacles
- Able to manoeuvre through normally (not perfectly) parked vehicle lanes

Challenges

- Excessive heat from ICE with catalytic exhaust gas treatment
- Dirt/water dripping off from the cargo/vehicle/undercarriage

This will be the starting point for the work with the design of a prototype vehicle, including constrains regarding height of the vehicle.

9.4 Other types of mobile installations

Since a ro-ro cargo deck is a complex area when cargo is lashed and vehicles are parked, usage or portable solutions or pods of sensor, batteries and communication link, that can be temporarily secured to the hull/deck using brackets, lashing, magnetic feet/support or even suction cups that can temporarily support sensor platforms.

It is always a concern to install equipment above areas/space that passengers and crew have access to, if a portable device is to be placed on a wall or higher e.g. celling there should always be a way for an extra securing, a wire or similar.

If the device is to be placed on the deck, it must probably be recovered prior to passengers are given access to car deck or before discharge starts.

Such portable devices can be designed in many ways to solve the task and use of low weight stainless steel or other light weight and heat withstanding material would make the pod/rig durable and would withstand initial heat and also adverse weather and water from sprinkler system. If an automated FIFI monitor/drencher is used and a SoS is applied, then it would be aware of all mobile sensors and avoid them as long as possible while hosing down a deck, so sensor could still operate and give valuable info back to control centre.

Figure 85 A concept sketch of a portable sensor-rig, the sensor-bed that moves vertically and can rotate. (Robert Rylander, RISE image of vehicle derived under CC)

As illustrated in Figure 67, a portable tripod is placed by a vehicle/cargo that needs extra monitoring. The sensor bed can move vertically and scan both the trucks drive train and it can rotate allowing it to cover larger horizontal area.

9.5 Monitoring of gases

The sensor technology for monitoring of gases is evolving fast and depending on sensor, they are relatively cheap. The challenges with gases on large areas/volumes as a cargo deck are several:

- They dilute fast and easily spread in all directions with airflow or forced ventilation. Some gasses are lighter than air, some are heavier, and some are similar to the air we breathe.
- In general, the sensors are specific to what substance they can detect, so to be able to capture various gases it will be a combination of sensors and techniques.
- Optical sensors can be used to detect some types of gases using specific light and filtering techniques.
- Larger particles in gasses such as sooth, are much easier to detect than the chemicals in the gas.

This makes the placement of gas sensors complicated, one could place them at strategic places/spaces such as exhaust ventilation shafts or in low sections of decks where heavy gasses would accumulate or on portable devices placed close to or on the object that needs extra attention.

10 System of systems

A LASH FIRE system of systems (SoS) thinking is proposed, where the database concept developed in WP08 could acts as a new middle layer, that exchanges data with other systems, it could also be for live updates from subsystems with sensors or input from humans.
In WP06 crew of the ships could use data on fire patrols, aiding them to find areas or objects of interest for extra inspections during the regular fire patrols.

In WP07 an interactive table could receive updated information on the current situations in the cargo holds. WP09's Fire suppression systems could send information about their status and also receive sensor data from systems used in WP08.

In the future, an interactive system, that is used for planning, automatically supports the loading/unloading of cargo, can also be a support tool for the crew as they patrol the ship and in case of an incident, crew can use it to receive live information from sensors and cameras as well as sending on-scene data captured with handheld cameras and sensors back to the control rooms onboard the ship, as well as to shore. An interactive handheld device can also be part of a redundant system support for manually capturing information and possibly used for updating a ship local stowage plan, if the main system fails.

11 Demonstration of systems

Main author of the chapter: Robert Rylander, RISE

WP08 will use as many off-the-shelf products and open source software as possible, to build, demonstrate, and results from the systems.

11.1 LASH FIRE Cargo Fire Hazard Database

Together with the cargo manifest and the layout of the ship, the cargo fire hazard DB is one of the main inputs of the software planned to support the stowage process in LASH FIRE. To be more specific, the contents of the database will be taken as one of the criteria (in addition to several configuration parameters still to be defined) that will be used to perform a risk assessment of a cargo distribution for a given scenario.

The methodology for the construction of the database already included an implementation step under the umbrella of a relational model paradigm plus a development by means of a SQL compliant file-based component. This step was successfully completed and subsequently tested with a series of queries which results fed the risk analysis.

As previously mentioned, final implementation will depend on how the integration of the stowage planning tool and related components will be designed. Then, the construction of the DB will be tested by means of the current SQL scripts against the new RDBMS, if any (unit testing).

Finally, the exploitation of the DB will be tested in parallel with the development of the software components that will use it (integration tests).

Both unit and integration tests are related to software development, so they are oriented to prove that expected results are correctly generated for a given input and to check that the to be defined requirements are fulfilled.

11.2 LASH FIRE VHD and VDG system

Illustrated in Figure 86 below is a drawing of the LASH FIRE system that is customized and designed for the project and how the specific conditions at the Majnabbe terminal affect the installation of some of the sensors.

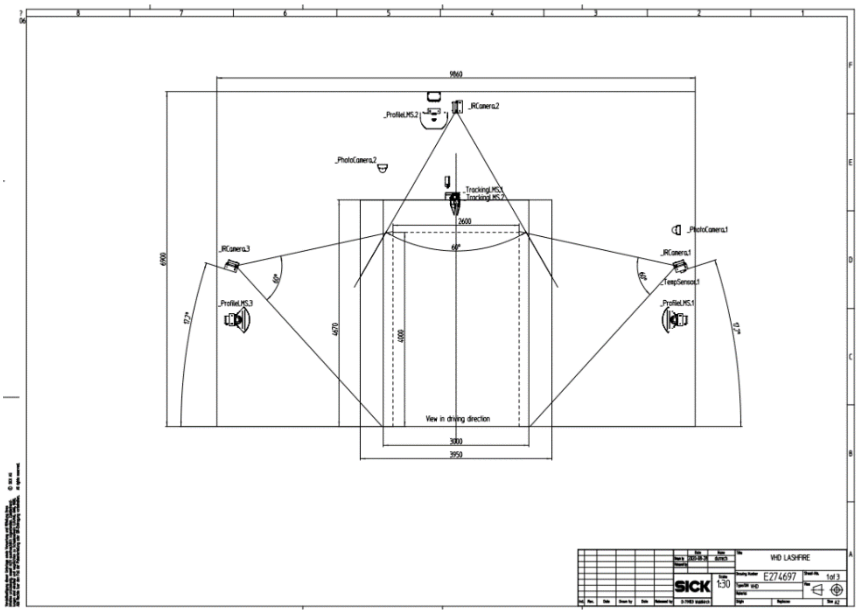


Figure 86 LASH FIRE site customization of VHD/VDG system at Majnabbe (source SICK AG)

Figure 87 Commissioning LASH FIRE VHD system February 2021 at Majnabbe terminal. (source LASH FIRE VHD system)

Illustrated above and below are images captured during the commissioning of the system. Before the system is fully operational several activities to tune the system will be ongoing during the spring of 2021. Above is a unit entering the Majnabbe terminal area, passing the second stage of the automated gate. And below is the corresponding thermal image. Even before the system installation is completed the thermal footprint is clear, equipment on the truck and trailer is recognisable to a human eye. Behind the truck, a vertical line of lighter blue is visible and that represents the reefer heat signature.

Figure 88 Thermal image during set up and initialisation of VHD system at Majnabbe (source LASH FIRE VHD system)

During the spring of 2021 completion and fine tuning of the system will take place.

Validation of the systems sensibility will be carried out when a base line of reefer units has been established, and by adding artificial hot spots close to motors and compressor units as illustrated earlier in section 8.1.1 will be set up and what could be an out-of-normal operational temperature range has been derived. An out-of- normal event will be investigated by the personnel at the terminal.

The LASH FIRE-VHD system will be mounted in parallel to the existing infrastructure to ensure that the daily operation of the terminal is not disturbed by the projects infrastructure or add the need for additional operational procedures. This will allow the project to capture real data from the stream of cargo and vehicles entering the terminal. And a “normal operation” baseline can be derived.

11.2.1 Data analysis to segment out areas of interest

In addition to the normal cargo flow, test of systems capability will be conducted to determine how sensitive the system is, what areas of the reefer unit can be seen and there by monitored and later as illustrated in Figure 74 segment out the AC unit of the reefer trailer. The project will consider relevant hot spot areas such as close to the electrical motor, ICE motor and compressor. All these three items have moving parts that wear down over time, such as bearings and belts. They are all inside the reefer unit and they are sources of malfunction and points of interests to monitor as detailed as possible from the outside on the reefer units cowlings to be able to detect heat signature anomalies. This will lead to early detection and early response and mitigating actions.

11.3 LASH FIRE AGV prototype mk.1

A small RC drone as illustrated below in Figure 89 will serve as the first prototype. The form factor of the LASH FIRE AGV is suitable for driving underneath most cars.

Figure 89 LASH FIRE AGV prototype mk1 (source Martin Torstensson, RISE)

11.4 System

The choices of which operating system and programming languages should be used will in part dictate what software can be used or at least easily integrated in the system. One alternative for the main processing unit of the drone is a Jetson board (Nvidia, 2021) that runs on Arch Linux. The structure of the software used is a combination of Python and ROS, utilizing the Rospy library. Python was chosen as the main programming language because it has bindings to many popular programming languages, it is free and easily accessible. The intention is to use as many prebuilt programs as possible for the drone and both Python and ROS creates a good environment that can incorporate many of these programs.

11.5 Navigation and path planning

A navigation system is essential for the drone to be able to effectively travel across the ship's deck and know which areas it has yet to cover. Among the potential options of navigation systems that are available the Cartographer project (Google, 2021) has been chosen. The Cartographer project offers a code base that performs Simultaneous localization and mapping, based on either 2D or 3D LiDAR data. It is mainly based on C++ and the code is provided under an Apache-2.0 license. The core program has been ported into several systems, such as ROS, Turtlebot and Fetch. The system is used for localization, navigation and creating detailed visualizations of the generated map. A collision avoidance system is necessary for the drone application to function in a safe manner. For the navigation system a LiDAR will be used, and the same LiDAR can, if chosen correctly, be a base for the collision avoidance function as well.

Another potential solution other than a LiDAR could be to use GPS. The accuracy does, however, need to be high to manoeuvre in small spaces. Considering that the drone would have to operate within the hull of the ship the LiDAR was assessed as more likely to be able to provide the precision needed.

Among the restrictions of operating a drone on a ship's deck is that the cargo and transports will likely be loaded in and out repeatedly creating a dynamic environment, at least between voyages. In that case a static path planning system will likely not work as the path may be blocked, inefficient or not cover all the necessary objects. A dynamic path planning tool could then be preferable. One option could be to use the map gathered by the SLAM system and plan a path that covers the whole area with as little overlap as possible. Another option would be to use machine learning for the task and more specifically Reinforcement learning is an interesting approach. Then the focus could be set on covering specific areas more frequently.

11.6 Object detection

One of the tasks of the mobile screening system is to be able to identify and map potential ignition sources. To achieve a system that can successfully do so there also needs to be a component that can separate these ignition sources from the rest of the environment.

A promising candidate is to make use of camera data in combination with machine learning algorithms specifically trained to find these types of objects e.g. reefer units. There are also algorithms made for detecting license plates, which is another interesting prospect in combination with a log of what vehicles the license plates correspond to. It is possible that more than one method needs to be used to cover all the objects and potential ignition sources of interest.

11.7 Heat detection

Heat detection is a core functionality requirement and, thus, a sensor to detect temperatures needs to be integrated into the drone system. One of the options would be to use an IR-camera for the heat detection. Due to the size constraints a FLIR Lepton (FLIR, 2021) camera is considered.

11.8 Communication

Two forms of information that needs to be sent to the ship’s crew is the map showing the locations of the potential ignition sources and system information, such as malfunctions and if there are tasks that cannot be completed.

In the given environment, it is not guaranteed that communication streams will be uninterrupted. Therefore, aspects such as average downtime and interruption frequency are important as well as resilient communication with multiple types of means of communication will be necessary. The maximum downtime in communication is to some degree even more important as it will dictate the maximum delay of the information. Communication range can also be an issue if there are only parts of the deck where communications can go through. The data transfer capacity will for some applications be of importance, especially if there is to be computing on an edge server.

12 Conclusion

Main author of this chapter: Robert Rylander, RISE

Impact of COVID-19

The governmental restrictions in the EC member states imposed to limit the spread of COVID-19 during 2020-21 has impacted the work in WP08. After the outbreak in February 2020 all physical meetings have been cancelled, excursions to collect data from actors, ships and terminal have been kept to an absolute minimal. All meeting has been web/phone meetings.

This has hampered the progress, since actors/companies/authorities have not been accessible or limited availability for interaction or collaboration due to COVID.

As new data or input will be available during the project time, it will be merged into the Cargo fire hazard database.

At the terminal at Majnabbe-terminal, less data than is needed for the development can be captured, but development will be supported by the upcoming test phase of LASHFIRE VHD functionality.

The AGV concept and development on the software side has been ongoing, and if the COVID situation allows, the practical phase of the development can start during the summer of 2021 on shore and move onboard during the autumn of 2021.

Inference

There is good guidance in various rules, regulations, and codes such as the IMDG, how cargo and vehicles that are classified as hazardous should be stowed and segregated. As identified in previous research and during the HAZID, the landscape is changing:

Increasing number of trailers and APVs shipped today, compared to ten years ago

APVs will change the way how to tackle a fire onboard a ship

Sensor technology and the computing power moves away from stand-alone desktop/server solutions and can be conducted at the edge or even at the sensor

There is an increasing capacity in sensor fusion systems and machine learning leading to more real time applications available to the persons working at the ports, terminals, and ships

There is increasing necessity to know more about the cargo/vehicles carried on board, where they are placed in relation to other goods/vehicles.

This, to be able in a pre-emptive way to limit consequences in case of a fire and during fire fighting have a better situational awareness to make the right tactical decisions.

Today there are more robust ways for sharing data than five or ten years ago, this opens possibilities for systems that support collaborative decision making and machine-to-machine data exchange, while keeping the human in the loop without increasing cognitive workload. The intention with the tools developed in the work package is to strive for a safer environment using automated and connected systems. Systems that can be adapted or updated or systems that adapts automatically to the ever-changing environment in which they operate in. Some of the concepts developed in WP08 are already being tested as a product.

The VHD system that is in development will soon be able to detect heat signature anomalies on reefers entering a terminal or ship. This will be demonstrated at the Majnabbe terminal in Gothenburg. The cargo fire hazard database can be incorporated as an add-on or a module to current terminal/stowage software and already in the stowage planning help to mitigate a high-risk situation onboard the ship in case of a fire. AGV drones can be commercialised relatively fast, as they will be based on off the shelf components but operate in a new environment.

The concept is to build on open specifications as far as possible so that they enable a system of systems philosophy, where data can be shared in an ecosystem of support systems aiding all the individuals and stakeholders involved in the sector. Such systems will enhance the safety for the passengers, crew, cargo, and ships. It will allow better usage of limited resources such as ships and infrastructure by allowing safe and faster turn arounds in port, early detection also leads to less damage to equipment and losses in downtime and cancelled connection. A more efficient seaborne transportation system greatly helps the environment with more efficient handling of cargo and vehicles, making the ships a more attractive route compared to the stressed road networks.

There are several attractive similar technologies that could match a specific trade/route better than the concepts that LASH FIRE has decided as its scope of work in this work package. The ambition of the work at this stage is to plant a seed for future innovation and development of use of software, sensors, automation, robotic technologies and demonstrate how it could increase the safety by pre-emptive tools feed with representative historical data such as the cargo fire hazard database and the real time systems such as remote scanning of cargo and vehicles and usage of drone to continuously monitor specific cargo and vehicles of interest.

During the next stage of the LASH FIRE project, the different concepts presented will be incrementally moved from desktop exercises and simulations, towards testing in realistic situations and then in real operations, to the largest possible extent. This iterative methodology will collect necessary data and information from sensors and human interaction. This will lead to further development in technical aspects and most importantly usability with input from crew and personnel that are directly involved with the daily operations. One example for shipping companies is the Safety Management System manuals (SMS) that will be affected when new technology is introduced. Procedures and routines need to be updated or designed, it will lead to a preparedness on what actions should be taken when a cargo/vehicle is at level that is close to or triggered an alarm, on shore and prior to loading as well as what actions should been in place on the ship if the unit/vehicle is loaded. Areas designated for inspection of cargo/vehicle, under what circumstances can the unit still be loaded e.g., is a cool down enough for an overheated wheel/brakes and how asses that the unit is fit for loading e.g., by handheld sensors. This will increase the safety staring in the terminal area and could cover all the way until the cargo/vehicle leaves the terminal at the destination.
Over time, cost will be lower the threshold for final products to be adopted into the shipping industry in the future.

13 References

ACXIS. (2021, 03 01). *Research on Automated Comparison of X-ray Images for cargo Scanning*. Retrieved from ACXIS: https://www.acxis.eu/

ALBERO . (2021, 03 01). *Transport of alternatively powered vehicles on ro-ro ferries*. Retrieved from alberoprojekt: https://alberoprojekt.de/index_htm_files/5.3%20Detektion%20kritischer%20Zustaende%20bei%20Elektrofahrzeugen.pdf?

ALBERO Project. (2021, 03 01). *ALBERO Project*. Retrieved from ALBERO Project: https://alberoprojekt.de/#xl_xr_page_index-eng

Bloomberg.com. (2019). Tesla and NIO Fires in China Spur Electric-Car Safety Checkups. Retrieved from Bloomberg.com. *https://www.bloomberg.com/news/articles/2019-06-17/spate-of-electric-car-fires-spur-china-to-order-safety-checks*.

Brzezinska, D. (2019). LPG Cars in a Car Park Environment—How to Make it Safe. *Journal of Environmental Research and Public Health.*

Bureau Veritas. (2021, 03 01). *Bureau Veritas*. Retrieved from DRONES ARE REVOLUTIONIZING THE INSPECTION BUSINESS: https://group.bureauveritas.com/magazine/drones-are-revolutionizing-inspection-business

Cristofer Englund, B. D. (2017). *Lighthouse report - In-door positioning on RoRo vessels.* Retrieved from Lighthouse: https://www.lighthouse.nu/sites/www.lighthouse.nu/files/indoor_positioning_webbcompressed.pdf

DNV, G. (2016). Fires on ro-ro decks. *DNV GL.*

EMSA. (2021, 03 12). *Fire safety in ro-ro passenger ships – FIRESAFE studies*. Retrieved from www.emsa.europa.eu: http://www.emsa.europa.eu/firesafe.html

European Commission DIRECTIVE 2014/34/EU . (2021, 03 01). *DIRECTIVE 2014/34/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 26 February 2014 on the harmonisation of the laws of the Member States relating to equipment and protective*. Retrieved from European Commission DIRECTIVE 2014/34/EU : https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014L0034&from=EN

European Comssion. (2021, 03 01). *MOBILITY AND TRANSPORT*. Retrieved from Cooperative, connected and automated mobility (CCAM): https://ec.europa.eu/transport/themes/its/c-its_en

FLIR. (2021, 03 01). *FLIR*. Retrieved from lepton: https://www.flir.eu/products/lepton/

Google. (2021, 03 01). *Cartographer ROS Integration*. Retrieved from Cartographer ROS: https://google-cartographer-ros.readthedocs.io/en/latest/index.html

Hemighaus, G. (1998). Analysis of Kerosine, Diesel and Aviation Turbine fuel. . *n A. W. Drews, Manual on hydrocarbon analysis (*, 22-24.

ICAS & ICAS ltd 2021. (2021, 03 01). *UR E10 Rev7 CLN*. Retrieved from IACS: https://www.iacs.org.uk/publications/unified-requirements/ur-e/ur-e10-rev7-cln/

IMO. (2020). *International Maritime Dangerous Goods Code.*

IMO, (. M. (2008). *MSC-MEPC.3/Circ.3 Reports on Marine Casualties and Incidents.*

Intel . (2021, 03 01). *Intel*. Retrieved from Intel Realsense: https://www.intelrealsense.com/

International Electrotechnical Commission. (2021, 03 01). *IEC*. Retrieved from ip-ratings: https://www.iec.ch/ip-ratings

LASH FIRE. (2020). *LASH FIRE Deliverable D04.1 Review of accident causes and hazard identification report.* Borås: LASH FIRE.

Maritime Safety Committee Circulars, I. (2014). *RECOMMENDATION ON SAFETY MEASURES FOR EXISTING VEHICLE CARRIERS CARRYING MOTOR VEHICLES WITH COMPRESSED HYDROGEN OR NATURAL GAS IN THEIR TANKS FOR THEIR OWN PROPULSION AS CARGO.*

Martime, K. (2021, 03 03). *DP Alert System*. Retrieved from Kongsberg Martime AS: https://www.kongsberg.com/globalassets/maritime/km-products/product-documents/dp-alert-system

Mushrush, G. W. (2006). Petroleum-Based Hydraulic Fluids and Flammability. *Petroleum Science and Technology*, 1441-1446.

Nvidia. (2021, 03 01). *Jetson Xavier NX Developer Kit.* Retrieved from Nvidia: https://developer.nvidia.com/embedded/jetson-xavier-nx-devkit

Securius, P. &. (2013). Study on fire safety in connection with the transport of vehicles with electric generators or electrically powered vehicles on ro-ro and ro-pax ships.

SICK AG. (2021, 03 01). *Profiling systems*. Retrieved from SICK AG: https://www.sick.com/ag/en/system-solutions/profiling-systems/vhd/c/g322552

Smiths Detection. (2021, 03 01). *Smiths Detection*. Retrieved from HCVG: https://www.smithsdetection.com/products/hcvg/

Sun, P. B. (2019). A review of barrery fires in electrical vehicles.

Swedish Accident Investigation Authority, S. (2019). Slutrapport RS 2019:02. *Swedish Accident Investigation Authority*.

The North of England P&I Association, T. (2017). Ro-Ro Fires. Loss prevention briefing.

Transportation, U. D. (2013). Natural Gas Systems: Suggested Changes to Truck and Motorcoach Regulations and Inspection Procedures. *U.S. Department of Transportation*.

Transportstyrelsen. (2018). Retrieved from Charging electric vehicles on board Swedish Ropax vessels:. *https://www.transportstyrelsen.se/globalassets/global/publikationer/sjofart/charging-of-electric-vehicles-onboard-swedish-ropax-vessels-20180711.pdf*.

Uveye. (2021, 03 01). *UVEYE*. Retrieved from Security Solutions: https://www.uveye.com/security-solutions/

Wikman, J. E. (2016). Study investigating costeffective measures for reducingthe risk from fires on ro-ropassenger ships (FIRESAFE). *EMSA*.

14 Indexes

14.1 Index of tables

14.2 Index of figures

15 ANNEXES

15.1 ANNEX A APV ground clearance

15.1.1 BEV Unloaded if not else is stated

Type BEV	Ground clearance (cm)	Source
Tesla Model 3	~14	https://www.car.info/sv-se/tesla/model-3/model-3-50-kwh-16314903/specs
Nissan Leaf	~15	https://www.car.info/sv-se/nissan/leaf/leaf-40-kwh-2018-16463769/specs
Kia e-Niro	~16	https://www.car.info/sv-se/kia/niro/niro-64-kwh-s-2021-23817519/specs
VW id3	~15	https://se.automobiledimension.com/modell/volkswagen/id-3
BMW i3	~14	https://www.car.info/en-se/bmw/i3/i3-18084608/specs
Volvo Polestar 2	~15	https://www.dagensps.se/motor/polestar-2-kan-bli-en-succe/
Chevrolet Bolt	~15	https://www.evspecifications.com/en/model/18a190
Renault Zoe	~12	https://www.evspecifications.com/en/comparison/3dac1e52
Mercedes-Benz A 250 e Sedan	~10	https://www.car.info/sv-se/mercedes-benz/a-class/a-class-sedan-19126305/specs

15.1.2 FCBV Unloaded if not else is stated

Type FCBV	Ground clearance (cm)	Source
Toyota Mirai mk.1	~13	https://www.car.info/sv-se/toyota/mirai/mirai-fuelcell-s-2020-19509960/specs
Honda Clarity Fuel Cell	~11 (loaded)	https://www.honda.ca/clarity/specs)