Horizon 2020

Project acronym: **LASH FIRE**

Project full title: **Legislative Assessment for Safety Hazard of Fire and Innovations in Ro-ro ship Environment**

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Deliverable D04.2

Ro-ro space fire database and statistical analysis report

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Abstract

The Formal Safety Assessment (FSA) carried out in LASH FIRE requires a consolidated comprehensive database on fires in ro-ro spaces and the corresponding ship fleet to be set-up for specific use in the project. Such a database would allow a better understanding of the type of casualties and characteristics of ships in the FSA scope, and provides probabilities and frequencies that will be used in the quantification phase of the LASH FIRE risk model.

For this purpose, a comprehensive database was built by aggregation of different pools of information. Marine casualties, incidents and ship characteristics data were investigated, and collected from different maritime stakeholders. A data quality assessment was performed to select the data to be aggregated. A challenge was to propose a homogeneous and unbiased database. The available data were completed with 'data science' methods. Moreover, different case by case studies were performed on datasets provided by the two LASH FIRE Maritime Advisory Groups to refine the scope of the FSA study and to build additional key features. Those studies enabled, for example, to separate SOLAS compliant ships from non-SOLAS compliant ships and to estimate the size distributions of different types of ro-ro spaces based on ship characteristics.

As a result, the comprehensive database was processed in order to draw statistics for the LASH FIRE fleet and fires in ro-ro spaces. The statistics provided an extensive overview of the fleet considered for the FSA study and frequencies of ignition per type of ro-ro ship. A result to highlight is the frequency of fire ignition per type and unit of ro-ro space (lane meter or car equivalent unit). The fire frequencies per ro-ro space type and unit could however only be determined for the ro-ro passenger ships and vehicle carriers. The calculated novel frequencies should pave the way for a risk model that better matches the space-type categorisation in the SOLAS Convention, and it better reflects the effectiveness of solutions depending on ship size.

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Content

1 Executive summary

Problem definition

The LASH FIRE project aims to develop solutions to enhance fire safety in ro-ro spaces by the development of innovative technologies as well as by the modification of operations and applications. An evaluation of each solution, in line with IMO Formal Safety Assessment (FSA) procedures, will be carried out within the project. This includes the development of a ro-ro fire risk model and a cost-effectiveness assessment of each solution. A prerequisite to the development of the risk model is the collection and structuring of marine casualty data into a comprehensive database built by the aggregation of marine casualty and ship information. Such data allow fire frequencies to be calculated. It also allows a better understanding of the casualties and characteristics of ships, as basis for the development of the risk model.

The main challenges when developing and using such a database are the transparency and the availability of the data. Most of the FSA studies conducted have used commercial databases as basis and not databases administrated by the maritime authorities [1]. Moreover, no consolidated and comprehensive database on fires in ro-ro spaces or ro-ro vessel fleet is currently available.

Technical approach

To address the described problems above, the D04.2 report was built around four major axes:

- Collection of databases available to perform the LASH FIRE FSA. Not only traditional fire casualty databases, but alternative data sources were identified thanks to the network established by WP04 beneficiaries, e.g. through the two Maritime Advisory Groups established by the project;
- Data quality assessment based on the FSA purpose and aggregation of data in the WP04 database. A methodology based on data quality assessment was developed to construct a homogeneous and unbiased consolidated database;
- Exploitation of available data with 'data science' methods to impute missing data or build new features; and
- Analysis of the WP04 database and other relevant information collected but not included in the database in order to draw statistics for the LASH FIRE fleet and fires in ro-ro spaces, which will be inputs to the risk model.

Results and achievements

Six different casualty/incident databases were collected and their strengths and limitations were described. Different case by case studies were performed on datasets provided by the ship operators from Maritime Operators Advisory Group (MOAG) and by European Maritime Safety Agency (EMSA) to refine the scope of the FSA study and to gain more knowledge.

As a result, the **WP04 database** was constructed. The comprehensive WP04 database will be used only in the context of the LASH FIRE project and will not be used nor maintained after the project. As per the consortium agreement [2], access to raw data is restricted to the LASH FIRE beneficiary Bureau Veritas only.

The ro-ro ships constituting the LASH FIRE fleet were described. The fleet statistics provide an extensive overview of the ro-ro ships that will be considered in the FSA study.

The frequency of fire ignition in ro-ro spaces was determined per type of ro-ro ship and per type of ro-ro space. The calculated fire frequencies per type of ro-ro ship are comparable to frequencies computed in other FSA studies on the same topic. The calculation of fire frequencies per type and unit of ro-ro space is a novel approach and could only be calculated for the ro-ro passenger ships and vehicle carriers. The result should be interpreted with caution and considering the errors provided in annexes. These novel frequencies should pave the way for a risk model that better matches the space-type categorisation in the SOLAS Convention, and it better reflects the effectiveness of solutions depending on ship size.

Contribution to LASH FIRE objectives

The IMO strategic plan for 2018-2023 highlights the importance of integrating new and advancing technologies in the regulatory framework. One of the objectives of LASH FIRE is to support the aforementioned strategic plan, in part through this deliverable. This deliverable will furthermore lay the groundwork for achieving the LASH FIRE objective 3:

> LASH FIRE will provide a **technical basis** for future revisions of regulations by **assessing risk reduction and economic properties of solutions**.

This is particularly achieved by contributing to the goal of action 4-A:

> **Development of a holistic ro-ro ship fire risk assessment** model and tool for consequence quantification of fires originating in ro-ro spaces.

Indeed, construction and statistical analysis of the WP04 database are part of the preparatory steps of any FSA study and, in particular, prerequisites to develop the risk model.

Exploitation and implementation

The results will be used within LASH FIRE to describe the fleet of ro-ro ships considered in the FSA study and to feed the risk model with statistics, i.e. frequency of fire ignition and probabilities. The deliverable can be used by external parties at different levels:

- The deliverable provides general knowledge on the reporting of casualties and an overview of different casualty databases. This information can be useful by any actor in the maritime industry and may serve to homogenise the different sources of casualty data;
- One of the challenges was to propose a solution to the requirements of validity of input data in the IMO FSA guidelines [3]. This was addressed in this deliverable by the aggregation methodology based on data quality concept. The proposed solution could be used by any actor who handles data from different sources;
- The deliverable provides a novel approach to calculate a frequency of fire ignition per unit of space. This approach better matches the space-type categorisation in the SOLAS Convention and could be re-used and refined for future FSA studies; and
- Correlations and statistics in this deliverable describe the world fleet of ro-ro ships and fires originating in ro-ro spaces. Statistics often provide an objective picture that can serve future measures to improve the safety at sea. Indeed, the statistics can be used by decision bodies to draw the current state of the ro-ro fleet and fires originating in ro-ro spaces.

2 List of symbols and abbreviations

AIB	Accident Investigation Body
AIBN	Accident Investigation Board Norway
BV	Bureau Veritas
BSU	Bundesstelle für Seeunfalluntersuchung (Federal Bureau for Maritime Casualty Investigation) (DE)
CEU	Car Equivalent Unit
DB	DataBase
DMAIB	Danish Maritime Accident Investigation Board
DSB	Dutch Safety Board
EMCIP	European Marine Casualty Information Platform
EMSA	European Maritime Safety Agency
Equasis	Electronic Quality Shipping Information System
EU	European Union
FSA	Formal Safety Assessment
GISIS	Global Integrated Shipping Information System
GT	Gross Tonnage
HazId	Hazard Identification (workshop)
HBMCI	Hellenic Bureau for Marine Casualties Investigation
HSC	High-Speed Craft
IACS	International Association of Classification Societies
IHS	Information Handling Services
ILT	Inspectie Leefomgeving en Transport (Inspectorate human environment and transport) (NL)
IMO	International Maritime Organization
ISM (Code)	International Safety Management (Code)
LM	Lane Meter
LOA	Length Overall
LPP	Length between PerPendiculars
LOO	Leave One Out
MAAG	Maritime Authorities Advisory Group
MAIB	Marine Accident Investigation Branch (UK)
MARPOL	MARine POLlution (International Convention for the Prevention of Pollution from Ships)
MCI	Marine Casualties and Incidents
MEPC	Marine Environment Protection Committee
MIT	Ministero delle Infrastrutture e dei Trasporti (Ministry of Infrastructure and Transport) (IT)
MOAG	Maritime Operators Advisory Group
MODU	Mobile Offshore Drilling Unit
MoU	Memorandum of Understanding
MS	Microsoft
MSC	Maritime Safety Committee
NMA	Norwegian Maritime Authority
NTSB	National Transportation Safety Board (USA)
P&I	Protection and Indemnity
PAX	Passenger (capacity)

PSC	Port State Control
PSCO	Port State Control Officer
RO	Recognised Organisation
RMSE	Root of the Mean Square Error
SMAIC	State Marine Accident Investigation Commission (PO)
SMS	Safety Management System
SOLAS	International Convention for the Safety of Life at Sea
TSB	Transportation Safety Board (of Canada)
t	Metric tonnes
UNCLOS	United Nations Convention on the Law of the Sea

3 List of definitions

This chapter provides the definitions of important terms used in the report. Those terms shall be understood as the below definitions provided by IMO regulations.

Marine casualty:

A "**marine casualty**" means an event, or a sequence of events, that has resulted in any of the following which has occurred directly in connection with the operations of a ship:

.1 the death of, or serious injury to, a person;

.2 the loss of a person from a ship;

.3 the loss, presumed loss or abandonment of a ship;

.4 material damage to a ship;

.5 the stranding or disabling of a ship, or the involvement of a ship in a collision;

.6 material damage to marine infrastructure external to a ship, that could seriously endanger the safety of the ship, another ship or an individual; or

.7 severe damage to the environment, or the potential for severe damage to the environment, brought about by the damage of a ship or ships.

However, a marine casualty 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. (Casualty Investigation Code, MSC.255(84), Part I, Chapter 2, 2.9) [4]

A "**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. (Casualty Investigation Code, MSC.255(84), Part I, Chapter 2, 2.18) [4]

A "**material damage**" in relation to a marine casualty means:

.1 damage that:

.1.1 significantly affects the structural integrity, performance or operational characteristics of marine infrastructure or a ship; and

.1.2 requires major repair or replacement of a major component or components; or

.2 destruction of the marine infrastructure or ship. (Casualty Investigation Code, MSC.255(84), Part I, Chapter 2, 2.16) [4]

A "**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. (Casualty Investigation Code, MSC.255(84), Part I, Chapter 2, 2.19) [4]

A "**very serious marine casualty**" means a marine casualty involving the total loss of the ship or a death or severe damage to the environment. (Casualty Investigation Code, MSC.255(84), Part I, Chapter 2, 2.22) [4]

"**Very serious casualties**" are casualties to ships which involve total loss of the ship, loss of life, or severe pollution, the definition of which, as agreed by the Marine Environment Protection Committee at its thirty-seventh session (MEPC 37/22, paragraph 5.8), is as follows:

> "Severe pollution" is a case of pollution which, as evaluated by the coastal State(s) affected or the flag Administration, as appropriate, produces a major deleterious effect upon the environment, or which would have produced such an effect without preventive action. (MSC-MEPC.3/Circ.3) [5]

"**Serious 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.

* The ship is in a condition, which does not correspond substantially with the applicable conventions, presenting a danger to the ship and the persons on board or an unreasonable threat of harm to the marine environment. (MSC-MEPC.3/Circ.3) [5]

"**Less serious casualties**" are casualties to ships which do not qualify as "very serious casualties" or "serious casualties" and for the purpose of recording useful information also include "marine incidents" which themselves include "hazardous incidents" and "near misses". (MSC-MEPC.3/Circ.3) [5]

A "**marine incident**" 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.

However, a marine incident 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. (Casualty Investigation Code, MSC.255(84), Part I, Chapter 2, 2.10) [4]

Near-miss: A sequence of events and/or conditions that could have resulted in loss. This loss was prevented only by a fortuitous break in the chain of events and/or conditions. The potential loss could be human injury, environmental damage, or negative business impact (e.g. repair or replacement costs, scheduling delays, contract violations, loss of reputation). (MSC-MEPC.7/Circ.7, Annex, 2.1) [6]

Deficiency: A condition found not to be in compliance with the requirements of the relevant convention. (Procedure for Port State Control, 2017, A.1119(30), Annex, Chapter 1, 1.7.3) [7]

<u>Ro-ro space:</u>

A **weather deck** is a deck which is completely exposed to the weather from above and from at least two sides. (SOLAS II-2/3) [8]

IACS UI SC 86 [9] 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. (SOLAS II-2/3) [8]

A **closed vehicle or ro-ro space** is any vehicle or ro-ro space which is neither open nor a weather deck. (SOLAS II-2/3) [8]

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

4 Acknowledgments and disclaimer

4.1 Acknowledgements

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4.2 Disclaimer

The opinions expressed in this report are those of the authors and should not be construed to reflect the views of aforementioned organisations.

5 Introduction

Main author of the chapter: Eric De Carvalho, BV.

Data concerning marine casualties and incidents are very important for the purpose of making more balanced, proactive and cost-effective legislation [3]. Casualty data are used at different levels, from drawing key figures and statistical indicators on safety to quantitative risk assessment. The final objective of using those data is the same: improve the safety at sea.

Casualty data are the results of the reporting of marine accidents and incidents. The reporting of marine accidents is mandatory according to various international regulations. In particular, the Code of the International Standards and Recommended Practices for a Safety Investigation into a Marine Casualty or Marine Incident (Casualty Investigation Code) [4], adopted by resolution MSC.255(84), provides a common approach for the Member States to report marine casualties and incidents as well as marine safety investigations to IMO.

Casualty data are generally found in the form of unstructured datasets, e.g. accident investigation reports, or structured databases. A structured database is more easily handled and analysed, and is often one of the main data sources for safety studies, such as the Formal Safety Assessment (FSA). When handling data, their validity (transparency, comprehensiveness, availability) is crucial and must be verified [3].

Numerous different databases exist; they are administrated by different entities for different objectives of use. Most of the FSA studies conducted have used commercial databases as basis and not databases administrated by the maritime authorities [1]. From this, the question of transparency has risen, since, by definition, the use of a commercial database is limited by a data supplier contract. When an FSA is submitted to IMO, “an FSA study should be open and transparent for review by all interested Member States and non-governmental organizations which have not participated in the conduct of the FSA study” [3].

The question of the availability of data is underlined in the FSA training course held by IACS (International Association of Classification Societies) [10], where it is stated that "lack of data" is the most common excuse for not undertaking an FSA study. For the purpose of the LASH FIRE project, there was currently no relevant database available. Therefore, the goal of Task T04.3 was to construct a comprehensive ro-ro space fire database in order to perform qualitative and quantitative analysis on fires originating in ro-ro spaces and to support the development of the risk model.

The creation of such a database within the project is described in the following chapters, where chapter 6 describes the results of the data collection. A wide range of information sources and data have been investigated and, if possible, relevant data were collected. Chapter 7 describes the methodology for data quality assessment and aggregation into a comprehensive database. Chapter 8 and chapter 9 describe the main steps for the development of the WP04 Fleet and Casualty database, how missing data have been imputed and how new features have been built. Lastly, chapters 10 and 11 provide the outcomes of the statistical analyses performed on the basis of the WP04 database. Key figures about the fleet and the frequencies of fire ignition will be used as inputs of the risk model. Chapter 11 also provides the novel fire frequencies per ro-ro space type and unit. The annexes provide a complete list of data fields of the WP04 database and more details about the mathematical background used for the creation of the database.

The LASH FIRE project is not the first project that investigates different statistical pools of fire casualty data. Previous such studies are, for example:

- 2005-2009 - SAFEDOR RoPax Ships (MSC 85/INF.3): use of Lloyds Maritime Information Unit data (now, IHS data);
- 2015 - Electric Mobility on RoRo/RoPax vessels (MSC 96/INF.3): use of SAFEDOR data;
- 2016 - FIRESAFE I: casualty data analysis based on FSI 21/5, MARINFO, IHS, EMCIP and GISIS MCI data but further limited to MARINFO and IHS data for risk analysis; and
- 2017-2018 - FIRESAFE II: use of FIRESAFE I data.

The above studies focused on ro-ro passenger ships and, to the knowledge of the authors, no investigations were made regarding ro-ro cargo ships, nor vehicle carriers. Investigations have also been performed for other scopes, e.g. fires on passenger ships (FIREPROOF, 2009-2012) and damage stability of passenger ships (EMSA 3, 2013-2015).

6 Data collection

Main author of the chapter: Eric De Carvalho, BV.

Both traditional[1] and alternative statistical sets of fire casualty data were investigated. These sources of casualty related information are mainly handled through structured databases administrated by different entities (e.g. data provider companies, authorities, insurers, ship owners or operators, etc.) with different objectives of use. Depending on the purpose, scope and level of information may differ from one dataset to another.

This chapter provides relevant general information about the collected data. First, for each dataset, a brief summary about data retrieval is provided. Then, a focus on the relevant fields for the LASH FIRE project is provided, i.e. mainly the categorisation by casualty type, casualty severity and ship type. Lastly, when possible, some background information is provided on how the different entities collect information used to populate their data system (e.g. legal requirement, voluntary schemes, etc.).

6.1 Commercial database – IHS Maritime & Trade

6.1.1 Retrieval of the database

IHS Maritime & Trade, branch of IHS Markit®, is one of the world's leading commercial maritime data providers. A bespoke maritime data service was used by Bureau Veritas Marine & Offshore to tailor a ship database and a casualty database. The data were downloaded in September 2019 and made available in MS Access format.

As defined in the LASH FIRE consortium agreement, access to IHS Maritime & Trade raw data is restricted to Bureau Veritas Marine & Offshore only.

6.1.2 Presentation of the database

6.1.2.1 General

IHS Maritime & Trade collects its data from an extensive maritime network. Information sources related to casualty include flag registration authorities, accident investigation reports, classification societies, broker reports, salvage organisations, coast guards, open media, etc.

6.1.2.2 Data fields related to fires in ro-ro spaces

The fire casualty events are categorised as "Fire/Explosion (FX)". As reported in the FIRESAFE I study [11], the definition of "Fire/explosion (FX)" considered in IHS is: fire/explosion is the first event reported, except where fire/explosion results from hull/machinery damage, i.e. this category includes fires due to engine damage, but not fires due to collision etc.

The severity of casualties is categorised as "Serious" and "Non-Serious", which differs from IMO classification. About this categorisation, IHS Maritime & Trade provided the following clarifications. All "Fire/Explosion (FX)" events are recorded regardless of severity. If the damage caused by the fire/explosion is sufficient to disable the vessel so that it requires tug assistance to reach port, or if it catches fire in port and the damage requires significant repairs before the vessel continues trading, then the casualty will be classed as "Serious". If the damage is minor and the vessel can be quickly returned to service without significant repairs (e.g. single cargo fires), the casualty will be classed as "Non-Serious"". In addition, IHS Maritime & Trade clarified that:

[1] Traditional database, to be understood as a common commercial database used in FSA.

- "The Non-Serious incident usually involved a casualty in which the vessel was not required to move to a shipyard for repairs, the vessel continued trading almost immediately, the vessel does not need external assistance for propulsion, and no fatality arises from the incident. Very minor cases, in which the problem resolved within 24 hours are normally not included within the database"; and
- An accident can be qualified Non-Serious and involves people injury, "if the vessel operation does not impact in a prolonged manner".

The types of ships, related to the ro-ro ships considered in the LASH FIRE project, are categorised as "Passenger/Ro-Ro Ship (Vehicles)" (IHS StatCode5 A36A2PR), "Passenger/Ro-Ro Ship (Vehicles/Rail)" (IHS StatCode5 A36A2PT), "Ro-Ro Cargo Ship" (IHS StatCode5 A35A2RR) and "Vehicles Carrier" (IHS StatCode5 A35B2RV).

6.1.3 Reporting requirements and criteria

The data provided by IHS Maritime & Trade originates from various sources of information. By definition, they are not subjected to any reporting requirements nor criteria except those defined in the data exchange agreements. The collection of information is based on agreement between IHS Maritime & Trade and various organisations and, thereby, is not systematic to all the maritime stakeholders (in particular, maritime authorities).

The ship and casualty population is considered to be the most exhaustive within the limits of data exchange agreements. IHS Maritime & Trade is considered to provide comprehensive information on all vessels of 100 GT and over [12].

6.2 International Maritime Organization (IMO) database – GISIS MCI

The main objective of GISIS MCI module is to gather reports related to marine casualty and incidents, to analyse them in order to extract lessons learned from each one and to issue recommendations to interested parties, with the main objective to avoid similar casualties or incidents in the future and to do not assign any fault or responsibilities to any party involved on those incidents.

6.2.1 Retrieval of the database

Three different levels of access to the GISIS MCI module can be granted:

- Public access;
- Member State access; or
- Secretariat access.

The Member State access is granted to the Member States in order to report to IMO any marine casualty and incident and to review the analysis of marine safety investigation reports. The differences between a public access and a Member State access are mainly:

- Some marine casualties or incidents and/or information related to a marine casualty or incident may not yet have been published as public content because they are still under the review process of the IMO Secretariat; and
- Some marine safety investigation reports may not have been made available to the public by the Member State.

The secretariat access includes all contents of the Member State access. This content is used by the Secretariat for the purpose of activities such as drawing key figures and statistics about casualties, safety analyses etc. It also includes IHS data. A one-year access to IHS data would be granted to the participants in the FSA Group of Experts for the purpose of reviewing an FSA study (III 5/15 §4.9 [13] and SSE 7/6 §25 [14]).

After several exchanges with the IMO Secretariat, the LASH FIRE consortium was granted with a public access available through the IMO website [15], with the applicable disclaimers and terms of use that can be found on the web page [16]. The data were retrieved in csv format (30 July 2020).

6.2.2 Presentation of the database

6.2.2.1 General

The GISIS MCI module is a web database. Log-in is required. As illustrated in Figure 1, it contains three categories of information related to ship casualties:

- The first category of information ("Incident summary") is based on factual data collected from various sources;
- The second category of data is constructed from elaborated information based on the reports of casualty investigations, submitted to IMO by reporting Member States, and may be full investigation reports ("Investigation reports") or reporting forms annexed to MSC-MEPC.3/Circ.3 [5] ("Reporting forms"); and
- The third category of information ("Analyses") is made of analyses of safety investigation reports, which are aimed at identifying overall trends or issues of potential concern to the marine transportation (or to the shipping industry). The procedure of analysis of casualty investigation reports is described in document FSI 17/WP.1, annex 2 [17].

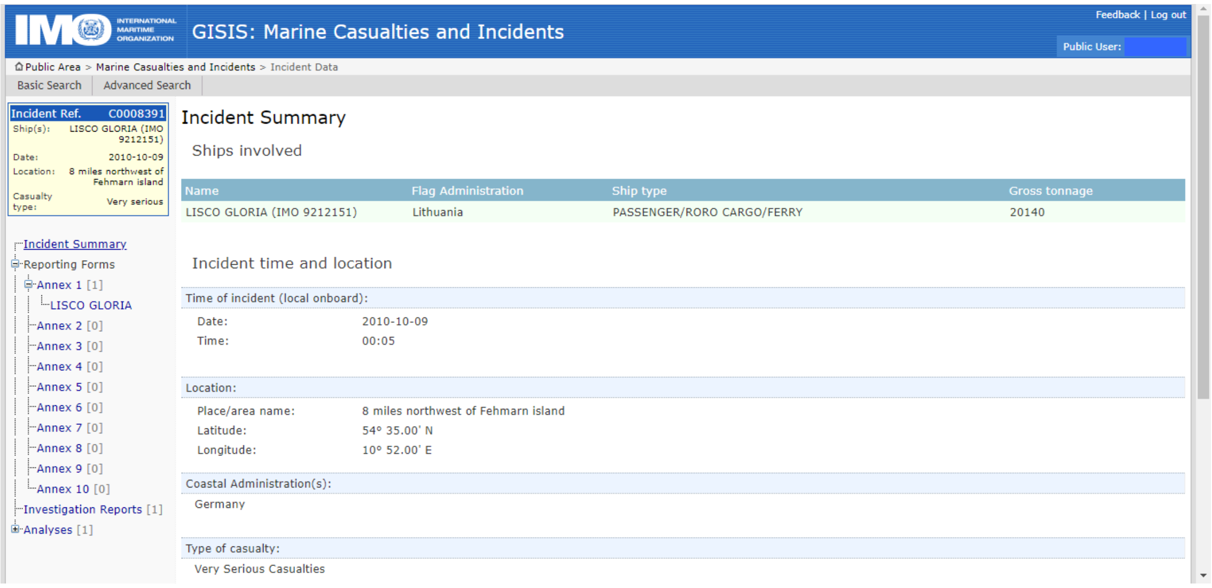

Figure 1. GISIS MCI – Screenshot. Source: [15].

The reporting forms submitted by the Member States are divided into different annexes, among which the following annexes are deemed relevant in the context of LASH FIRE:

- Annex 1: Ship identification and particulars;
- Annex 2: Data for very serious and serious casualties;
- Annex 3: Supplementary information related to very serious and serious casualties;
- Annex 4: Information from casualties involving dangerous goods or marine pollutants in packaged form on board ships and in port areas; and
- Annex 6: Fire casualty record.

The complete taxonomy of the reporting forms is described in MSC-MEPC.3/Circ.3 [5]. It shall be noted that a redesign work of the GISIS MCI module is currently on-going, with a new taxonomy described in MSC-MEPC.3/Circ.4/Rev.1 [18]. At the time of this writing, the redesigned MCI module was in its testing phase.

6.2.2.2 Data fields related to fires in ro-ro spaces

The fire casualty events are categorised as “Fire or explosion”.

The severity of casualties is categorised as “Very serious casualties”, “Serious casualties”, “Less serious casualties” or “Unspecified”, as defined in IMO regulations (refer to definitions of chapter 3 of this report).

The types of ships, related to the ro-ro ships considered in the LASH FIRE project, are categorised as “Passenger/Ro-Ro Cargo Ship” and “Ro-Ro Cargo Ship”. No dedicated ship category exists for vehicle carriers.

6.2.3 Reporting requirements and criteria

The reporting of marine accidents is mandatory under various international regulations [19]: UNCLOS, SOLAS, MARPOL, International Convention on Load Lines, MODU Code and Casualty Investigation Code.

The Casualty Investigation Code [4] requires every very serious marine casualty to be investigated by the flag state of a ship involved. The code also recommends an investigation of other marine casualties and incidents to be conducted by the flag state of a ship involved. This recommendation is given “if it is considered likely that it would provide information that could be used to prevent future accidents”.

According to the Casualty Investigation Code [4] as well as MSC-MEPC.3/Circ.4/Rev.1 [18], a marine safety investigation report should be submitted by the Member States to IMO through the GISIS MCI module for every very serious marine casualty. The marine safety investigation report is submitted in addition to the data required by IMO harmonised reporting procedures [18]. There is no mandatory reporting requirement for marine casualties other than very serious marine casualties or marine incidents. However, where there are important lessons to be learnt from casualties or incident, it is recommended to apply the same reporting process. In general, IMO strongly encourages Member States to report any casualty or incident and to feed the GISIS MCI module.

Reported cases to GISIS MCI module is generally limited to “investigated” cases, “notified” cases, i.e. with no further investigation, are not necessary reported to GISIS MCI module.

The reporting formats contained in MSC-MEPC.3/Circ.4/Rev.1 [18] have replaced the reporting forms contained in MSC-MEPC.3/Circ.3 [5]. They represent the taxonomy of the future GISIS MCI module.

6.3 European Maritime Safety Agency (EMSA) database – EMCIP

6.3.1 Retrieval of the database

EMSA provided an extract of the EMCIP database to the LASH FIRE consortium on 15 July 2020 in the format of several MS Excel, MS Word, pdf and jpg files and granted the authorisation to use the data for the purpose of the LASH FIRE project within the confidentiality required and with the strict limitation of its use to marine safety related objectives.

6.3.2 Presentation of the database

6.3.2.1 General

The EMCIP database is a web database (Figure 2). Two types of access exist: one public and one restricted (for authorised users). It is a centralised database for the European Union Member States to store and analyse information related to marine casualties and incidents [20]. The EMCIP database is connected to the GISIS MCI module, enabling automatic transfer of casualty data reported by the European Union and European Economic Area Member States [20]. The EMCIP database is administrated by EMSA.

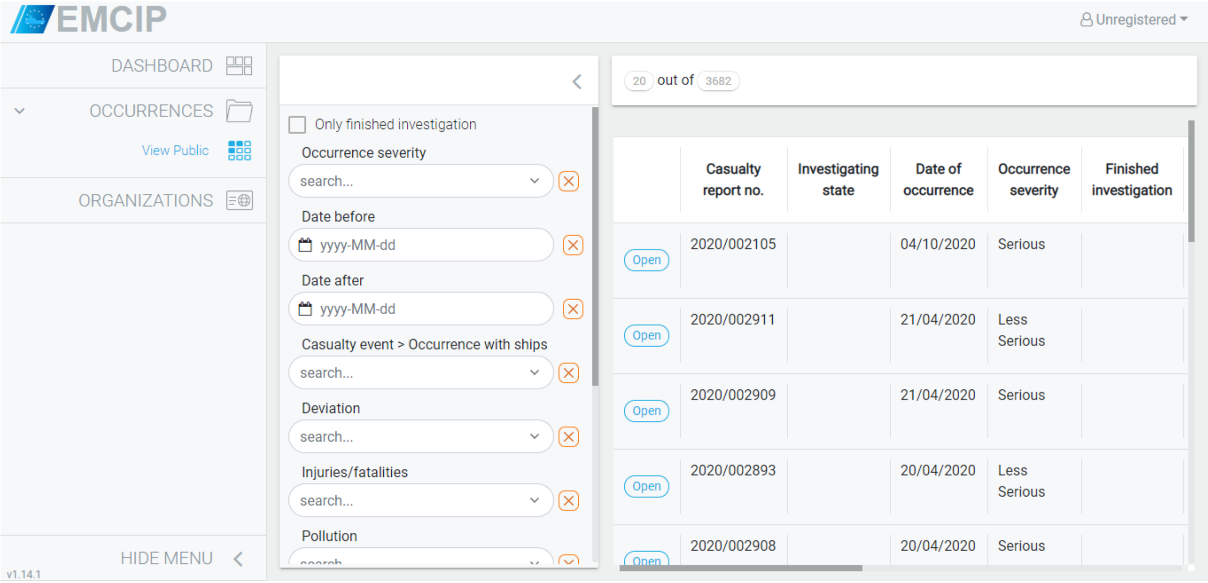

Figure 2. EMCIP – Screenshot. Source: [21].

The complete taxonomy of the EMCIP database can be found in [22], which is in line with MSC-MEPC.3/Circ.3 [5] used in the current GISIS MCI module and also with MSC-MEPC.3/Circ.4/Rev.1 [18] to be implemented in the redesigned GISIS MCI module.

6.3.2.2 Data fields related to fires in ro-ro spaces

The fire casualty events are categorised as "Fire/Explosion", defined as "an uncontrolled ignition of flammable chemicals and other materials on board of a ship:

- Fire is the uncontrolled process of combustion characterised by heat, smoke or flame, or any combination of these.
- Explosion is an uncontrolled release of energy which causes a pressure discontinuity or blast wave." [23]

The severity of casualties is categorised as "Very serious", "Serious", "Less serious" and "Marine incident", which correspond to the definitions contained in IMO regulations (refer to definitions of chapter 3 of this report).

The types of ships, related to the ro-ro ships considered in the LASH FIRE project, are categorised as "Passenger ship - Passenger and Ro-Ro cargo" and "Cargo ship - Solid Cargo - Ro-Ro Cargo". No dedicated ship category exists for vehicle carriers.

6.3.3 Reporting requirements and criteria

The EMCIP database was established based on the provisions of article 17 of the European Directive 2009/18/EC [24]. As reported in article 2.1 of the Directive, “1. This Directive shall apply to marine casualties and incidents that:

(a) involve ships flying the flag of one of the Member States;

(b) occur within Member States' territorial sea and internal waters as defined in UNCLOS; or

(c) involve other substantial interests of the Member States.”

Article 5 of the Directive provides the obligation of each Member State of the European Union to investigate very serious casualties. Every serious casualty shall be assessed in order to decide whether or not to undertake a safety investigation.

All data on marine casualties and incidents shall be stored in the EMCIP database, as defined by article 17 of the directive. As a minimum, the data reported to the EMCIP database shall contain the notification data as defined in Annex II of the Directive and the same data as requested by IMO regulations.

The reporting of data resulting from safety investigations in the EMCIP database has been mandatory since 17 June 2011.

6.4 European Maritime Safety Agency (EMSA) database – MARINFO

As reported in the FIRESAFE I study [11], the MARINFO database is “an application developed by EMSA which combines data from four different commercial databases (Lloyds List Intelligence, IHS Maritime & Trade, Clarksons Research Services and AXSMarine)”.

As the MARINFO database was the main source of information used for the FIRESAFE I and FIRESAFE II studies, it was deemed relevant to investigate the possibility to access the MARINFO database for the purpose of the LASH FIRE project. However, the retrieval of the MARINFO database was not possible in the context of the LASH FIRE project.

6.5 National databases

The Maritime Authorities Advisory Group (MAAG) consists of representatives of flag states and authorities. The formal establishment process of the MAAG was completed in March 2020 through a memorandum of understanding between the representatives and the LASH FIRE consortium.

As part of MAAG, four flag states agreed to share casualty related information with the LASH FIRE consortium: the Netherlands, Norway, Panama and the United Kingdom.

6.5.1 The Netherlands

6.5.1.1 Retrieval of data

According to the Dutch Safety Board (DSB), there is no occurrence of fire accidents on Dutch ro-ro ships (cargo/passenger).

6.5.1.2 Reporting requirements and criteria

The accidents involving the Dutch sea-going vessels must be reported to the Netherlands Shipping Inspectorate (ILT) by phone [25] and to the Dutch Safety Board (DSB). The DSB is required to investigate the very serious marine casualties and needs to assess serious marine casualties. "The ILT keeps record of every reported accident/casualty. All reported accidents/casualties/injuries are transferred to the accident investigation department. All accidents and casualties are reported towards the DSB immediately when they are reported to the ILT. The DSB is filling the EMCIP database of EMSA, reports are automatically transferred to the IMO GISIS module."

The ILT does not conduct safety investigations. Conducting safety investigations into the shipping accidents and injuries sustained by the occupants of sea-going vessels is the task of the DSB. The DSB requires the serious accidents to be investigated. The DSB can also conduct an investigation if a less serious accident has occurred [25].

6.5.2 Norway

6.5.2.1 Retrieval of data

Two datasets were downloaded from the Norwegian Maritime Authority's (NMA) website [26]:

- Dataset of accidents involving injuries to persons from 1981 to 2019: *personskader-1981-2019.xlsx*; and
- Dataset of accidents involving commercial vessels and recreational crafts from 1981 to 2019: *ulykker-1981-2019.xlsx*.

6.5.2.2 Presentation of the dataset

The dataset is in Norwegian. Some fields were translated to English by the LASH FIRE consortium for the purpose of the assessment. The dataset *ulykker-1981-2019.xlsx* was mainly assessed.

The fire casualty events (column "ulykketype") are categorised as "Brann/Eksplosjon" (Fire/Explosion).

The severity of casualties (column "konsekvens") is categorised as "Svært alvorlig sjøulykke"/Very serious marine casualty, "Alvorlig ulykke"/Serious casualty, "Sjøulykke"/Marine casualty, "Mindre alvorlig sjøulykke"/Less serious marine casualty, "Sjøhendelse"/Marine incident, "Annen hendelse"/Other incident and "Andre hendelser"/Other events.

The types of ships (column "Type fartøy"), related to the ro-ro ships considered in LASH FIRE project, are categorised as "3D: Bil"/Car, "4E: Roll-on/Roll-off", "4I: Spesialbygd bilskip"/Tailor-made car ship, "5C: Bil"/Car, "5C1: Bilferge"/Car ferry and "5C2: Ro/Ro-passasjerferge"/Ro-ro passenger ship.

6.5.2.3 Reporting requirements and criteria

The incidents and accidents related to the operation of vessels must be notified and reported to the NMA or other relevant authority [26]. The very serious marine casualties, marine casualties and serious casualties with a vessel shall be reported to the NMA within 72 hours by filling in the NMA form KS-0197 Maritime casualty reporting - Ship and personnel.

The Accident Investigation Board Norway (AIBN) is the authority in charge of marine safety investigations. They are also in charge of registering accident data in the EMCIP database.

6.5.3 Panama

The Panamanian flag state agreed to share information on a case-by-case basis with the LASH FIRE consortium to be used solely for the purpose of this project. All information shared by Panama must be treated confidentiality and its use is strictly limited to carry out analysis related to maritime safety matters. The Panamanian flag state shared three accident investigation reports and released statements of not to assign fault or determine civil or criminal liability to any party involved in those reports because they were not created to be used in legal, disciplinary, or other proceedings.

6.5.4 The United Kingdom

6.5.4.1 Retrieval of data

So far, the Marine Accident Investigation Branch (MAIB) has conducted two investigations related to fires originating in ro-ro spaces: one serious marine casualty and one less serious marine casualty. Their full investigation reports can be found on the MAIB website [27]. Each year, the MAIB receives on average between two and three reports of other than serious or very serious marine fire casualties breaking out on ro-ro ferry vehicle decks. It was not possible to provide more details because MAIB is currently developing a new database.

6.5.4.2 Reporting requirements and criteria

It is a national legal requirement that any marine casualty or marine incident is notified to the MAIB by the quickest means possible. The accidents can be notified by phone or by submitting electronically the MAIB's accident report form. Then, the MAIB can decide whether to investigate the accident without delay. The regulations for casualty reporting are:

- SI 2012 No. 1743 - The Merchant Shipping (Accident Reporting and Investigation) Regulations 2012; and
- MGN 594 - Marine guidance: explaining the obligations under the above regulations.

The MAIB conducts the investigation of marine accidents involving UK vessels worldwide and all vessels in UK territorial waters.

6.6 Port State Control (PSC) databases

6.6.1 Generalities about Port State Control (PSC)

PSC is the inspection of foreign ships in national ports for the purpose of verifying that the competency of the master and officers on board, and the condition of the ship and its equipment, comply with the requirements of international conventions and that the vessel is manned and operated in compliance with applicable international law. The regime carrying out the PSC has the authority to board any vessel to verify compliance. The inspection process consists of a check of the documentation combined with a condition survey of the vessel.

The main objective of the PSC is to establish a "safety net" in order to find and reduce the number of substandard ships. To make sure that substandard ships will not escape the "safety net", it must have a worldwide coverage ensured by the various PSC regimes or memoranda of understanding (MoU). The various PSC regimes around the world implement harmonised procedures for inspection, detention, training, etc. and exchange information on ships and inspections in order to tighten the "safety net".

Each year, PSC regimes perform a large number of inspections, e.g. annually more than 17 000 in the ports included in the Paris MoU. Each PSC regime have developed their own procedures and guidelines for targeting ships for inspection. During an inspection, the PSC Officer (PSCO) may identify one or more deficiencies and include these in the PSC inspection report. Each deficiency has a unique code. Each code corresponds to a particular defective item, e.g. fire detection, lifeboats, etc.

6.6.2 Attempt to gain access to PSC data

In the past, attempts to investigate a potential link between PSC inspection reports and general ship safety have been carried out. In particular, Knapp (2007) [28] performed a detailed investigation on the effect of PSC inspection on the rate of casualties by correlating deficiencies and casualties. Following Knapp, the casualty rate of both categories, i.e. inspected and not inspected, was roughly the same considering all reports but for very serious casualties a positive effect of PSC inspection was found.

In the context of LASH FIRE, it was deemed very interesting to investigate the potential correlation between PSC inspection reports and the occurrence of casualties. PSC inspections have economic consequences by binding human and time resources. All things considered, if a link is found, PSC inspections could be considered in a risk model as a risk control measure and could be assessed as regards to their associated risk reduction related to their cost.

A selection of inspection results related to ro-ro ships found in the Paris MoU [29] and Equasis [30] online databases were reviewed. It was challenging to draw any conclusions relevant for the LASH FIRE project due to the following difficulties:

1. The granularity of the inspection databases was not sufficient for the purpose of LASH FIRE i.e. it was not possible to single out the deficiencies of system that would jeopardise the fire safety of ro-ro spaces.
2. Even if procedures, guidelines, trainings etc. exist, the result of an inspection may be subject to disparity in application of guidelines linked to the “random” nature of inspection. This factor may be handled when investigating a link between inspection results and ship general safety. But, when focuses on a particular type of casualty (e.g. fire) occurring in a particular space of the ship (e.g. ro-ro spaces), the analysis becomes much more complex and uncertain.
3. The Paris MoU and Equasis are online databases (at least the version that was reviewed). No functionality for data extraction in order to ease the post-processing of data was found. Therefore, a more detailed analysis of data would be time-consuming without the support of the Paris MoU Secretariat.

The aforementioned difficulties could have been overcome by exchanging with PSC MoU Secretariat and/or PSC local administrations. But no PSC MoUs were contacted. The narratives of the deficiencies themselves would not be found in PSC databases, but in PSC reports. In case of detention, PSC reports would obligatorily be sent to the RO/Class of the vessel. Inspection reports without detention are kept in local PSC administrations and copies are on board vessels (for a period of 3 years).

Finally, and despite the interest on working on PSC inspection results, the LASH FIRE consortium decided to not extend the investigation further. This decision was motivated because of the uncertainty of the outcomes as regards to the additional resources to be engaged in this work.

6.7 Ship operators' databases

6.7.1 Retrieval of the databases

Very serious marine casualties shall be reported to the authorities but reporting of "marine casualties other than very serious marine casualties" or "marine incidents", including "near misses", is not mandatory. This was recognized by the expert group on FSA: "The group noted that near miss data may facilitate the hazard and risk analysis; however, it was also noted that there exists no scheme on reporting near miss cases in the Organization" [31].

6.7.1.1 MOAG incident dataset

Information about incidents and near-misses is likely held only in the ship operators' Safety Management System (SMS). Therefore, the LASH FIRE consortium inquired five ship operator representatives from the Maritime Operators Advisory Group (MOAG) to gain access to any incidents or near-misses related information for ro-ro spaces held in their SMS. It was agreed that the data provided by operators would be anonymized and aggregated before diffusion to the LASH FIRE partners. For this purpose, a template in MS Excel format was agreed by the ship operators (Figure 3).

Summary of fire related incidents on ro-ro decks

Incident Date Year	Incident Log	Type	Sister Vessels	Hours Sailed Per Year	Miles Sailed PA	Size	Event	Incident Description/Fault	Severity	Investigation Report/ Firefighting Equipment Used	Remarks/Damage Provided by Operator
	Events to be anonomyous	Ro-Pax Ro-Ro Con-Ro Vehicle	Which Vessels are Sister Ships?	(Hours sailed by the ship involved in the incident	(Miles sailed per annum by the ship involved in the incident	Lane Metres (Ro-Ro) CEU (Vehicle)	Smoke Fire Explosion Fire Risk	As provided by the Operator	Very Serious Serious Marine Incident /Near Miss	As provided by the Operator	IMO MSC-MEPC3 /CIRC 4 rev Annex Page 14 Table 5 & MSC-MEPC.7/CIRC.7 categories and definitions used for severity of incidents.

Figure 3. Template for ship operators' incidents/near-misses related information for ro-ro spaces.

The final version of the Excel file with consolidated data from the ship operators was established on 21 May 2020.

6.7.1.2 ForeSea dataset

In addition to data provided by the ship operators, an extract from the ForeSea database was provided on 12 June 2020 by one of the ForeSea contributors (also a member of the MOAG). The extract was consolidated and anonymised based on the template elaborated by the MOAG ship operators.

As per the ForeSea website [32], "ForeSea is an information system for accidents, incidents / 'near misses' and non-conformities at sea. The system is designed and used by the shipping industry in Sweden and Finland."

6.7.2 Presentation of the databases

6.7.2.1 MOAG incident dataset

The data transmitted by the ship operators are related to:

- 107 events that could have resulted or that have resulted in a fire/explosion ("Fire" or "Explosion") or emission of smoke ("Smoke") in ro-ro spaces, as well as events that could have jeopardised the fire safety ("Fire Risk") in ro-ro spaces;
- Almost all of the 107 events were marine incidents or near-misses;
- Ro-ro passenger ships, ro-ro cargo ships and vehicle carriers; and

- A time period from January 2009 to May 2020.

For each event, information related to the date of the event, hours and miles sailed per year by the ship which sustained the event, size of the ship, description of the event, fire-fighting actions taken, damage sustained to the ship and/or cargo and other valuable information were provided (wherever possible) in relation to that particular event.

6.7.2.2 ForeSea dataset

The extracted data from the ForeSea database are related to:

- 35 events that could have resulted or that have resulted in a fire/explosion (“Fire” or “Explosion”) or emission of smoke (“Smoke”) in ro-ro spaces, as well as events that could have jeopardised the fire safety (“Fire Risk”) in ro-ro spaces;
- Almost all of the 35 events were marine incidents or near-misses;
- Ro-ro passenger ships and ro-ro cargo ships; and
- A time period from October 1999 to April 2016.

6.7.3 Reporting requirements and criteria

6.7.3.1 MOAG

ISM Code [33] Section 9 requires: “9.1 The SMS should include procedures ensuring that non-conformities, accidents and hazardous situations are reported to the company, investigated and analysed with the objective of improving safety and pollution prevention.”

More specific to a near-miss, Annex of MSC-MEPC.7/Circ.7 “Guidance on near miss reporting” [6] recommends: “1.1 Companies should investigate near-misses as a regulatory requirement under the ‘Hazardous Occurrences’ part of the ISM Code. Aside from the fact that near-miss reporting is a requirement, it also makes good business and economic sense because it can improve vessel and crew performance and, in many cases, reduce costs. Investigating near-misses is an integral component of continuous improvement in safety management systems. This benefit can only be achieved when seafarers are assured that such reporting will not result in punitive measures. Learning the lessons from near-misses should help to improve safety performance since near-misses can share the same underlying causes as losses.”

6.7.3.2 ForeSea

As per the ForeSea website [32], “ForeSea collects reports from the person who is responsible of ISM at the shipping company and the reporting that is voluntary is registered anonymously in ForeSea's ‘experience bank’.”

6.8 Protection & Indemnity (P&I) Club databases

The P&I company The Swedish Club was contacted in order to retrieve marine casualty data. At the end of August 2020, no data was received. Therefore, this option was not further investigated in order not to delay the construction of WP04 database.

6.9 Accident investigation reports

A set of 26 public accident investigation reports related to fires originating in ro-ro spaces was retrieved from Flag States websites, accident investigation body websites, as well as from the online GISIS MCI module (with public access). The list of the available reports is provided in ANNEX A: List of public accident investigation reports.

6.10 Summary and conclusion of data collection

Mainly casualty related information databases were collected. The collection was a lengthy activity involving:

- Multiple actors;
- A lot of exchanges with database administrators in order to clarify the scope and content of the databases; and
- Administrative processes to grant authorisation of use of the data for the purpose of LASH FIRE.

The collection was delayed by the COVID-19 pandemic, which compelled the LASH FIRE consortium to extend the period for casualty data collection.

Finally, six different casualty and incident databases were collected:

- IHS database;
- GISIS MCI module (public access);
- EMCIP database;
- Norway database;
- Ship operators incident dataset (MOAG); and
- ForeSea dataset.

Table 1 provides a summary of the main characteristics of each of the collected databases.

In general, EMCIP database was found to be the most comprehensive database with the higher number of data fields. The version of GISIS MCI module, which was used for this study, was the public access version with the old taxonomy. The redesigned MCI module with the new taxonomy was not used and, thereby, not assessed.

Table 1. Summary of collected databases

	IHS	GISIS MCI (public access)	EMCIP	Norway database	Ship operators incident database (dataset collected)	ForeSea (dataset collected)
Type(1)	Traditional / Commercial	Alternative	Alternative	Alternative	Alternative	Alternative
Administrator	IHS Maritime & Trade	IMO	EMSA	NMA	Shipping companies (MOAG)	IRIS
Source of information for administrator	Various sources of information	IMO Member States	EU Member States	Ship masters and shipping companies	Shipping companies (MOAG)	Shipping companies (Sweden and Finland)
Reporting criteria based on severity	N/A	Mandatory = very serious marine casualties Recommended = other casualties and incidents	Mandatory = very serious marine casualties and serious casualties(2) but all marine casualties and incidents shall be notified	Mandatory = very serious marine casualties, marine casualties and serious casualties with a vessel	Mandatory = accidents and hazardous situations	Volunteer
Severity definition	As defined by IHS	As defined by IMO	As defined by IMO	As defined by IMO	As defined by IMO	As defined by IMO
Severity population(3)	N/A	Mostly populated by marine casualties	Marine casualties and incidents	*Not assessed in this study*	Marine incidents including near-misses	Marine incidents including near-misses
Fleet coverage	World fleet	World fleet	EU Member States ships in the World, foreign ships in EU Member States waters and ships involving interests of EU Member States in the World	Norwegian ships in the World and foreign ships in Norwegian waters	MOAG shipping companies' ships in the World	Swedish shipping companies' ships in the World
Time period	-	-	Since June 2011	Since 1981	-	-
Number of fields	54	32(4)	> 100	31	13	13
Accident investigation reports available?	No	Yes	Yes	No	No	No
Language	English	English	English	Norwegian	English	English

(1) The field "Type" aims at differentiating the "traditional" casualty database used in most of FSA studies [1] with the alternative ones investigated by the LASH FIRE consortium.

(2) Submitted to the decision of the investigative body.

(3) The field "Severity population" aims at providing an appraisal on the type of casualty severity mostly found in the database (type of severity as defined by IMO).

(4) 32 represents the number of fields of Annex 1.

NB! The information reported in Table 1 reflects the data collected and restricted to the interest of LASH FIRE. The contents of the aforementioned databases may be wider.

7 Methodology for WP04 database construction

Main author of the chapter: Matthieu Gadel, BV.

7.1 Introduction

One of the challenges in the FSA methodology is to quantify risk by relevant and reliable data. However, such public data are scarce due to lack of reporting and since data owners limit public access to detailed information, and the data is non-homogeneous, since the acquisition process is performed by different actors.

Assessing the quality of data is a key point when constructing a database for an intended purpose. This allows to assess the strengths, limitations and possible biases of available data, before continuing the process to construct the database with as relevant and reliable data as possible.

The current task requires a methodology based on data quality in order to build a reliable and homogenous database, which meets the importance of repeatability and transparency, as required by the IMO FSA Guidelines [3].

The following sections will provide a brief description of concepts of data quality and how they were applied to build the WP04 database. Finally, the general architecture of the WP04 database will be provided.

7.2 Data quality

Data quality can be difficult to characterise, even if it is a simple concept. The approach carried out in LASH FIRE is inspired by concepts defined in Solvency II Directive 2009/138/EC [34], which defines three criteria for the assessment of data quality:

- 'Complete': enough historical information is available to address risks and trends,
  - Sufficient historic information to assess experience,
  - Sufficient granularity of data to allow identification of:
    - Trends (time),
    - Behaviour of underlying risks (data coverage). This can be compared to the concept of homogeneity developed in the FSA methodology,
- 'Accurate': sufficient degree of confidence in the data,
  - Free from important mistakes, errors and omissions,
  - Coherent in time (old data, not representative of the problem, should not be considered),
  - Recording is performed timely and in a consistent manner,
  - Recognition of credibility through wide usage,
- 'Appropriate': the database provides comprehensive information to deal with the problem,
  - Suitable for the intended purpose,
  - No bias.

7.3 Flow chart of database construction

A process was set up to assess the data quality criteria described in the previous section (7.2) and to construct the WP04 database, as presented in the flow chart in Figure 4.

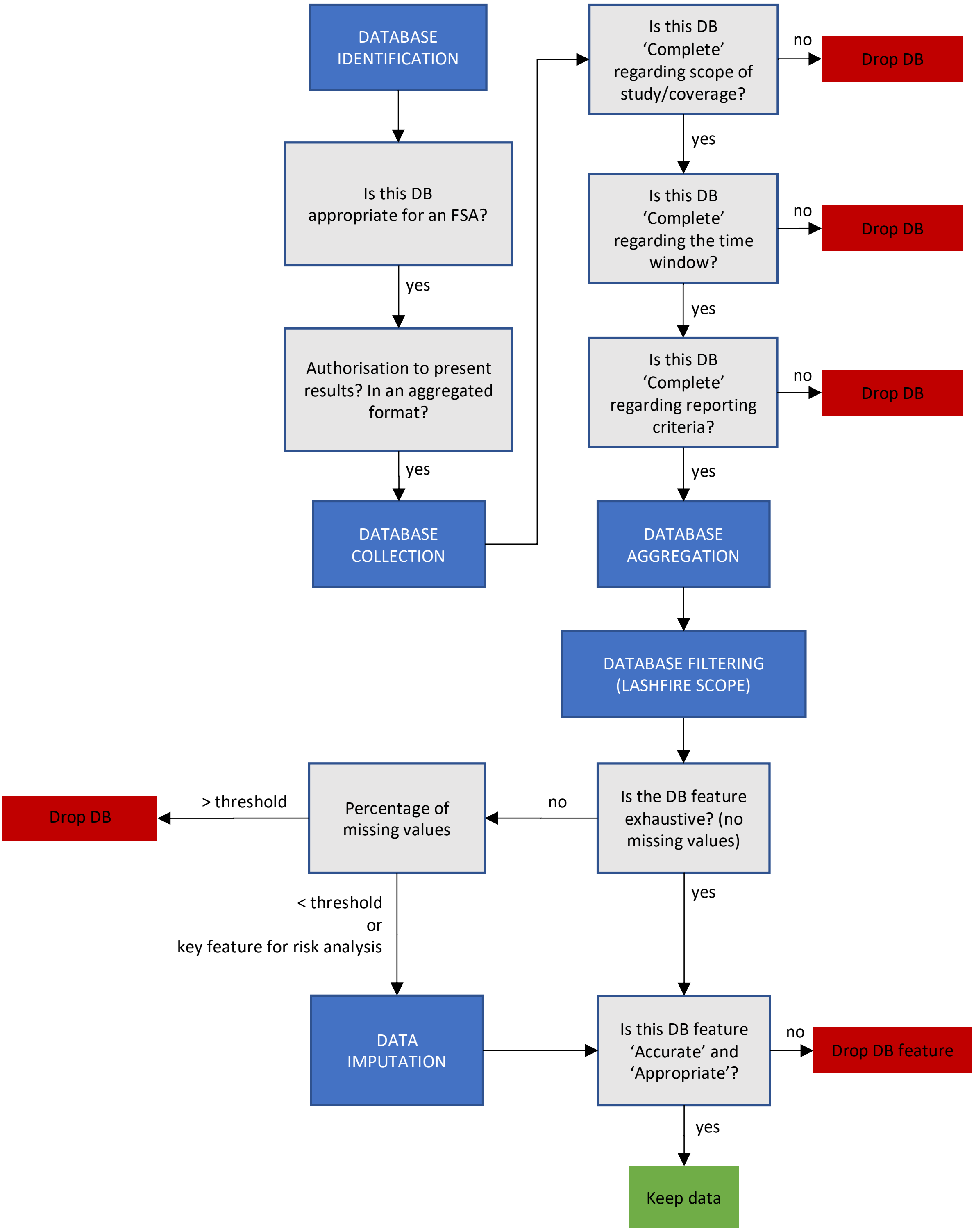

Figure 4. Flow chart of database construction.

7.4 Database architecture

Considering the relatively small amount of data to be handled and interdependent, all WP04 databases were set up in MS Excel format. The architecture of the data aggregation is illustrated in Figure 5.

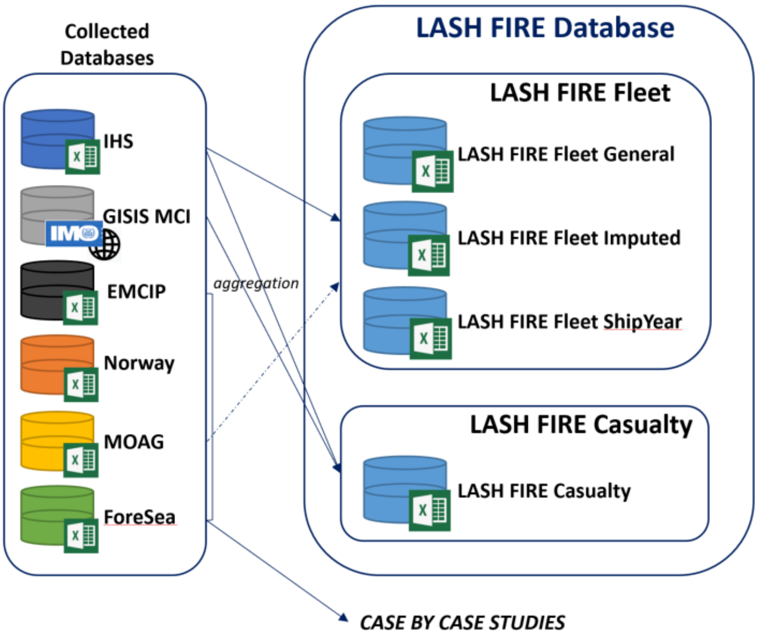

Figure 5. WP04 database architecture.

As illustrated in Figure 5, the WP04 database was composed of:

- WP04 Fleet database:
    - WP04 Fleet General database: ship level information with data from IHS Fleet database only. IMO Number is a primary key for this database.
    - WP04 Fleet Imputed database: ship level information for features with imputed data. IMO Number is a primary key for this database.
    - WP04 Fleet ShipYear database: ship level information with shipyears calculated from IHS ClassHistory database for all year of the time window. IMO Number is a primary key for this database.
- WP04 Casualty database: casualty level information with data from an aggregation of databases. An index is set as a primary key, where the pair (AccidentDate, IMO Number) defines a unique variable in the database.

In addition, an interactive world map with casualty information (Figure 6) was built and used internally for the casualty analysis.

Figure 6. Interactive world map used for casualty analysis.

8 WP04 Fleet database

Main author of the chapter: Matthieu Gadel, BV.

8.1 Introduction

This chapter describes the approach used to build the WP04 Fleet database. The data sources and criteria for the definition of the WP04 Fleet database for ro-ro passenger ships, ro-ro cargo ships and vehicle carriers are presented. The construction of the database, based on the methodology described in chapter 7, is detailed and the techniques used for imputation of missing values in key database features are presented.

8.2 Data sources

The IHS Fleet database was used as the main source of data for the WP04 Fleet General database. When key features were not available in this database, MOAG members' data were considered as an alternative source of data.

The IHS ClassHistory database was exploited for the construction of WP04 Fleet ShipYear database and to construct the additional features: "ShipCurrentlyIACS" and "ShipHasBeenIACS". The IHS ClassHistory database describes the history of a ship navigating with a given class society.

8.3 Scope of WP04 Fleet database

The FSA study focuses on ro-ro passenger ship, ro-ro cargo ship and vehicle carrier fleets constituted of non HSC (High-Speed Craft) SOLAS ships compliant with SOLAS 1974. Only ships which have been IACS-classed at least once during their life were considered, in order to minimise the effect of under-reporting (see section 8.3.5 below).

The filtering criteria used in the FIRESAFE studies [11] and [35] were used as a starting point for LASH FIRE. Those criteria were extended to ro-ro cargo and vehicle carrier fleets as they are based on general considerations (i.e. not specific to ro-ro passenger ships).

The LASH FIRE ro-ro passenger ship, ro-ro cargo ship and vehicle carrier fleets were composed of ships which are:

- Classed as ro-ro passenger ship, ro-ro cargo ship or vehicle carrier in the IHS database;
- Delivered on or after 01/01/1970;
- With a Gross Tonnage equal or greater than 5 000 GT;
- With a Froude number less than or equal to 0.5; and
- Classed or having been classed by an IACS member during their lifetime.

These criteria are described in detail in the following sections.

8.3.1 Ro-ro ship type

Ships classified as *Ro-Ro Cargo* or *Passenger/RoRo-Cargo* in feature 'ShipTypeLevel3' of the IHS Ship database were considered (Table 2).

In order to build the most homogeneous fleet, the following values for the feature 'ShipTypeLevel5' were not included in the database (Table 2):

- *Passenger/Landing Craft* were not included in the study as they were not included in FIRESAFE (*"since the architecture and types of voyages of such ships are likely to be different from the two previous sub-types considered"* [11]*);*

- *Container/Ro-Ro Cargo Ship*: few of these ships were compliant with LASH FIRE criteria. Moreover, general arrangement and operations of this type of ship are closer to a container ship than to a ro-ro cargo ship; and
- *Rail Vehicles Carrier:* very few of these ships were compliant with LASH FIRE criteria. Cargo and cargo-specific operations of this type of ship are different from a typical vehicle carrier.

Table 2. IHS ship type included into the WP04 Fleet database

StatCode5	ShipTypeLevel5	ShipTypeLevel3	(%) of LASH FIRE fleet	LASH FIRE category	In WP04 DB (yes/no)
A35B2RV	Vehicles Carrier	Ro-Ro Cargo	100%	Vehicle Carrier	yes
A35A2RR	Ro-Ro Cargo Ship	Ro-Ro Cargo	100%	Ro-ro cargo ship	yes
A36A2PR	Passenger/Ro-Ro Ship (Vehicles)	Passenger/Ro-Ro Cargo	91.6%	Ro-ro passenger ship	yes
A36A2PT	Passenger/Ro-Ro Ship (Vehicles/Rail)	Passenger/Ro-Ro Cargo	8.4%	Ro-ro passenger ship	yes
A35A2RT	Rail Vehicles Carrier	Ro-Ro Cargo	1.8%	Vehicle Carrier	no
A35C2RC	Container/Ro-Ro Cargo Ship	Ro-Ro Cargo	1.4%	Ro-ro cargo ship	no
A35D2RL	Landing Craft	Ro-Ro Cargo	0%	Ro-ro cargo ship	no
A36B2PL	Passenger/Landing Craft	Passenger/Ro-Ro Cargo	0%	Ro-ro passenger ship	no

8.3.2 Delivery date

Ships with a delivery date on or after 1970 was included in LASH FIRE (same approach as FIRESAFE II [35]).

8.3.3 Gross tonnage

Ships with a gross tonnage above or equal to 5 000 GT were included in WP04.

Only SOLAS compliant ships were considered in the scope of the current FSA. Thereby, domestic ships, which are not necessarily compliant with the SOLAS Convention, were excluded from the database (except European Domestic Class A, which are SOLAS compliant, based on Article 4 of the Directive 2009/45/EC).

In other FSA studies, a threshold of 1 000 GT is commonly used to separate domestic ships from international ships. WP04 studied different thresholds on a dataset of EU domestic and international ships provided by the EMSA and a threshold of 5 000 GT was considered as a more appropriate threshold to separate domestic and international ships. This threshold was therefore used in the WP04 database. Refer to ANNEX C: SOLAS vs non-SOLAS classification for demonstration and mathematical background.

8.3.4 Froude number

High Speed Craft (HSC) have been excluded from the study, as they have to comply with a specific regulation regarding fire protection. A ship is considered to be a HSC when the Froude number is higher than or equal to 0.5. The Froude (Fr) number is defined as:

$$Fr = \frac{v}{\sqrt{gL_{pp}}}$$

Where:

- v is the maximum speed of the ship (m/s).
- g = 9.81 m/s².
- L_{pp} is the Length between perpendiculars (taken at 0.9 LOA (length overall) if not available).

8.3.5 IACS-classed ship or which have been IACS-classed

Ships which have been classed by one of IACS members at least once during their lifetime are considered in LASH FIRE.

It is acknowledged that the maritime industry faces under-reporting of casualties [1], which in the context of LASH FIRE can lead to an underestimation of the risks. To address this problem, it is a common approach in FSAs to consider that casualty reporting is more accurate on-board IACS-classed ships. In order to minimise the effects of under-reporting on the fire ignition frequency, this frequency was calculated as the ratio of number of casualties occurring on board IACS-classed ships over the exposure time of the IACS-classed fleet.

The list of IACS members was taken regardless of the actual membership status over time (FIRESAFE approach [11]), i.e. IACS members at the time of the study:

- American Bureau of Shipping (ABS),
- Bureau Veritas (BV),
- China Classification Society (CC),
- Croatian Register of Shipping (CRS),
- Det Norske Veritas Germanisher Loyds (DNV GL),
- Indian Register of Shipping (IRS),
- Korean Register of Shipping (KR),
- Lloyd's Register (LR),
- Nippon Kaiji Kyokai (NK),
- Polish Register of Shipping (PRS),
- Registro Italiano Navale (RINA),
- Russian Maritime Register of Shipping (RS).

8.4 WP04 Fleet database construction

8.4.1 Database construction: identification and collection

The WP04 Fleet database was constructed based on data from the IHS Fleet database, without aggregation with other databases.

The IHS database has been widely used in other FSA studies. By experience, this database can be considered 'complete' for the task. A complete description of this database can be found in chapter 6.

8.4.2 Database construction: IHS Fleet additional features

This section presents how features were added to the Fleet General database.

The IHS database was filtered using the LASH FIRE fleet criteria.

Additional key features, present in unstructured text fields, were added to the database in structured numerical fields: 'Lanes', 'TotalPassengers' and 'CEU'. An additional feature 'ShipAge' was also calculated.

For ship length and ship speed, it was decided to perform the same approach as in FIRESAFE in order to obtain Froude numbers. Therefore, two fields were added to the database:

- 'LengthAggregate' built on the Length Between Perpendiculars (LPP) and if missing on the Length Overall (LOA); and
- 'SpeedAggregate' built on the service speed of the ship and if missing, on the maximum speed.

Feature exhaustiveness was studied through the evaluation of missing values.

The features with more than 10% of missing value were identified (Table 3). When those features were identified to be key parameters for the study, imputation techniques were used (see section 8.4.3).

Table 3. Assessment of percentage of missing values for key features

LASH FIRE category	Feature	% missing	Key feature for LASH FIRE
Ro-ro passenger ship	Crew	44.7%	No
	L lanes	21.5%	Yes (imputed)
	Total Passengers	1.7%	Yes (imputed)
Ro-ro cargo ship	Crew	45.6%	No
	L lanes	7.4%	Yes (imputed)
Vehicle carrier	Crew	75.9%	No
	CEU	5.1%	Yes (imputed)

Outliers were kept in the database and handled on case-by-case basis during model construction.

8.4.3 Database construction: missing value imputation

This section presents how the Fleet Imputed database was built with consideration of missing values.

Considering the relatively high amount of missing data and for the sake of reproducibility of the study, missing data were imputed through regression techniques.

It is to be noted that MOAG fleet information was added to WP04 Fleet database when missing in this database.

Formulas below are further developed in ANNEX D: Data imputation.

8.4.3.1 Ro-ro passenger ships: length of roro lanes and total passengers

For ro-ro passenger ships, 'Total Passengers' and 'L lanes' were identified as key features for the risk model development.

Considering the small number of missing values (1.7%) and that no clear correlation appears with other data, missing values for 'Total Passengers' were imputed as the mean of all 'Total Passengers' values:

$$Total\ Passengers_{missing} = \overline{TotalPassengers} = 1080$$

Missing ‘L lanes’ values were imputed as:

$$\begin{cases} L\ lanes_{missing} = 190 * GT_s - 210 * Pax_s + 300\ Lpp_s + 210 * B_s + \ 1300 \\ L\ lanes_{missing} = 100\ if\ L\ lanes_{missing}\ < 100 \end{cases}$$

Where features were standardised and defined as:

$$GT_s = (GrossTonnage - 19000)/10000$$

$$LPP_s = (LengthBetweenPerpendiculars - 140)/27$$

$$Pax_s = (Tota\ Passengers - 1100)/680$$

$$B_s = (BreadthMoulded - 23)/3.6$$

8.4.3.2 Ro-ro cargo ships: length of roro lanes

For ro-ro cargo ships, ‘L lanes’ was identified as a key feature for the risk model development.

Missing ‘L lanes’ values were imputed as:

$$L\ lanes_{missing} = (13 * GT_s + 4.7 * LPP_s - 8.8 * GT_s^2 + 41)^2$$

Where features are standardised and defined as:

$$GT_s = \frac{GrossTonnage - 1600}{11000}$$

$$LPP_s = \frac{LengthBetweenPerpendiculars - 150}{31}$$

$$GT_s^2 = \frac{GrossTonnage^2 - 3.9 * 10^8}{5.7 * 10^8}$$

8.4.3.3 Vehicle carrier: CEU

For vehicle carriers, ‘CEU’ was identified as key feature for the risk model development.

Missing ‘CEU’ values were imputed as:

$$CEU_{missing} = 0.11 * GT - 160$$

Where:

$$GT = GrossTonnage$$

8.4.4 Fleet ShipYear database and related additional features

This section presents how the Fleet ShipYear database was built.

8.4.4.1 Shipyears

For each ship in the LASH FIRE fleet, shipyears of ships navigating with an IACS class were calculated for each year of the time window. A dedicated Fleet ShipYear database was built with this information.

A python script was developed to process data from the IHS ClassHistory database, to a format more suited to LASH FIRE's needs. Indeed, IHS Class History provides data in a table format (Table 4) which makes direct processing difficult:

Table 4. Extract from IHS ClassHistory database

CurrentIndicator	EffectiveDate	Class	ClassIndicator	ClassCode
Historical	20170901	DNV-GL (VL)	Class contemplated	VL
Historical	20181001	DNV-GL (VL)	Classed	VL
Current	20181201	DNV-GL (VL)	Disclassed	VL
Historical	20181201	Registro Italiano Navale	Class contemplated	RI
Current	20181201	Registro Italiano Navale	Classed	RI

The Python class "Ship_History" was constructed with following attributes:

- h_start: 'DeliveryDate'; if missing 'DateOfBuild'.
- h_end: 'DeathDate'; if missing the ship is considered in service and the 'Current' date is set (01/01/2019 for LASH FIRE).
- df: IHS ClassHistory data for the ship. See above.
- IMO: 'LRIMOShipNo', IMO of the ship.
- Iacs_hist: interval of the ship navigating with IACS Class; for the above example, *Interval(20181001, 20190101).*
- Class_hist: dictionary of interval of navigation with the corresponding IACS class; for the example, *{'RI': Interval(20181201, 20200301), 'VL': Interval(20181001, 20181201)}.*

A dictionary of Class_History for all IHS fleet data was built for storage, with IMO Number as key.

A Python script was developed to process dictionary data and calculate shipyears for each ship in the LASH FIRE fleet.

8.4.4.2 Ship is currently IACS-classed / Ship has been IACS-classed

Two features were added to the Fleet General database in order to enable an easy access to the IACS status of ship:

- Ship has been IACS-classed: ships that have been classed by an IACS member class at least one time during their life; and
- Ship is currently IACS-classed: ship classed by an IACS member class the 01/01/2019.

8.4.5 Additional feature – ro-ro space distribution

This section presents how the Fleet Imputed database was built with consideration to ro-ro space distribution.

One of the ambitions in LASH FIRE is to construct a risk model based on the type of ro-ro space (and not based on the type of ship, as previous FSAs), aligned with the regulations which are based on the type of ro-ro space.

Ro-ro spaces are defined in three categories: closed ro-ro space, open ro-ro space and weather deck (refer to chapter 3 for definitions). Different techniques were studied on a dataset provided by MOAG members to provide an estimation of the distribution of these types of ro-ro spaces based on ship characteristics.

The approach used in LASH FIRE is described below, while the mathematical background is further elaborated in ANNEX E: Calculation of distribution of ro-ro spaces.

8.4.5.1.1 Ro-ro passenger ships

The following regression models were developed to define percentage of each type of ro-ro space given ship characteristics:

$$\begin{cases} p_{weather} = \begin{pmatrix} -0.62\ GT_s + 0.91\ Lane_s - 0.4\ Pax_s \\ +0.55\ GT_s.Pax_s - 0.64\ Lane_s.Pax_s - 0.18 \end{pmatrix} * 9.3 + 5.9 \quad \text{with} \quad 0 \leq p_{weather} \leq 100 \\ p_{open} = \begin{pmatrix} -0.77\ GT_s + 0.89\ Lane_s + 0.39\ Pax_s - \\ 0.64\ GT_s.Lane_s + 0.39\ Lane_s^2\ - 0.34\ Pax_s^2 + 0.38 \end{pmatrix} * 18 + 12 \quad \text{with} \quad 0 \leq p_{open} \leq 100 \\ p_{closed} = 100 - \ p_{weather} - p_{open} \end{cases}$$

Where features are standardised and defined as:

$$GT_s = (GrossTonnage - 23000)/12000$$

$$Lanes_s = (L\ lanes - 1600)/880$$

$$Pax_s = (Tota\ Passengers - 1100)/600$$

8.4.5.1.2 Ro-ro cargo ships and vehicle carriers

Vehicle carriers were considered to have 100% closed ro-ro spaces, based on expert judgement.

It should be noted that some small open ro-ro spaces and small weather decks, mostly storing containers, can be found on some vehicle carriers, but they are deemed a non-representative part of the world fleet.

The traditional approach based on the ignition frequency per ship was used for ro-ro cargo ships. The MOAG dataset available for the study was not representative of the world fleet of ro-ro cargo ships. Therefore, it was not deemed accurate to estimate the distribution of ro-ro space based on this dataset.

8.5 WP4 Fleet database: overview

Table 5 provides an overview of the general characteristics of the WP04 Fleet database. As the structure of the risk model is not finalised at this stage, all the data fields available in IHS have been included in the database (refer to ANNEX B: List of data fields – WP04 databases for the complete list of fields).

Table 5. Overview of WP04 Fleet database

Database Name	WP04 Fleet database
Time window	From 01/01/1970 to 01/01/2019
# Records	2886
Ro-ro passenger ships	884
Ro-ro cargo ships	834
Vehicle carriers	1168
Geographic coverage	Worldwide
# Total data fields	132
WP04 Fleet General	102
WP04 Fleet ShipYear	21
WP04 Fleet Imputed	9

9 WP04 Casualty database

Main author of the chapter: Matthieu Gadel, BV.

9.1 Introduction

This chapter describes the approach carried out to build the WP04 Casualty database. While the WP04 Fleet database is a “list” of all ro-ro ships compliant with the scope, providing their ship characteristics and their exposure time, the WP04 Casualty database is a “list” of all marine casualties compliant with the scope.

Data sources used and criteria for the definition of WP04 Casualty database for ro-ro passenger ships, ro-ro cargo ships and vehicle carriers are presented. The construction based on the methodology described in chapter 7 is detailed with discussion on data quality and data aggregation.

9.2 Data sources

Description of data collection is presented in chapter 6.

9.3 Scope of WP04 Casualty database

One of the goals in LASH FIRE is to investigate cost-effective measures to reduce the risk of fire in ro-ro spaces, when the ship is in operation.

The WP04 Casualty database was composed of casualties:

- Categorised as “Fire/Explosion (FX)”;
- On board ships verifying LASH FIRE fleet criteria (refer to chapter 8);
- With their Incident Date between 01/01/2002 and 01/01/2019 ;
- With their severity classed as “catastrophic”, “severe”, “significant” or “minor”;
- With their ignition located on Cargo Deck / Roro Space;
- On board IACS-classed ships at the time of the incident; and
- Not occurring on board ships performing repairs in shipyard.

All the criteria are discussed hereinafter.

9.3.1 Categorised as “Fire/Explosion (FX)”

Casualties with fire as the first event in the sequence of casualty occurrence have been considered in LASH FIRE. Data fields “Type of Casualty” were filtered on “Fire/Explosion (FX)”.

Casualties with fire as the second event, e.g. occurring after a collision, were investigated. Very few occurrences were although found in the databases and most were out of the scope of LASH FIRE (according to the bullet points defined in 9.3).

9.3.2 LASH FIRE fleet

Casualties on board ships complying with the LASH FIRE fleet characteristics were considered. The description of the LASH FIRE fleet is provided in chapter 8.

9.3.3 Time window

A time window of 01/01/2002-01/01/2019 was considered for the LASH FIRE study in order to constitute a homogeneous set of casualties with sufficient information to perform analysis and inference.

From an expert point of view, it is acknowledged that the rate of reporting has increased and the quality of reporting has improved after 2002, as an effect of the generalisation of the use of Internet. Moreover, there were no major changes in fire safety regulation since then.

9.3.4 Severity

Marine casualties with a severity classed as “catastrophic”, “severe”, “significant” or “minor” in MSC-MEPC.2/Circ.12 [3] have been considered.

The definitions of the severity of marine casualty are not yet normalised across the different databases used in the maritime industry. This can be a problem when the attempt is to build a homogeneous database by aggregating databases with different reporting criteria based on the severity of casualties.

The IMO severity classification is defined in MSC.255(84) [4], MSC-MEPC.3/Circ.3 [5] or MSC.MEC.7/Circ.7 [6] and is based on the effects of the casualty on human, ship or the environment. The exact definitions are presented in chapter 3.

For commercial databases, the definition of severity may be based on other considerations, for example operational. Taking IHS as an example of a commercial database, the definition of the severity of Fire/Explosion casualties is based on operational considerations and described as:

> *“Fire/Explosion - All fire/explosion incidents to be recorded regardless of severity.*
>
> - *If the damage caused by the fire/explosion is sufficient to disable the vessel so that it requires tug assistance to reach port, or if it catches fire in port and the damage requires significant repairs before the vessel continues trading the casualty will be classed as **Serious**.*
> - *If the damage is minor and the vessel can be quickly returned to service without significant repairs (e.g. cargo fires) the casualty will be classed as **Non-Serious**.”*

A proposition of comparison between the different severity definitions is presented below (Figure 7). This comparison was the basis for the approach adopted in LASH FIRE.

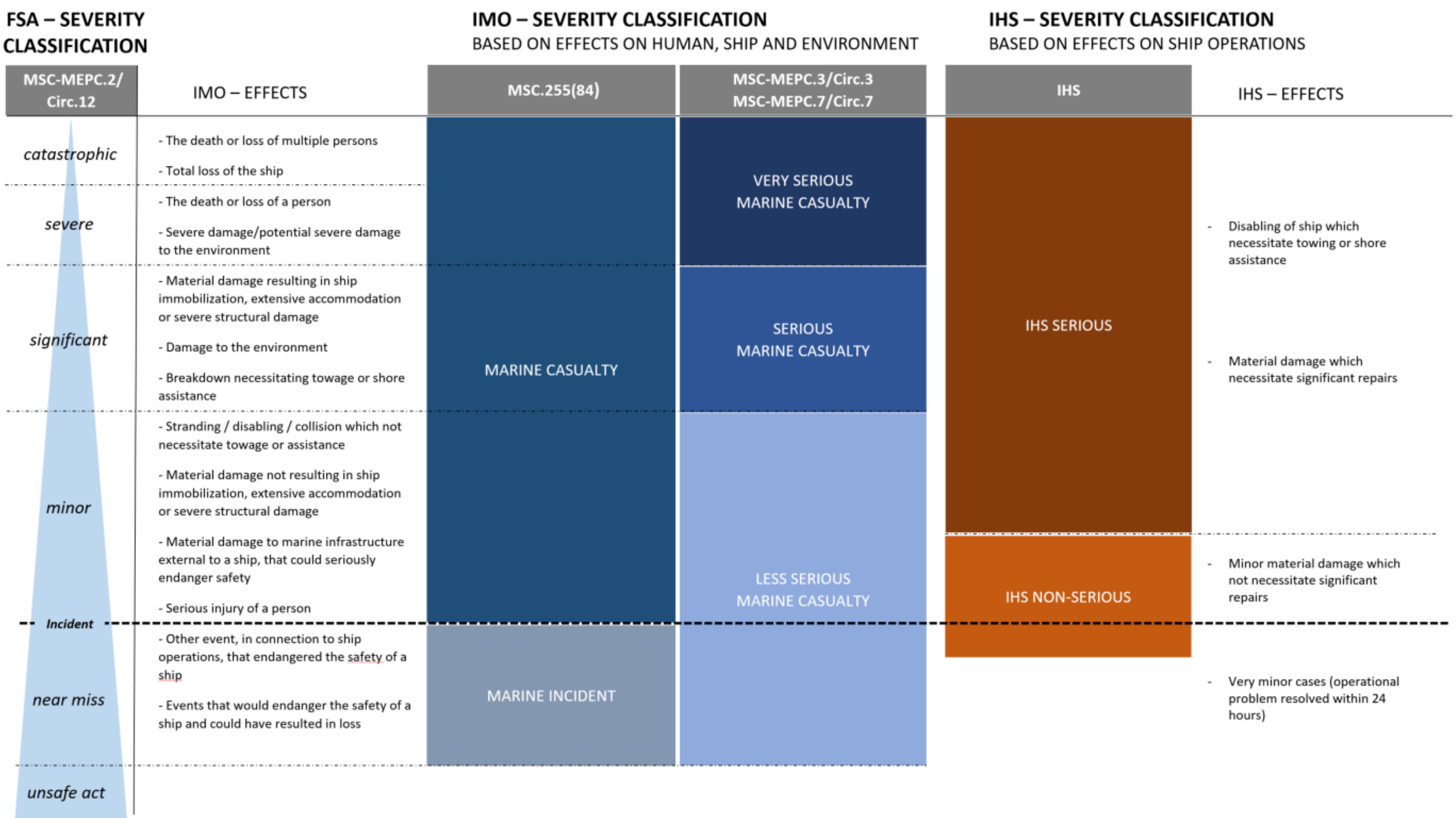

Figure 7. Comparison of different severity classifications.

Two levels of casualties are defined in LASH FIRE:

- LASH FIRE Serious: “IMO Very Serious” or “IMO Serious” or “IHS Serious”; and
- LASH FIRE Less Serious: “IHS Non-Serious” or “(IMO Less Serious) not (IHS Serious)”.

When the severity definition was inconsistent between the two databases (i.e. IHS Non-Serious and GISIS Serious), the LASH FIRE Serious was used. This was a means to tag inconsistencies. Very few such occurrences were found. Anyway, it will have no impact on the risk model because this is the combination of LASH FIRE Serious and Less Serious which is used to feed the risk model.

9.3.5 Fire location and cause

Only casualties occurring in roro spaces were considered in LASH FIRE. Casualties occurring on board ships performing repairs at shipyards were not considered, as they are dealing with different operational conditions and safety systems.

In most databases, the fire location and cause were accessible in an unstructured text field which was manually processed to build fields “Locations_LF” and “FireCause_LF”.

9.3.6 On board IACS-classed ships at the time of accident

Casualties on board IACS-classed ships at the time of the accident were considered.

It is a common FSA approach to consider that casualty reporting is more accurate on board IACS-classed ships. Therefore, in order to minimise the effect of under-reporting on the calculation of fire ignition frequency, this frequency has been calculated as the ratio of accidents occurring on board IACS-classed ships at time of incident, exclusively on shipyears of ships navigating with an IACS class.

9.4 WP04 Casualty database construction

9.4.1 Database construction: identification and collection

The quality of data was investigated for all collected databases:

- **‘Accurate’**
    - All databases are considered to be ‘accurate’ in general. Even if data are coming from external data sources, they can be considered ‘accurate’ as data providers are international organisations with data quality management process.
    - Some database fields have lots of missing values, those data fields were identified. Redundant features were aggregated in new fields in the WP04 database.
- **‘Complete’**
    - Time:
        - Given already performed FSA studies, a 17 years-historic period is considered acceptable to represent trends and behaviours.
        - As illustrated in Table 6, all databases presented can be considered ‘complete’ for the period of study except the EMCIP database for which reporting period started in 06/2011.

Table 6. Time period of collected databases

	IHS	GISIS MCI	EMCIP	Norway	MOAG	ForeSea
Time period	-	-	Since June 2011	-	-	-

- Coverage:
  - Geographic: the scope of LASH FIRE fleet is the worldwide fleet of ro-ro ships; however, some of the collected datasets, such as MOAG or EMCIP (Table 7), have smaller geographic coverage. Aggregating those data, regardless of their severity, may lead to a high bias and an overrepresentation of casualties occurring in those specific areas (as more casualties will be reported in those areas if criteria on severity reporting are different).

Table 7. Coverage of the collected databases

	IHS	GISIS MCI	EMCIP	Norway	MOAG	ForeSea
Geographic coverage	World fleet	World fleet	Worldwide EU MS ships All ships in EU MS waters All ships involving interests of EU MS	Worldwide Norwegian ships All ships in Norwegian waters	MOAG ships	Swedish shipping companies' ships

  - Reporting criteria: each database defines criteria for mandatory and recommenced reporting based on the severity of the incident. From an expert point of view, aggregating databases with different reporting criteria can lead to high bias if the database with the reporting criteria only requiring the most severe incidents has a wider geographic coverage than the database with a reporting criteria requiring both the most severe incidents and less severe ones. For example, it appears from Table 8 below that, for GISIS MCI (public access), only "very serious" casualties are mandatory, whereas, for the EMCIP database, "very serious" and "serious" casualties are mandatory. As GISIS has a wider geographic coverage than EMCIP, if we aggregate those two databases, "other than very serious marine casualties" from Europe or European fleet will be added to the database, whereas "other than very serious marine casualties" from other part of the world will not, creating a bias toward EU ships. However, EMCIP "very serious" casualties can be added to complete data provided by GISIS. As IHS and EMCIP do not have the same criteria, the same approach was not used.

Table 8. Reporting criteria and severity representativeness of the collected databases

	IHS	GISIS MCI	EMCIP	Norway	MOAG	ForeSea
Reporting criteria based on severity	N/A	**Mandatory** very serious casualties **Recommended** other casualties and incidents	**Mandatory** very serious casualties and serious casualties but all marine casualties and incidents shall be notified	**Mandatory** very serious casualties, serious casualties and serious casualties with a vessel	**Mandatory** accidents and hazardous situations	Volunteer
Severity population	N/A	Mostly casualties	Casualties and incidents	*Not assessed in this study*	Incidents including near-misses	Incidents including near-misses

- Severity definition: as illustrated in Table 9, the definition of severity may differ from one database to another, which may lead to a non-negligible bias. Equivalency for definition of severity have been studied in section 9.3.4 above.

Table 9. Severity definition of the collected databases

	IHS	GISIS MCI	EMCIP	Norway	MOAG	ForeSea
Severity definition	IHS	IMO	IMO	IMO	IMO	IMO

- **'Appropriate'**
  - All databases are 'Appropriate' for the problem and suitable for the purpose of an FSA, as they are databases dedicated to casualty reporting.

The WP04 Casualty database was built on aggregation of databases with a worldwide geographic coverage: IHS and GISIS MCI. The other databases with smaller geographic coverage were processed to complete missing values for mandatory reported values. The process of aggregation is summarized in Figure 8 below.

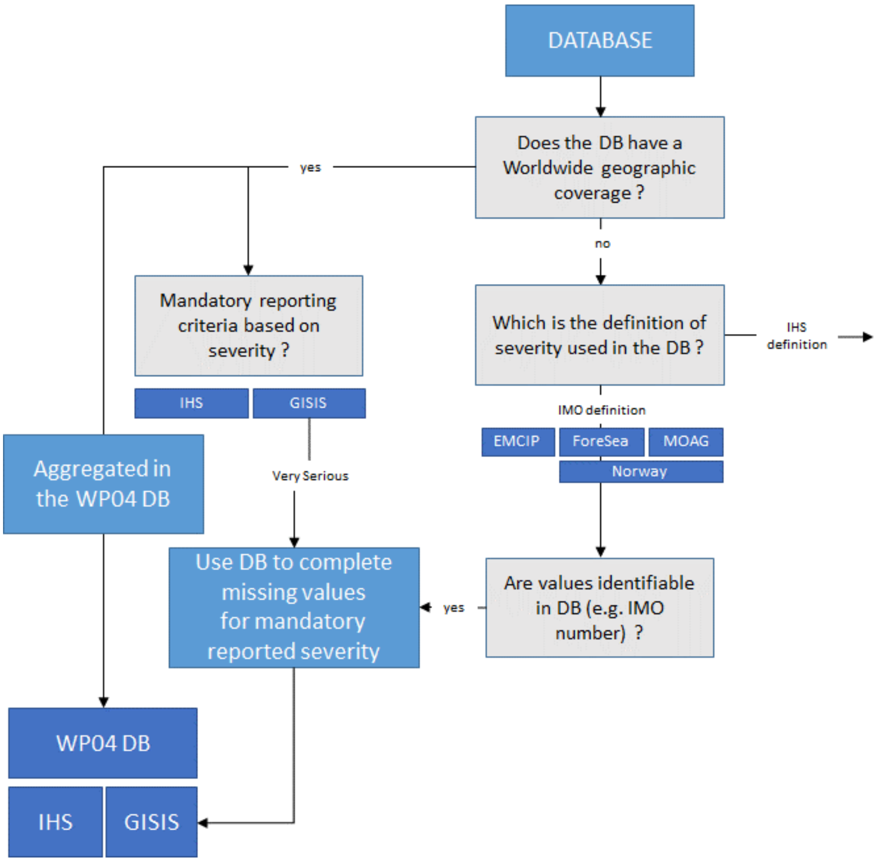

Figure 8. Process of database aggregation used for WP4 Casualty database construction.

9.4.2 Data aggregation

When possible, the records for very serious casualties in the EMCIP database, ForeSea dataset, MOAG dataset and Norway database were investigated to complete missing mandatory reported value in GISIS MCI (as IHS is not based on IMO definitions). No additional records of very serious casualties were found.

The redundant features between the IHS database and GISIS MCI were aggregated in one data field. When the two databases showed different values for a data, the value was manually extracted from the accident report and used in the WP04 Casualty database.

Unstructured text fields were manually processed to create additional key features in structured fields: fire location, type of ro-ro space location.

Most of the features available in casualty databases are deemed exhaustive. As the WP04 Casualty database is constructed before finalisation of the risk model, all features have been kept in the database.

Outliers were kept in the WP04 Casualty database.

9.5 WP04 Casualty database: overview

Table 10 provides an overview of the WP04 Casualty database (refer to ANNEX B: List of data fields – WP04 databases for the complete list of fields).

Table 10. Overview of WP04 Casualty database

Database Name	WP04 Casualty database
Time window	From 01/01/2000 to 01/01/2019
# Records	60
Ro-ro passenger ships	30
Ro-ro cargo ships	12
Vehicle carriers	18
Geographic coverage	Worldwide
# Total data fields	56

10 Fleet analysis

Main author of the chapter: Léon Lewandowski, BV.

This chapter aims at providing a general overview of the LASH FIRE fleet on which the FSA study is performed. In this analysis, ro-ro passenger ships, ro-ro cargo ships and vehicle carriers were separately considered, as ships of these three categories are different in terms of design, operations and regulation.

In this chapter, the key features for the analysis of the fleet were identified together with experts:

- Gross tonnage (GT);
- Length between perpendiculars (LPP);
- Age;
- Lane meter (LM) (for ro-ro passenger and ro-ro cargo ships);
- Car Equivalent Unit (CEU) (for vehicle carriers); and
- Passenger (capacity) (PAX) (for ro-ro passenger ships).

In order to facilitate reading, a colour code was applied throughout this study: ro-ro passenger ships are represented by blue, ro-ro cargo ships by red/orange and vehicle carriers by green.

10.1 Ro-ro passenger fleet analysis

10.1.1 General overview

The two tables below provide a general description for the ro-ro passenger ships composing the LASH FIRE fleet. Table 11 summarises key characteristics for all ro-ro passenger ships present in the fleet, while Table 12 describes ro-ro passenger ships from the fleet currently IACS-classed at the time of the study (01/01/2019).

Table 11. General description for all ro-ro passenger ships in the fleet

	Gross Tonnage (GT)	Length Between Perpendiculars (m)	Age (year)	Lane meter (m)	Total Passengers
Mean	18374	139	25	1368	1081
Standard deviation	12047	30	12	890	738
Min. value	5011	76	1	98	12
1st quartile (25%)	9080	116	15	610	550
Median (50%)	14088	136	27	1200	999
3rd quartile (75%)	25825	163	35	1950	1500
Max. value	75156	231	50	5566	4400

Table 12. General description for IACS-classed ro-ro passenger ships

	Gross Tonnage (GT)	Length Between Perpendiculars (m)	Age (year)	Lanes meters (m)	Total Passengers
Mean	20271	141	23	1622	1158
Standard deviation	12852	31	13	931	770
Min. value	5011	76	1	150	12
1st quartile (25%)	9792	116	13	900	590
Median (50%)	16966	142	22	1700	1000
3rd quartile (75%)	28789	169	33	2100	1586
Max. value	75156	231	50	5566	4400

In the following sections, some of the ship characteristics (gross tonnage, length between perpendiculars, passenger capacity, etc.) are further investigated. This includes e.g. plots for each of them, to more in detail describe the whole ro-ro passenger fleet as well as the IACS-classed ships.

10.1.2 Gross tonnage

Figure 9 shows the gross tonnage distribution with a comparison between IACS-classed ro-ro passenger ships and the whole ro-ro passenger fleet (the two graphs are superimposed, thus the “all ships” part corresponds to the addition of both light and dark part). It can be noticed that the likelihood for a ship to be classed by an IACS member increases with the gross tonnage (the vast majority of non IACS-classed ships have a gross tonnage below 30 000 GT).

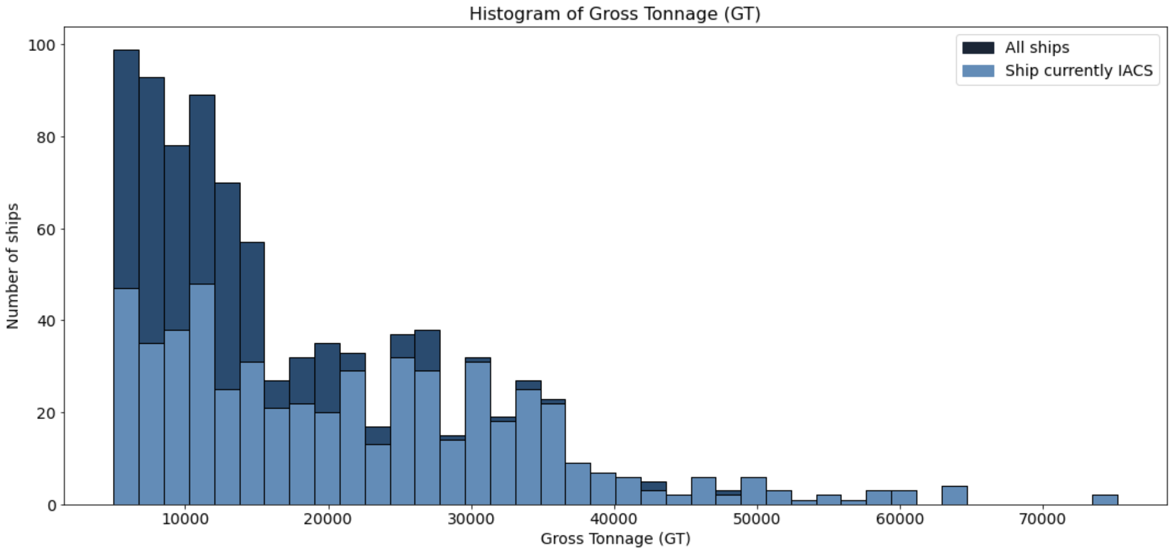

Figure 9. Gross tonnage distribution between IACS-classed ro-ro passenger ships and the whole ro-ro passenger fleet.

Figure 10 shows the evolution of median gross tonnage at delivery over the years, as well as the first quartile, third quartile (blue zone) and median moving average over 7 years (dashed line). The median moving average gross tonnage is increasing almost linearly from 1970 to 2005 (10 000 GT to 25 000 GT), then it starts decreasing.

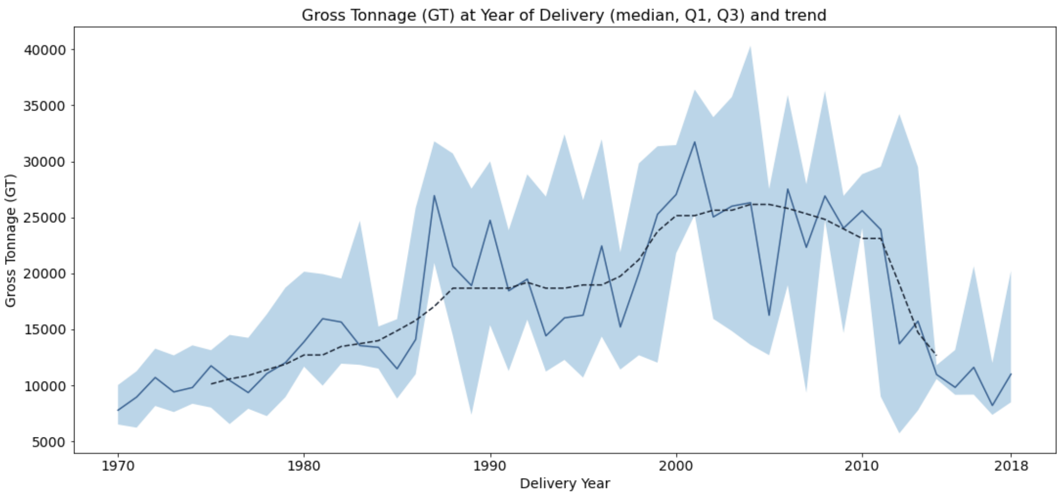

Figure 10. Evolution of median gross tonnage at delivery over the years – Ro-ro passenger ships.

10.1.3 Lane meter

Figure 11 shows the distribution of lane meter distribution for IACS-classed ro-ro passenger ships and the whole ro-ro passenger fleet. It is clearly noticeable that most of the ships have lane meters below 2 500 m (according to Table 11, 75% of the ro-ro passenger ships in the fleet have lane meters less than 1 785 m).

As for the gross tonnage above, the same trend on lane meter and IACS classification is observed (a ro-ro passenger ship with lane meters above 2 500 m is more likely to be classed by one of IACS' members).

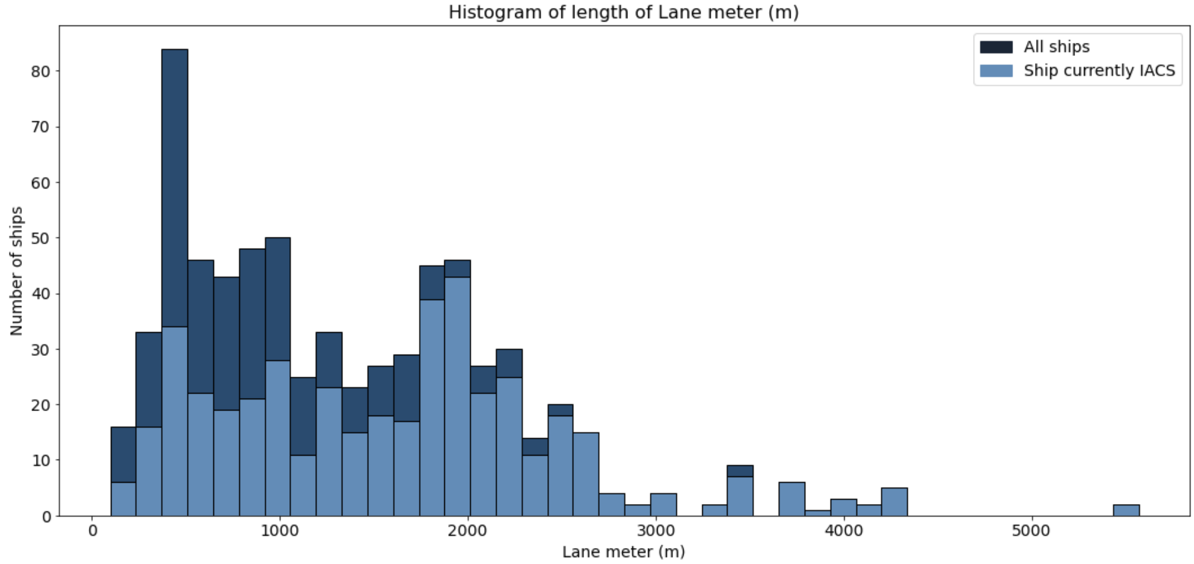

Figure 11. Lane meter distribution between IACS-classed ro-ro passenger ships and the whole ro-ro passenger fleet.

Figure 12 shows the median lane meter for ships per delivery year, as well as the first quartile, third quartile (blue zone) and median moving average over 7 years (dashed line). It is clear that over the year, the median number of lane meters is increasing almost linearly (the plot after 2010 must not be taken into account, due to too few data available).

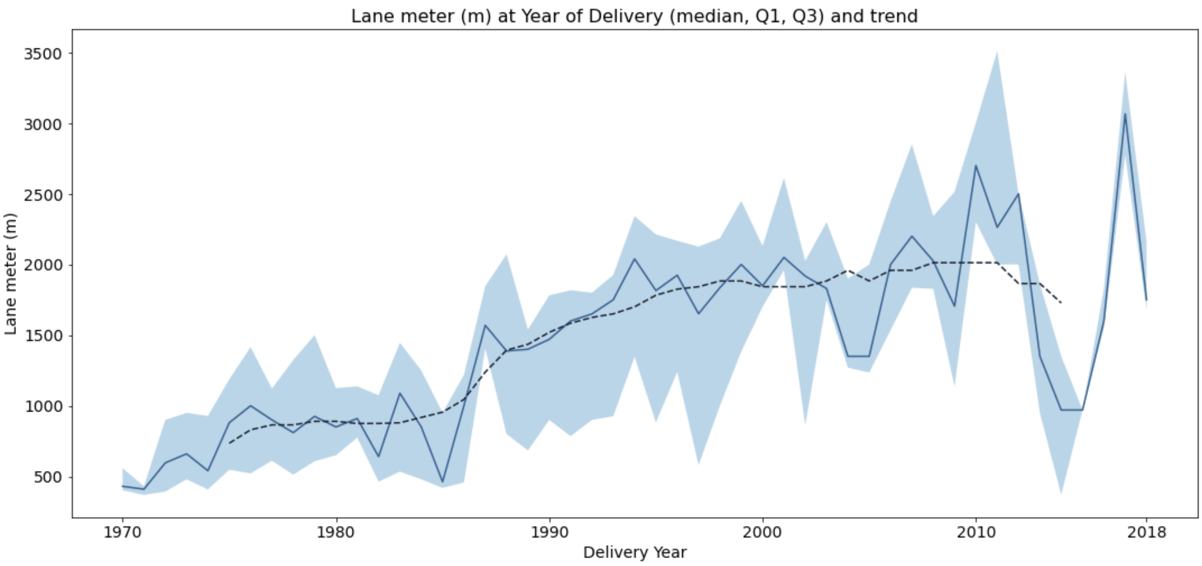

Figure 12. Evolution of median lane meter at delivery over the years – Ro-ro passenger ships.

10.1.4 Length between perpendiculars

Figure 13 shows the distribution of LPP for IACS-classed ro-ro passenger ships and the whole ro-ro passenger fleet. Unlike the two assumptions drawn on the number of gross tonnage and lane meter, IACS-classed and non IACS-classed ro-ro passenger ships seem to follow the same trend. This is confirmed by Table 11 and Table 12; the quartiles, min and max values, as well as the mean value are very close (Table 13). Figure 14 provides the median LPP for ships delivered each year, as well as the first quartile, third quartile (blue zone) and median moving average over 7 years (dashed line).

Table 13. Comparison between IACS-classed ships and the whole fleet about LPP – Ro-ro passenger ships

LPP (m)	IACS ro-pax ships	All ro-pax ships in the fleet
Mean	141	139
Standard deviation	31	30
Min. value	76	76
1st quartile (25%)	116	116
Median (50%)	142	136
3rd quartile (75%)	169	163
Max. value	231	231

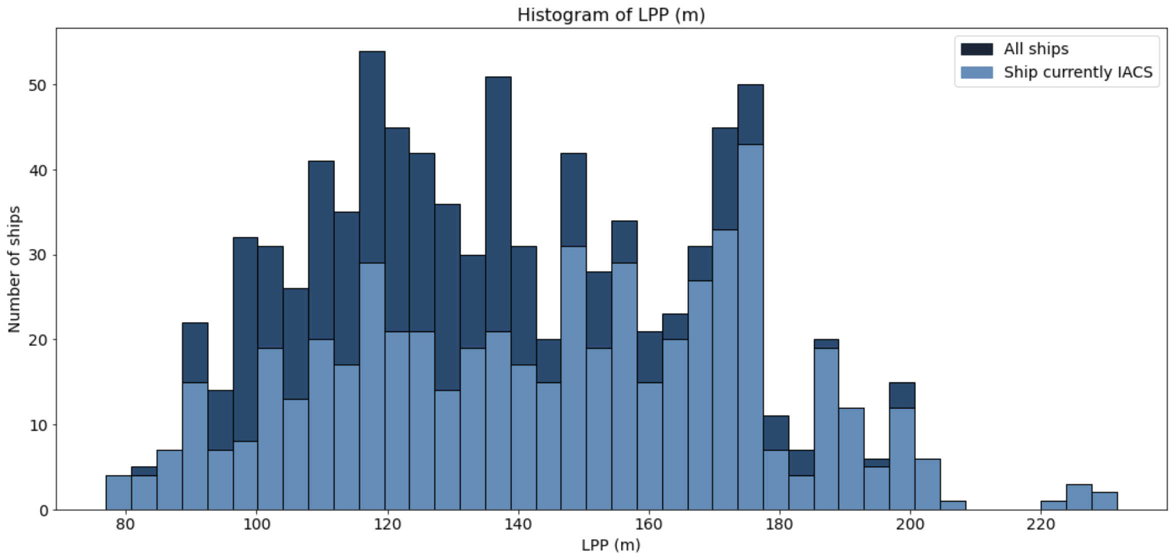

Figure 13. LPP distribution between IACS-classed ro-ro passenger ships and the whole ro-ro passenger fleet.

According to Figure 14, median LPP has been increasing until 2005, and since then it is globally decreasing. Considering the trend on gross tonnage, i.e. Figure 10, it is not unreasonable to assume a correlation between LPP and gross tonnage.

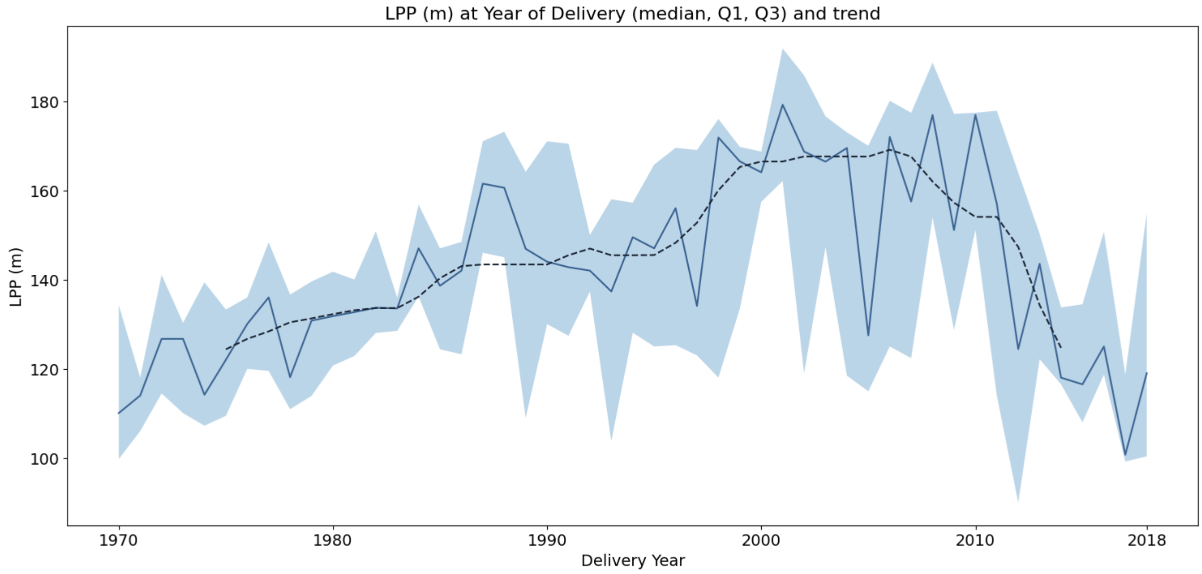

Figure 14. Evolution of median LPP at delivery over the years – Ro-ro passenger ships.

10.1.5 Passenger capacity

Figure 15 shows the distribution of passenger capacity in ro-ro passenger ships, for IACS-classed ships as well as in the LASH FIRE fleet. As above, quartiles, min and max values, as well as the mean value are very close for these two categories (Table 14). It is safe to assume that both IACS-classed and non IACS-classed ro-ro passenger ships share similarities in their passenger capacity.

Table 14. Comparison between IACS-classed ro-ro passenger ships and all ro-ro passenger ships of the fleet for passenger capacity – Ro-ro passenger ships

Passenger capacity	IACS ro-pax ships	All ro-pax ships in the fleet
Mean	1158	1081
Standard deviation	770	738
Min. value	12	12
1st quartile (25%)	590	550
Median (50%)	1000	999
3rd quartile (75%)	1586	1500
Max. value	4400	4400

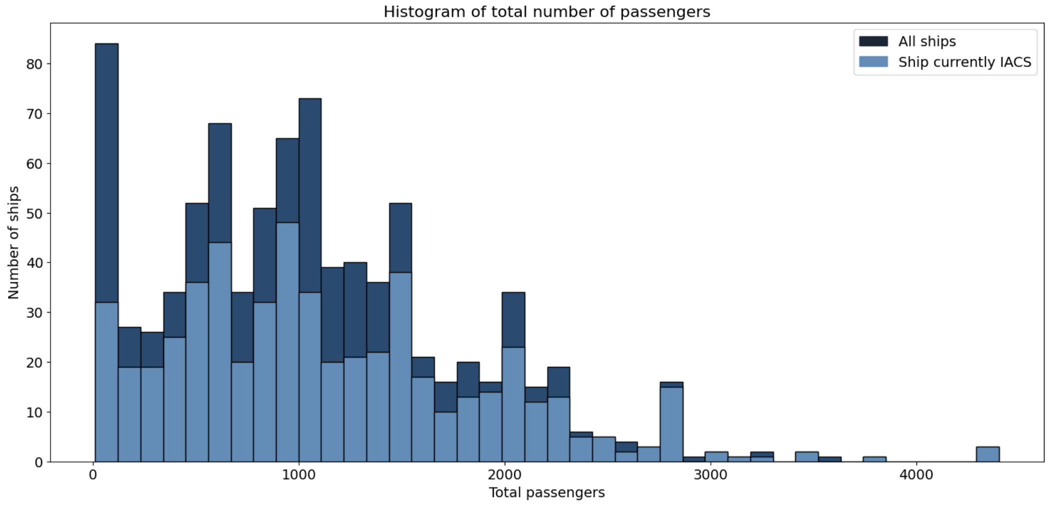

Figure 15. Passenger capacity distribution between IACS-classed ro-ro passenger ships and the whole ro-ro passenger fleet.

Figure 16 shows the median passenger capacity per ship delivery year, as well as the first quartile, third quartile (blue zone) and median moving average over 7 years (dashed line). By looking at the median moving average, it is clear that there is not any great change in passenger capacity during the studied years.

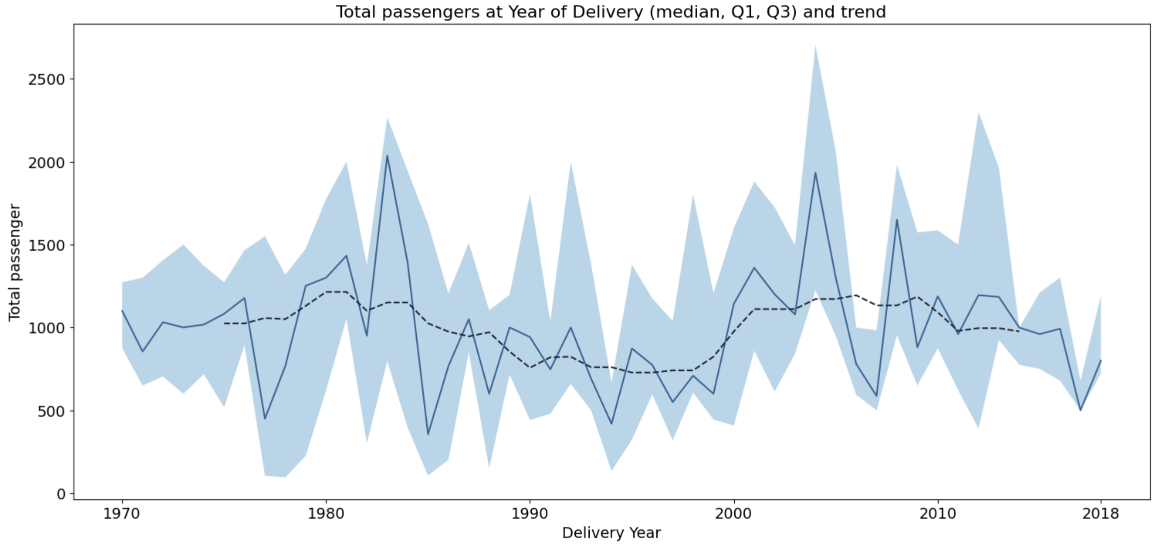

Figure 16. Evolution of median passenger capacity at delivery over the years – Ro-ro passenger ships.

10.2 Ro-ro passenger shipyears analysis

10.2.1 Delivery year and ship age

In this part, the link between the age of the ships and ship deliveries is investigated.

By comparing Figure 10 to Figure 17, which depicts the quantity of ships delivered each year (the dashed line stands for the moving average over seven years), it can be noticed that in the years 1983-1986, both fewer and smaller ro-ro passenger ships were produced and same thing happened in 2013.

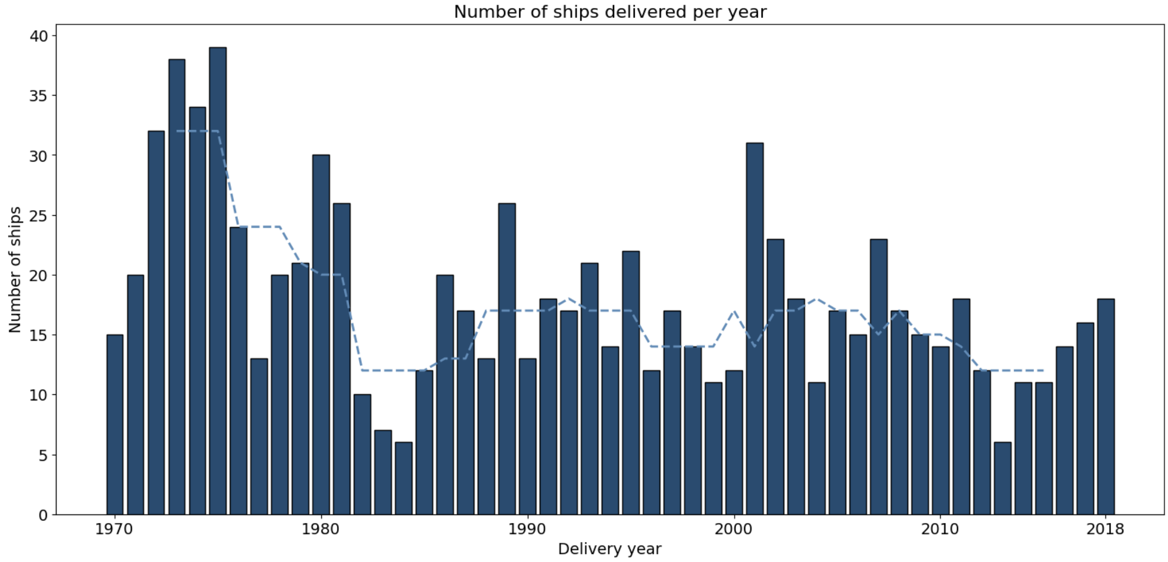

Figure 17. Number of ro-ro passenger ships delivered each year.

Figure 18 shows the distribution of ship ages on the 01/01/2019 or at the time the ship retired, with a distinction between IACS-classed ro-ro passenger ships and the whole ro-ro passenger fleet. The ages are rather well distributed amongst the IACS-classed ships.

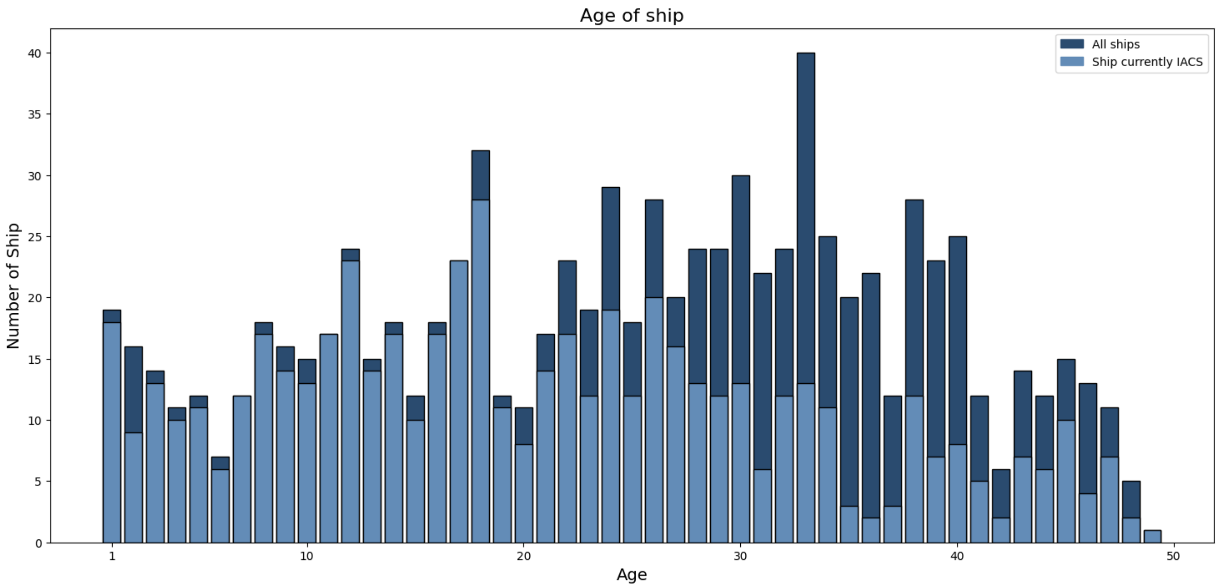

Figure 18. Ship ages distribution between IACS-classed ro-ro passenger ships and whole ro-ro passenger fleet.

The non IACS-classed ships in Figure 18 (dark part) have to be read carefully. If this graph is compared with Figure 17 (years of ship deliveries), the “peak” of 45 to 50 year-old ships that should be observed in Figure 18 due to the intense delivery between 1970 and 1975 is not present. These are ships that retired before 2019, at ages approximately between 25 and 40 years, and which are thus not considered IACS-classed in 2019.

In 2018, the average age of the fleet was 21.6 years old. The average life expectancy for the existing ro-ro passenger ships over the 2016-2018 period was estimated to 22.8 years. The life expectancy for newbuildings over the 2016-2018 period was estimated to 43.0 years. The life expectancy was estimated based on the United Kingdom Office for National Statistics’ methodology [36].

10.2.2 Closer look at shipyears for the period 2002-2018

Table 15 shows a summary of shipyear distribution amongst the whole ro-ro passenger fleet since 2002.

Table 15. Distribution of shipyears amongst the whole fleet from 2002 to 2019 – Ro-ro passenger ships

	Total Shipyears
Mean	11.28
Standard deviation	5.50
Min. value	0.07
1st quartile (25%)	7.18
Median (50%)	11.92
3rd quartile (75%)	17
Max. value	17

During the period 2002-2018, there were a total of 9 359 shipyears for the whole ro-ro passenger fleet.

10.2.2.1 Gross tonnage

Figure 19 shows the distribution of the total shipyears between five different categories of gross tonnage, both for the whole ro-ro passenger fleet and for IACS-classed ro-ro passenger ships.

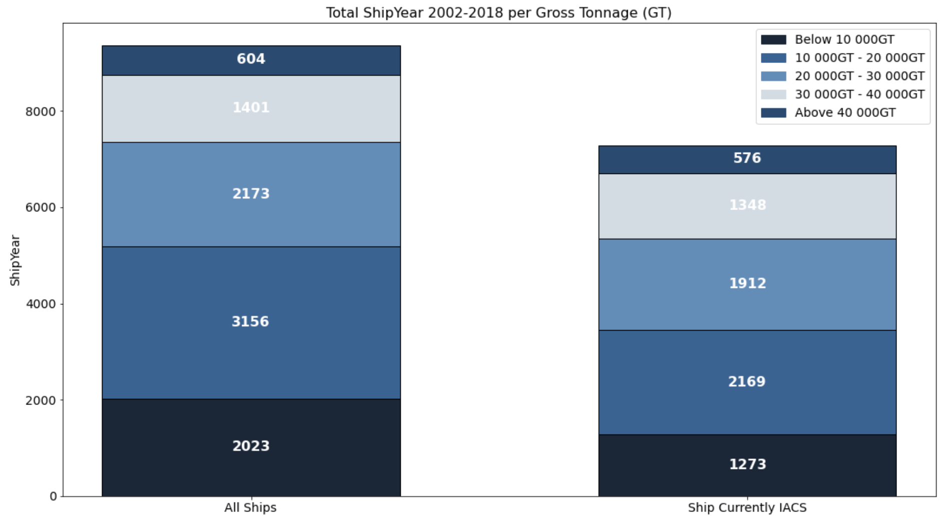

Figure 19. Total shipyears per gross tonnage for the whole ro-ro passenger fleet as well as IACS-classed ships.

Figure 20 shows the evolution of this distribution for all the ro-ro passenger fleet over the years. It can be pointed out that over the years, the proportion of shipyears (hence the proportion of ships) related to ships bigger than 20 000 GT has always been increasing.

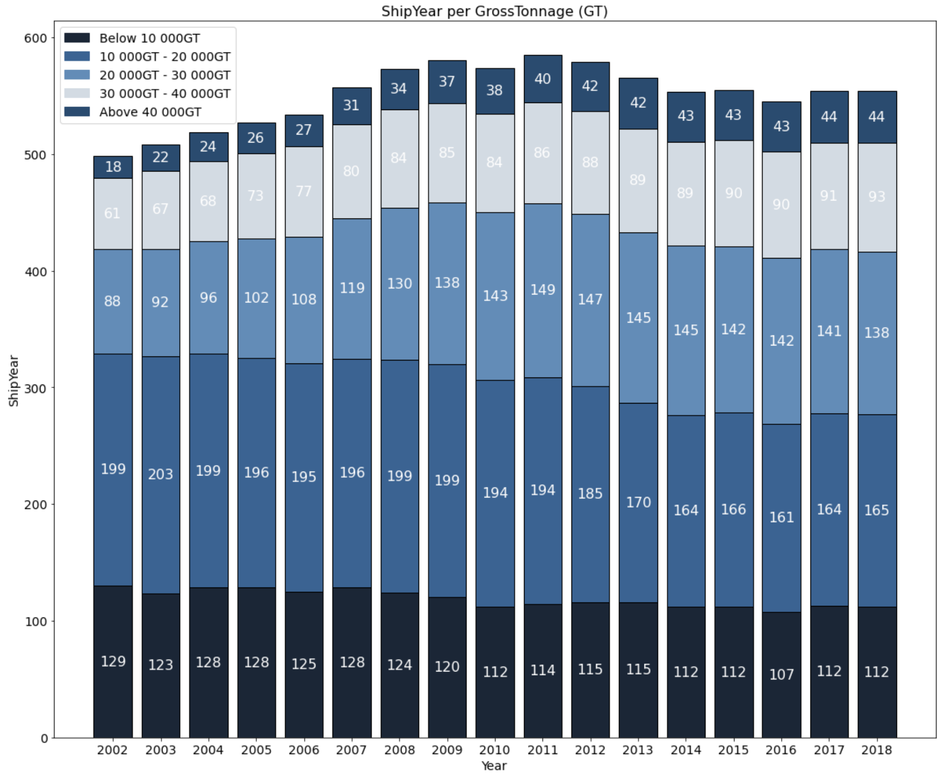

Figure 20. Evolution of shipyears per gross tonnage for the whole ro-ro passenger fleet from 2002 to 2018.

10.2.2.2 Length between perpendiculars

Figure 21 shows the distribution of the total shipyears between four different categories of LPP, both for the whole ro-ro passenger fleet and for IACS-classed ro-ro passenger ships.

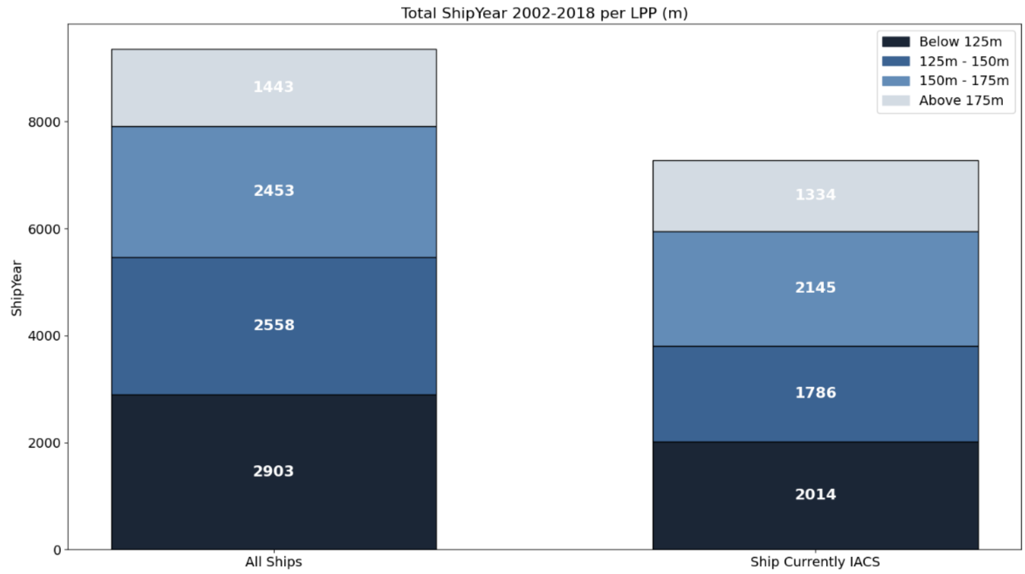

Figure 21. Total shipyears per LPP for the whole ro-ro passenger fleet as well as IACS-classed ships.

Figure 22 shows the evolution of this distribution for all the ro-ro passenger fleet over the years. It can be noticed that the proportion of shipyears (hence the proportion of ships) with a LPP over 150 m has been increasing, while the proportion of ships between 125 m and 150 m has been decreasing. The proportion of ships with a LPP below 125 m has remained constant.

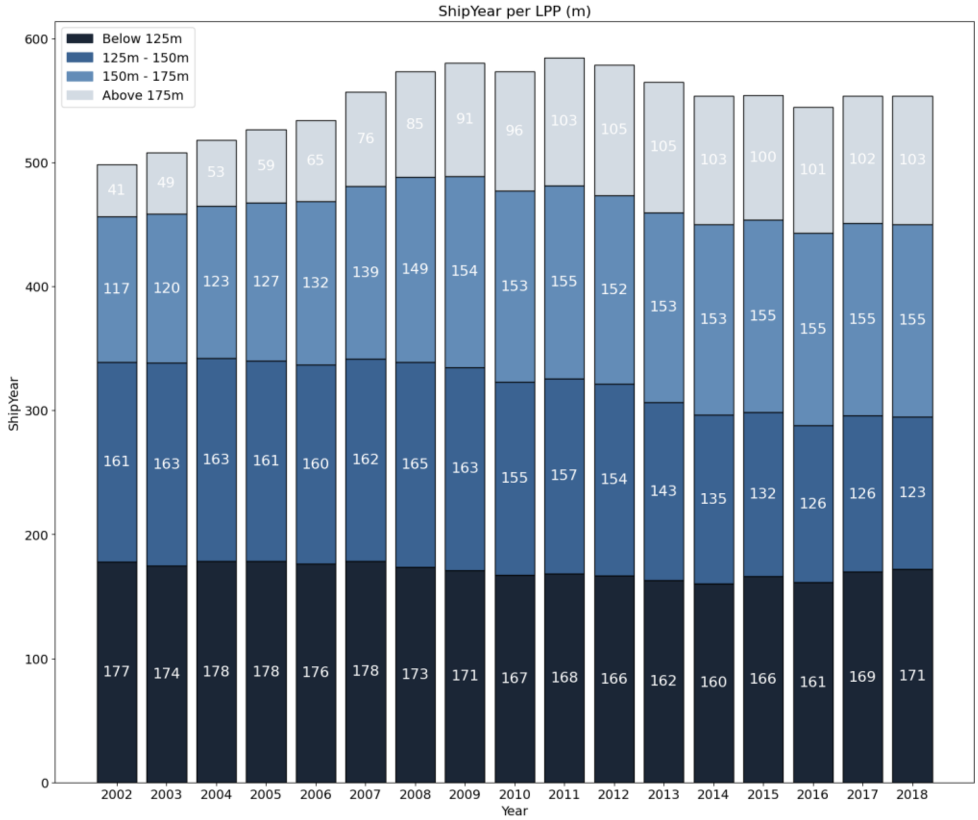

Figure 22. Evolution of shipyears per LPP for the whole ro-ro passenger fleet from 2002 to 2018.

10.2.2.3 Passenger capacity

Figure 23 shows the distribution of the IACS-classed ships and of the whole ro-ro passenger fleet between four categories of passenger capacity.

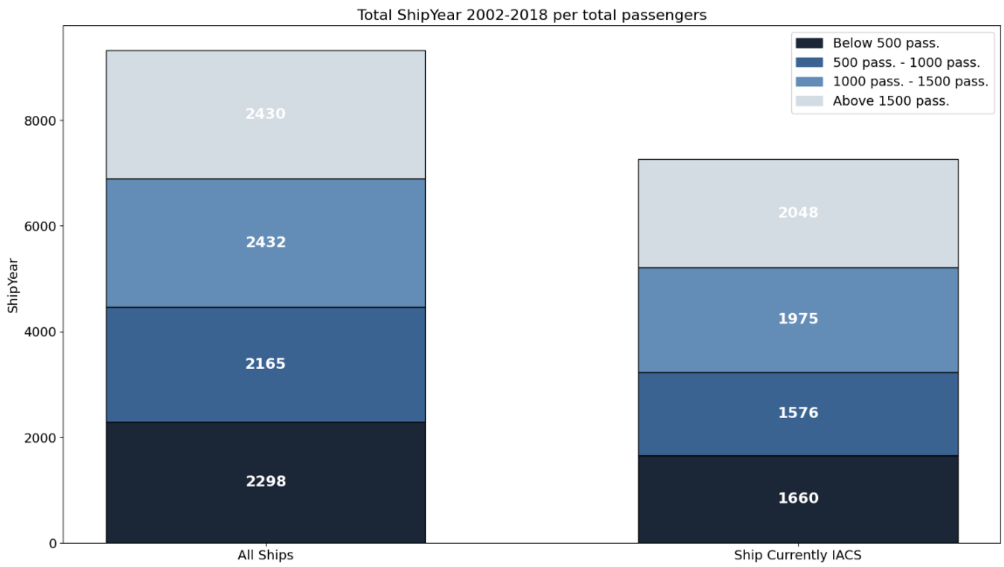

Figure 23. Total shipyears per passenger capacity for the whole ro-ro passenger fleet as well as IACS-classed ships.

Figure 24 shows the evolution of this distribution from 2002 to 2018 for the whole fleet. There is a slight increase in the proportion of ships above 1 000 passengers, and a slight decrease for ships below. It is coherent with previous conclusions based on Figure 16.

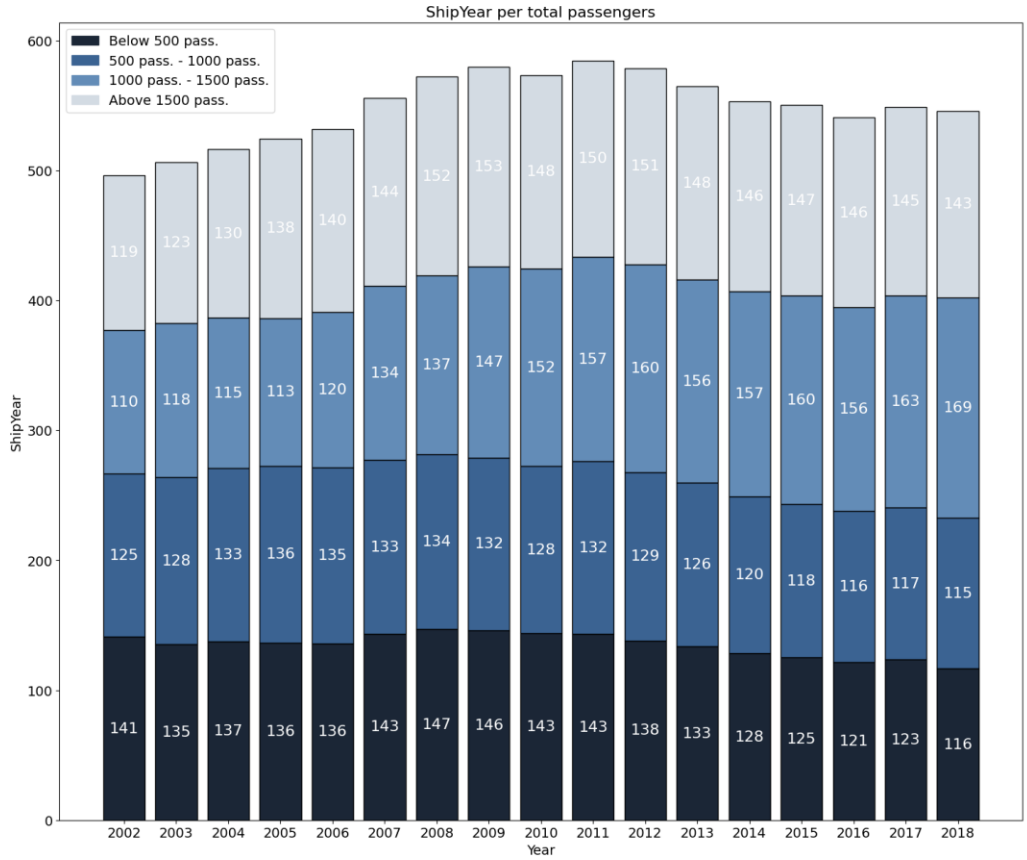

Figure 24. Evolution of shipyears per passenger capacity for the whole ro-ro passenger fleet from 2002 to 2018.

10.2.2.4 Lane meter

Figure 25 shows the distribution of the IACS-classed ships and of the whole ro-ro passenger fleet between five categories of lane meter.

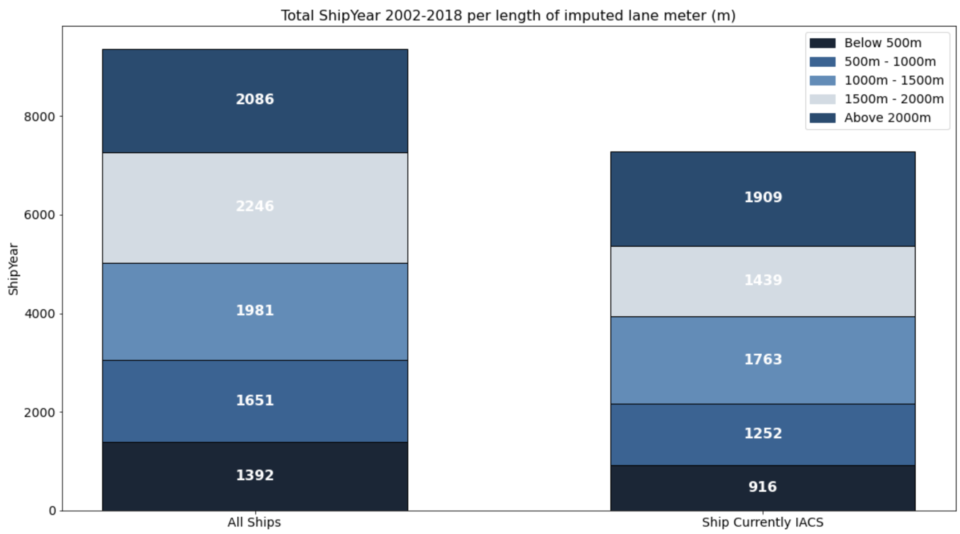

Figure 25. Total shipyears per imputed lane meter for the whole ro-ro passenger fleet as well as IACS-classed ships.

Figure 26 shows the evolution of this distribution from 2002 to 2018 for the whole fleet. There is change in the proportions of the lane meter categories over the years, but the average number of lane meters of ships below 1 000 m remains stable from 2002 to 2018.

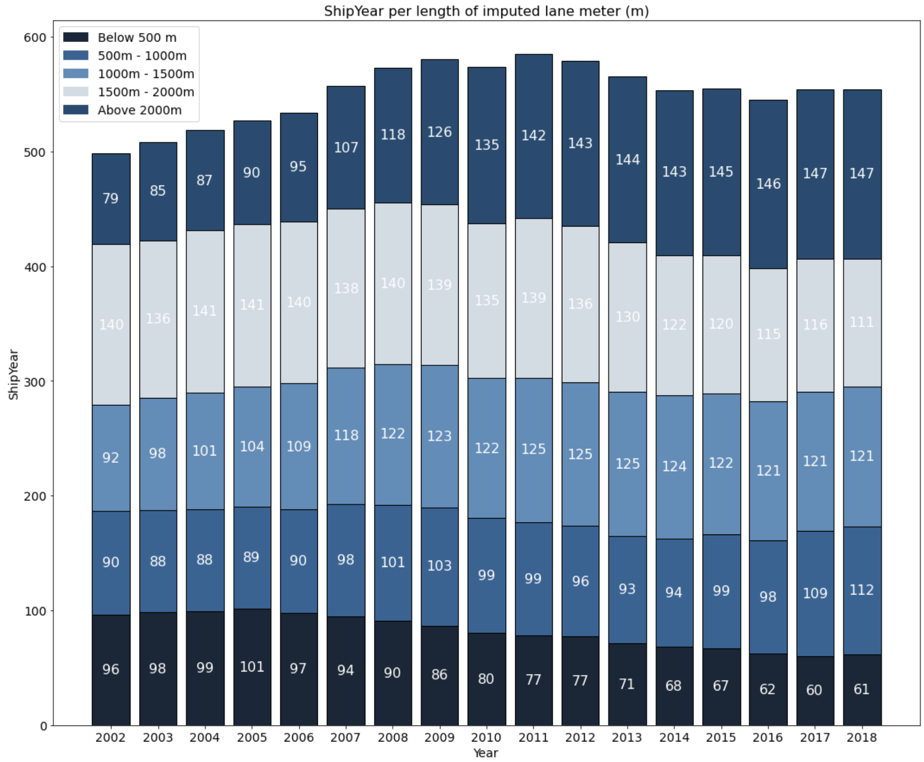

Figure 26. Evolution of shipyears per imputed lane meter for the whole ro-ro passenger fleet from 2002 to 2018.

10.3 Ro-ro cargo fleet analysis

10.3.1 General overview

The two tables below provide a general description for the ro-ro cargo ships composing the LASH FIRE fleet. Table 16 summarizes key characteristics for all ro-ro cargo ships present in the fleet, while Table 17 describes ro-ro cargo ships from the fleet currently IACS-classed at the time of the study (01/01/2019).

In the next subsections, a more precise distribution of these features across the fleet is presented.

Table 16. General description for all ro-ro cargo ships in the fleet

	Gross Tonnage (GT)	Length Between Perpendiculars (m)	Age (year)	Ro-ro lane (m)	Delivery Year
Mean	17838	147	24	2039	1990
Standard deviation	13080	34	11	1343	13
Min. value	5018	87	1	35	1970
1st quartile (25%)	8309	118	16	1056	1978
Median (50%)	13055	142	25	1722	1987
3rd quartile (75%)	23479	175	33	2695	2002
Max. value	74273	241	49	9700	2018

Table 17. General description for IACS-classed ro-ro cargo ships

	Gross Tonnage (GT)	Length Between Perpendiculars (m)	Age (year)	Ro-ro lane (m)	Delivery Year
Mean	22151	159	17	2401	2001
Standard deviation	15192	34	10	1382	10
Min. value	5199	87	1	230	1972
1st quartile (25%)	10091	133	8	1336	1996
Median (50%)	19722	158	17	2160	2002
3rd quartile (75%)	29424	186	23	3260	2010
Max. value	74273	241	47	7972	2018

In the following sections, some of the ship characteristics (gross tonnage, length between perpendiculars, ro-ro lane, etc.) is further investigated. This includes e.g. plots for each of them, to more in detail describe the whole ro-ro cargo fleet as well as the IACS-classed ships.

10.3.2 Gross tonnage

Figure 27 shows gross tonnage distribution amongst the whole ro-ro cargo fleet, as well as amongst IACS-classed ships (the two graphs are superimposed, thus the “all ships” part corresponds to the addition of both light and dark part). The number of ships is inversely proportional to the gross tonnage for the whole fleet. The higher gross tonnage of a ship, the higher probability that the ship is classed by an IACS member.

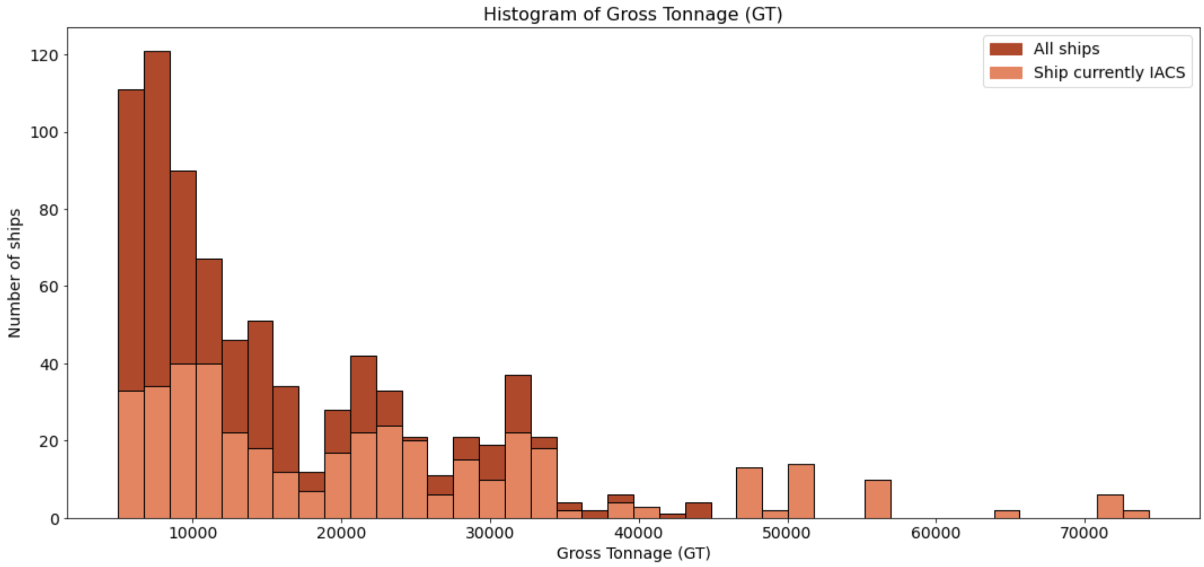

Figure 27. Gross tonnage distribution between IACS-classed ro-ro cargo ships and the whole ro-ro cargo ships.

Figure 28 shows the median gross tonnage evolution at delivery over the years for the whole fleet (solid line), the first and third quartile (red zone) as well as the median moving average over seven years (dashed line). There is an increase of the median gross tonnage moving average from 1970 to 2014, then the median decreases from 2014 to 2018. The period studied here does not last long enough to provide further information about this gap (the moving average does not cover the last seven years of the study).

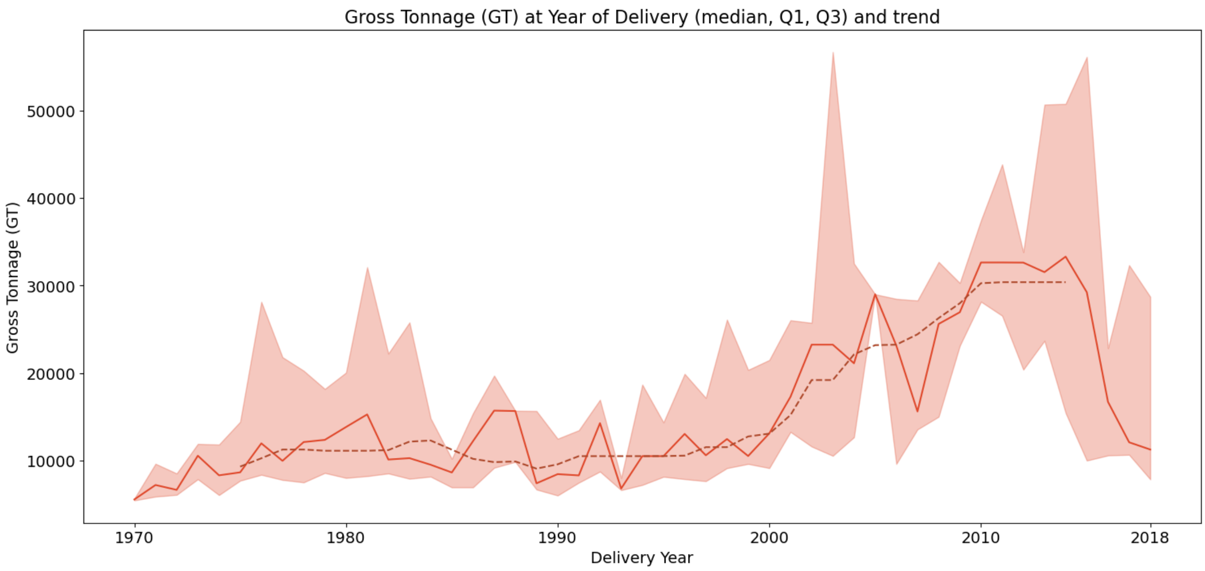

Figure 28. Evolution of median gross tonnage evolution at delivery over the years – Ro-ro cargo ships.

10.3.3 Lane meter

Figure 29 shows the lane meter distribution amongst the whole ro-ro cargo fleet, as well as amongst IACS-classed ships (same remark as above, the two graphs are superimposed, thus the “all ships” part corresponds to the addition of both light and dark part). One can notice that most of non IACS-classed ships have a number of lane meters below 3 000 m (75% of the whole fleet has a ro-ro lane length shorter than 2 695 m).

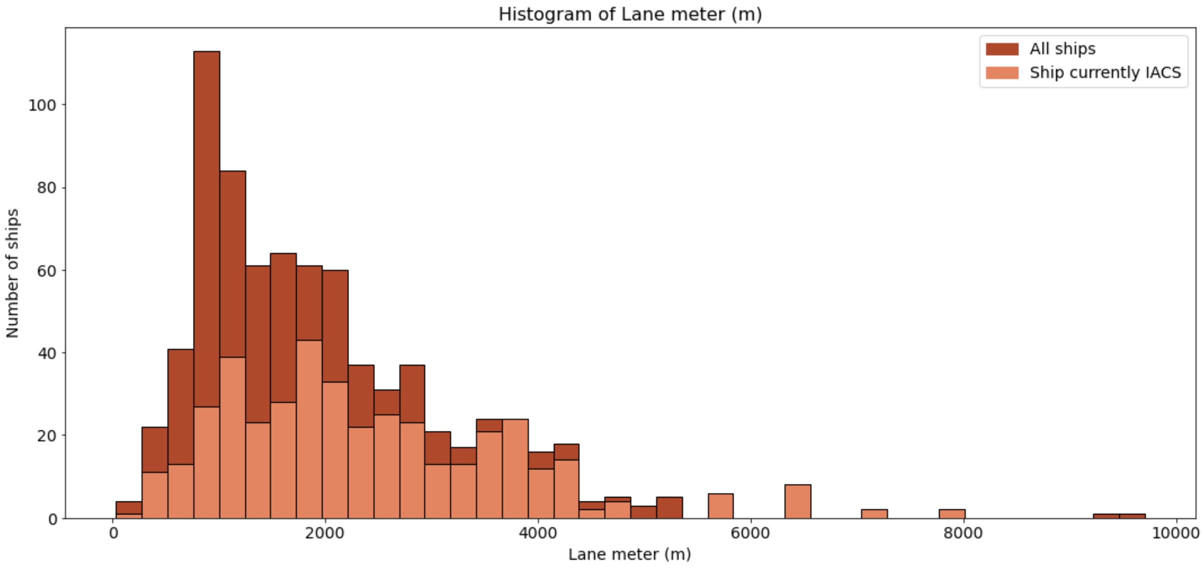

Figure 29. Lane meter distribution between IACS-classed ro-ro cargo ships and the whole ro-ro cargo ships.

Figure 30 shows the median lane meter evolution at delivery of ships, over the years for the whole fleet (solid line), the first and third quartile (red zone) as well as the median moving average over seven years (dashed line). As for the gross tonnage above, there is an increase in the median moving average from 500 m to 4 000 m (during the period 1970-2014). After 2014, the median moving average cannot be plotted, but the median decreases until the end of the period considered.

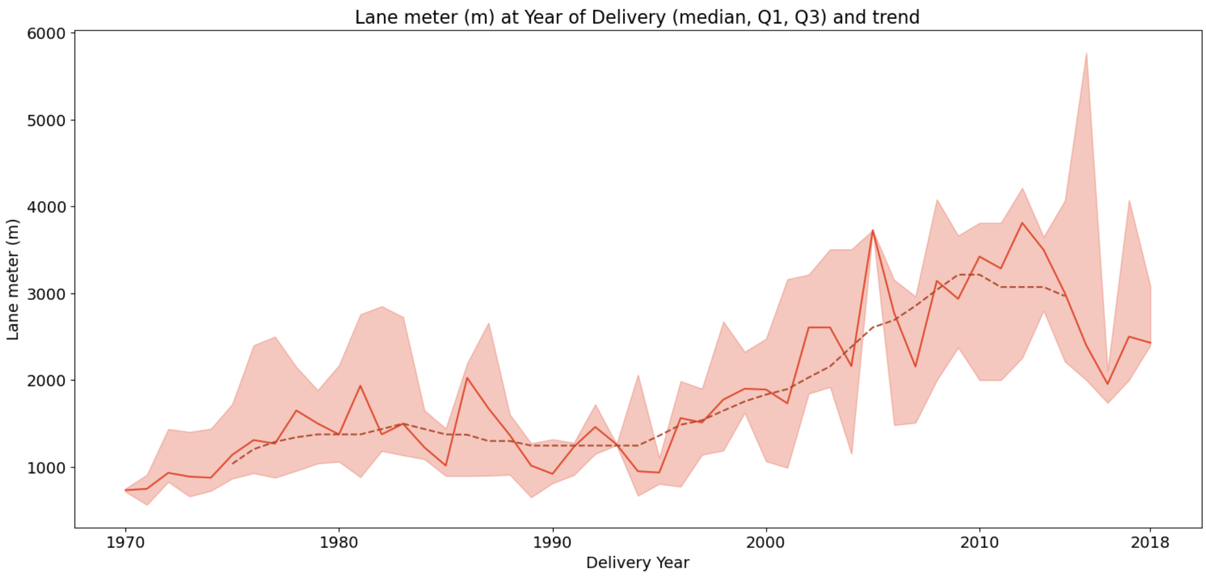

Figure 30. Evolution of median lane meter evolution at delivery over the years – Ro-ro cargo ships.

10.3.4 Length between perpendiculars

Figure 31 shows the LPP distribution amongst the whole ro-ro cargo fleet, as well as amongst IACS-classed ships. The difference between IACS-classed/non IACS-classed ships is less pronounced than in the previous parts, but there is nonetheless a tendency for larger ships to be classified by one of IACS member.

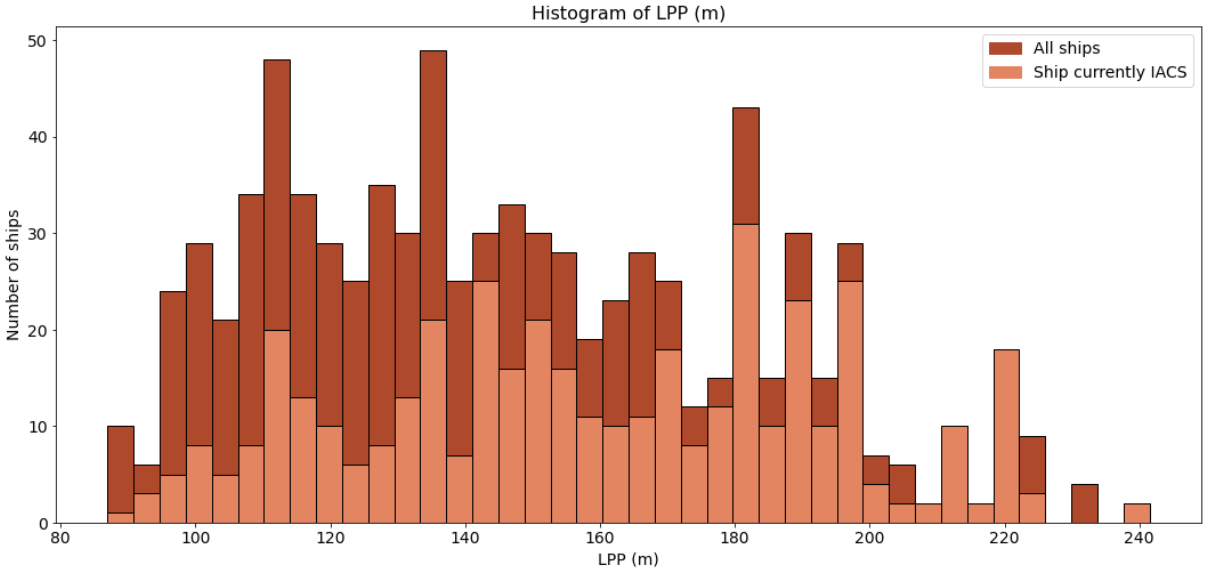

Figure 31. LPP distribution between IACS-classed ro-ro cargo ships and the whole ro-ro cargo ships.

Figure 32 shows the median LPP evolution at delivery over the years for the whole fleet (solid line), the first and third quartile (red zone) as well as the median moving average over seven years (dashed line). The median LPP moving average is quite stable from 1975 to 1995 (around 130 m), then it increases to reach around 180 m in 2010.

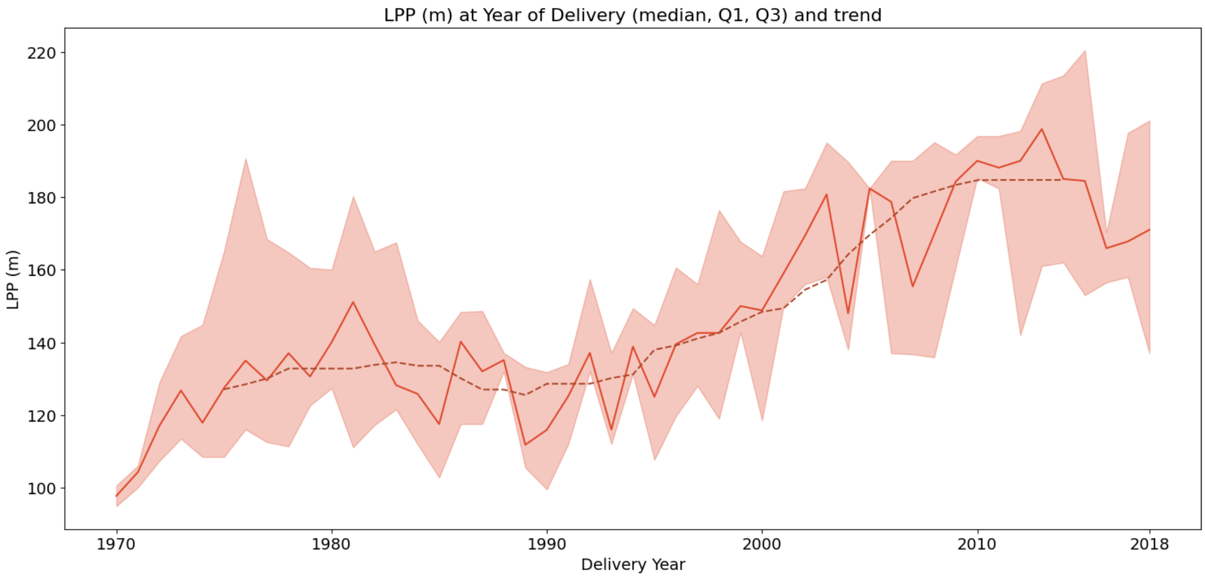

Figure 32. Evolution of median LPP at delivery over the years – Ro-ro cargo ships.

10.4 Ro-ro cargo shipyears analysis

10.4.1 Delivery year and ship age

Figure 33 shows the number of ships delivered each year, for the whole ro-ro cargo fleet, as well as the moving average over seven years. There is a peak of delivery around 1978, then the quantity delivered each remains quite stable, as it can be seen with the quantity moving average (dashed line).

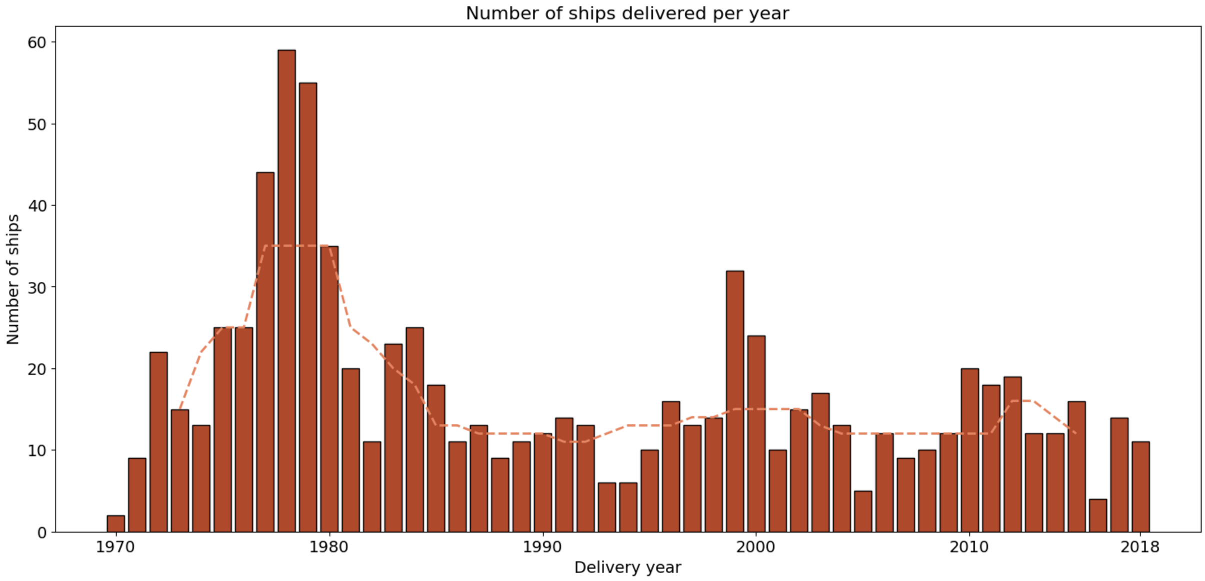

Figure 33. Number of ro-ro cargo ships delivered each year.

Figure 34 shows the distribution of ages amongst the whole ro-ro cargo fleet, as well as amongst the IACS-classed ships. Almost all ships under 20 years old are classed by an IACS member, and almost all ships over 30 years old are not IACS-classed on the 1st of January, 2019. If Figure 33 and Figure 34 are compared, there should be a peak of 45 year-old ships (due to the delivery peak around 1978). But this is not the case, one can deduce that these ships are the non IACS-classed ships on Figure 34 which retired before the end of the study.

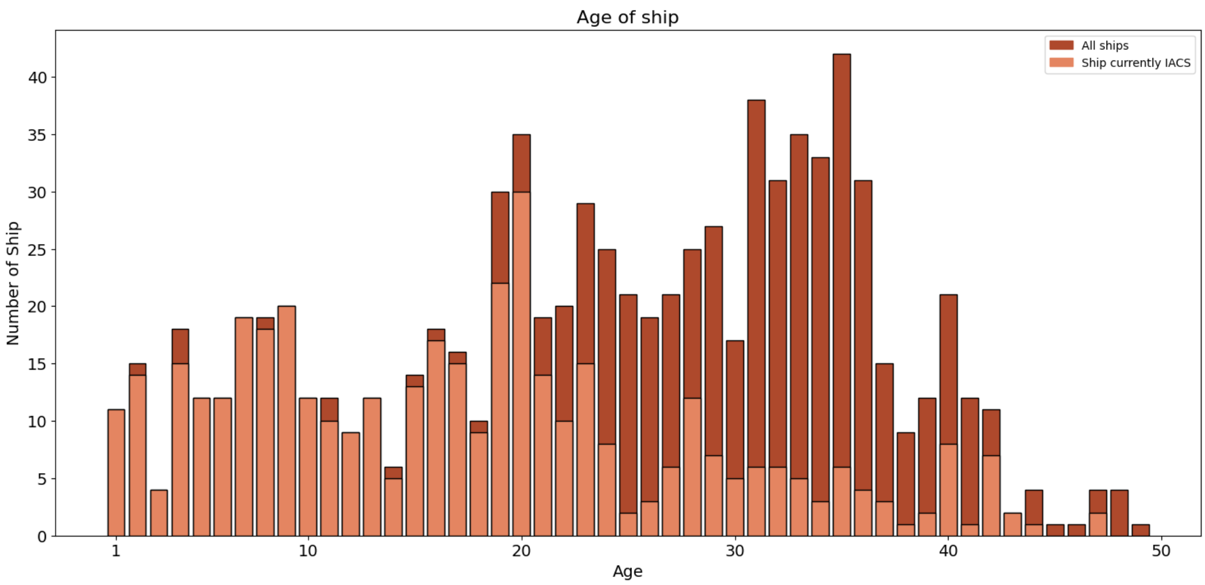

Figure 34. Ship ages distribution between IACS-classed ro-ro cargo ships and whole ro-ro cargo fleet.

In 2018, the average age of the fleet is 19.1 years old. The average life expectancy for the existing ro-ro cargo ships over the 2016-2018 period was estimated to 22.9 years. The life expectancy for newbuildings over the 2016-2018 period was estimated to 40.3 years.

10.4.2 Closer look at shipyears between 2002 and 2018

During the period 2002-2018, there was a total of 8 073 shipyears for the whole ro-ro cargo fleet.

10.4.2.1 Gross tonnage

Figure 35 shows the distribution of total shipyears between four gross tonnage categories for the period 2002-2018, both for the whole fleet as well as for the IACS-classed ships.

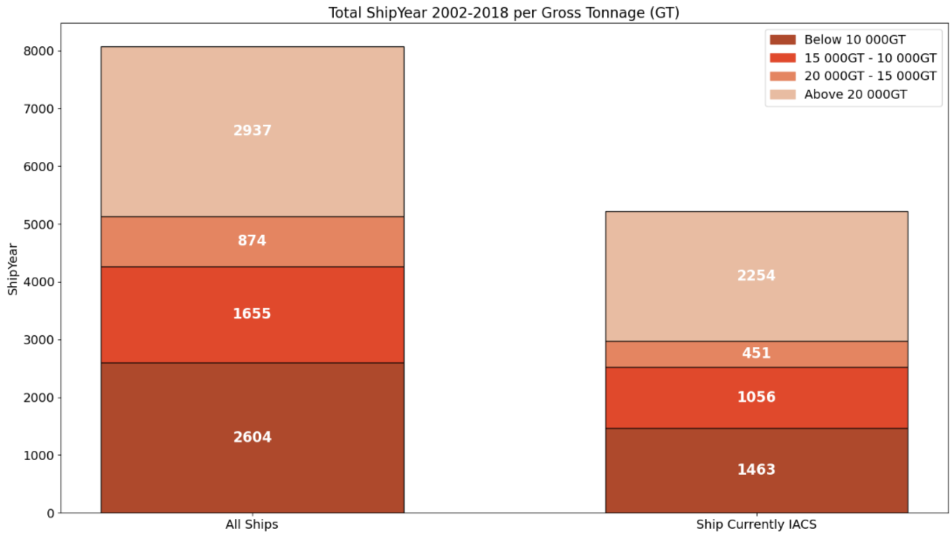

Figure 35. Total shipyears per gross tonnage for the whole ro-ro cargo fleet as well as IACS-classed ships.

Figure 36 goes more in details by detailing this distribution for the whole fleet for each year. The first noticeable thing is that the total shipyears are globally decreasing (from 514 shipyears in 2002 to 414 in 2018). The proportion of ships above 20 000 GT tends to increase over the years, while the proportion of ships below 15 000 GT is decreasing. It has been noted that numerous ships below 10 000 GT were built around 1970-1980 (see Figure 28), maybe retired during the study, and not enough small ships were built in 2002-2018 to compensate this loss. This could explain why there is less shipyears and proportionally more ships above 20 000 GT over the years.

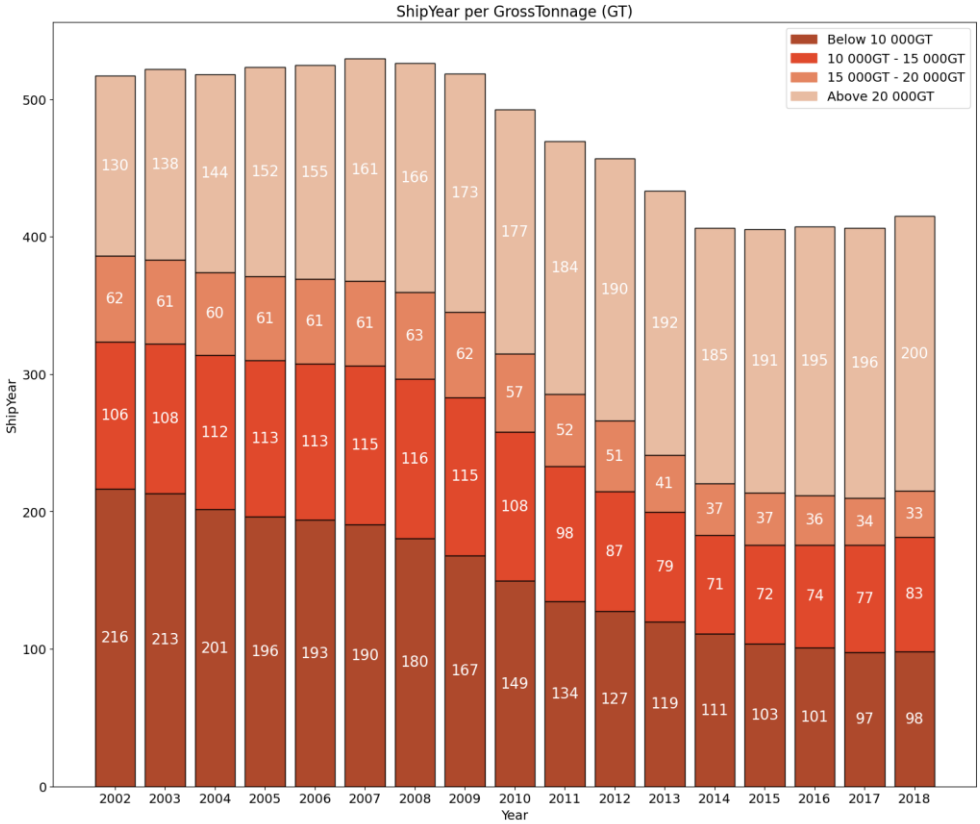

Figure 36. Evolution of shipyears per gross tonnage for the whole ro-ro cargo fleet from 2002 to 2018.

10.4.2.2 Lane meter

Figure 37 shows the distribution of total shipyears for the period 2002-2018 between four lane meter categories, both for the whole ro-ro cargo fleet as well as for IACS-classed ships.

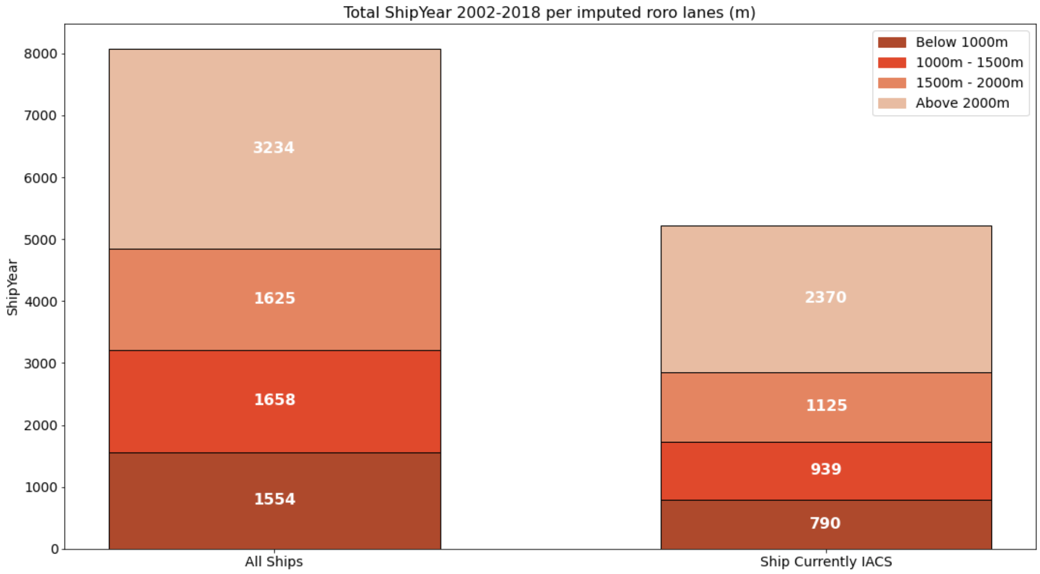

Figure 37. Total shipyears per imputed lane meter for the whole ro-ro cargo fleet as well as IACS-classed ships.

Figure 38 shows this distribution amongst the whole fleet for each year, from 2002 to 2018. As a proportional correlation between gross tonnage and ro-ro lane length is likely, same comments as above can be made about the total shipyears decrease, as well as the decrease for ships below 15 000 GT and the increase of ships above 20 000 GT.

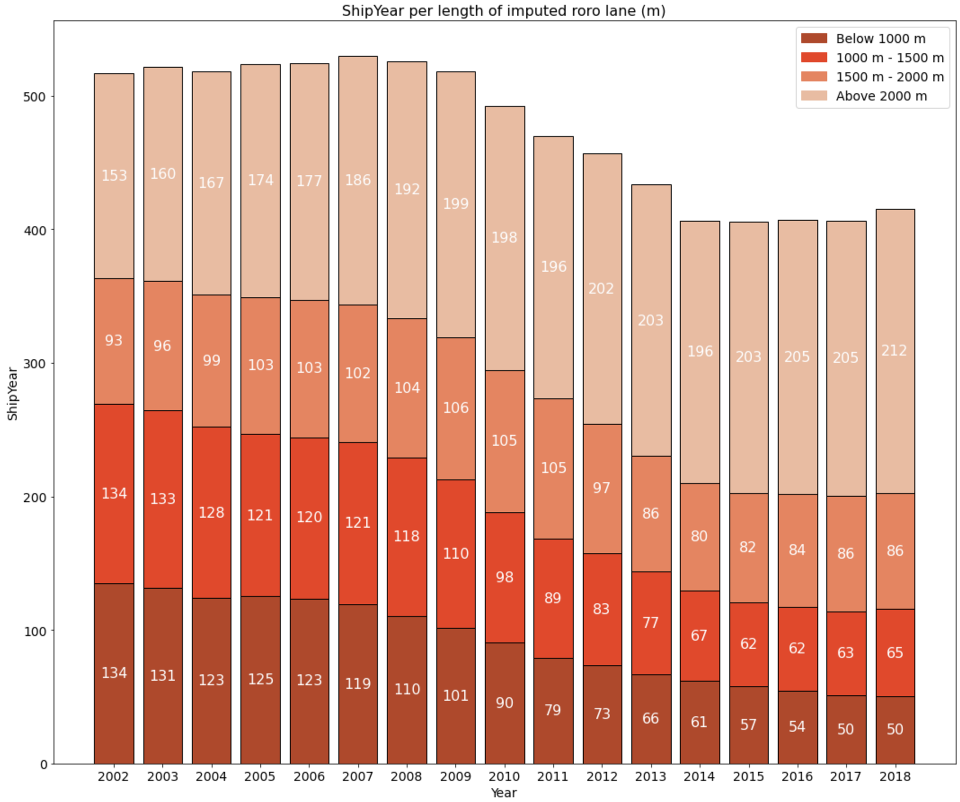

Figure 38. Evolution of shipyears per imputed lane meter for the whole ro-ro cargo fleet from 2002 to 2018.

10.4.2.3 Length between perpendiculars

Figure 39 shows the distribution of total shipyears for the whole fleet, for the period 2002-2018, between four LPP categories.

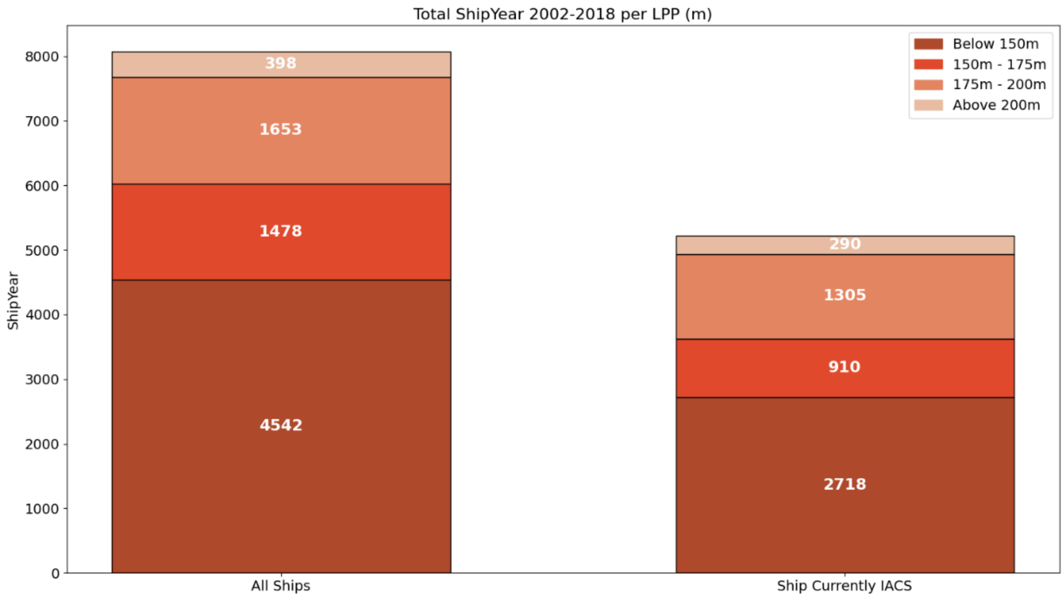

Figure 39. Total shipyears per LPP for the whole ro-ro cargo fleet as well as IACS-classed ships.

Figure 40 shows this distribution for the whole fleet for each year. As previously told, there is a decrease in total shipyears due to the peak of delivery in the years 1970-1980 (hence these ships retired before the end of the study), and the increase of the proportion of ships above 175 m is linked to the massive construction of smaller ships during this peak.

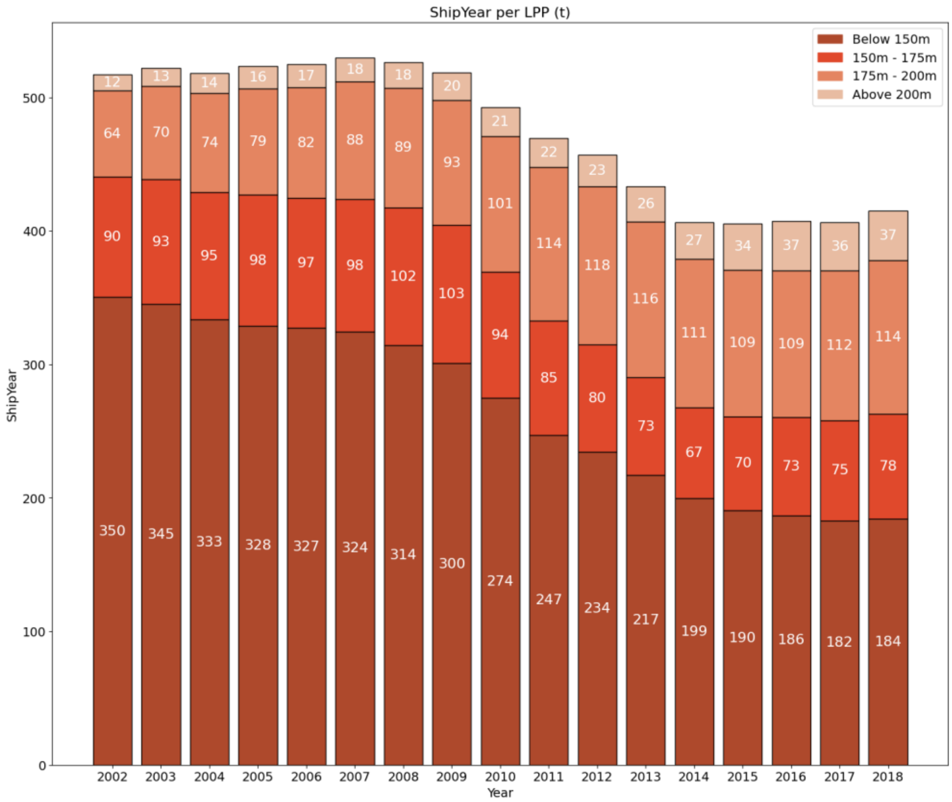

Figure 40. Evolution of shipyears per LPP for the whole ro-ro cargo fleet from 2002 to 2018.

10.5 Vehicle carrier fleet analysis

10.5.1 General overview

The two tables below provide a general description for the vehicle carriers composing the LASH FIRE fleet. Table 18 summarises key characteristics for all vehicle carriers present in the fleet, while Table 19 describes vehicle carriers from the fleet currently IACS-classed at the time of the study (01/01/2019).

In the next subsections, a more precise distribution of these features across the fleet is presented.

Table 18. General description for all vehicle carriers in the fleet

	Gross Tonnage (GT)	Length Between Perpendiculars (m)	Age (year)	Car Equivalent Unit (m)	Delivery Year
Mean	44093	172	17	4769	1998
Standard deviation	18987	28	9	2050	12
Min. value	5180	77	1	64	1971
1st quartile (25%)	29888	163	10	3500	1986
Median (50%)	47232	180	16	5080	2001
3rd quartile (75%)	59217	190	26	6354	2009
Max. value	76420	250	39	8500	2018

Table 19. General description of IACS-classed vehicle carriers

	Gross Tonnage (GT)	Length Between Perpendiculars (m)	Age (year)	Car Equivalent Unit (m)	Delivery Year
Mean	50626	178	12	5278	2006
Standard deviation	17085	25	7	1977	7
Min. value	5462	77	1	64	1980
1st quartile (25%)	42401	170	8	4216	2001
Median (50%)	57554	188	11	6147	2008
3rd quartile (75%)	60403	192	18	6500	2011
Max. value	76420	250	39	8500	2018

In the following sections, some of the ship characteristics (gross tonnage, length between perpendiculars, car equivalent unit, etc.) is further investigated. This includes e.g. plots for each of them, to more in detail describe the whole vehicle carrier fleet as well as the IACS-classed ships.

10.5.2 Gross tonnage

Figure 41 shows gross tonnage distribution amongst the whole vehicle carrier fleet, as well as amongst IACS-classed ships (the two graphs are superimposed, thus the “all ships” part corresponds to the addition of both light and dark part). One can notice that below 57 000 GT, IACS-classed and non IACS-classed vehicle carriers are distributed, but above 57 000 GT, almost all ships are classed by an IACS member.

There is also a peak of IACS-classed ships between 57 000 GT and 63 000 GT (actually, 25% of IACS-classed ships have a gross tonnage between 57 554 GT and 60 403 GT, according to Table 19). This is explained by the fact that Panamax ships (which have been very popular) with a LPP of 199.9 m must not be heavier than 60 000 GT (the reason why 199.9 m has been chosen is explained in section 10.5.4).

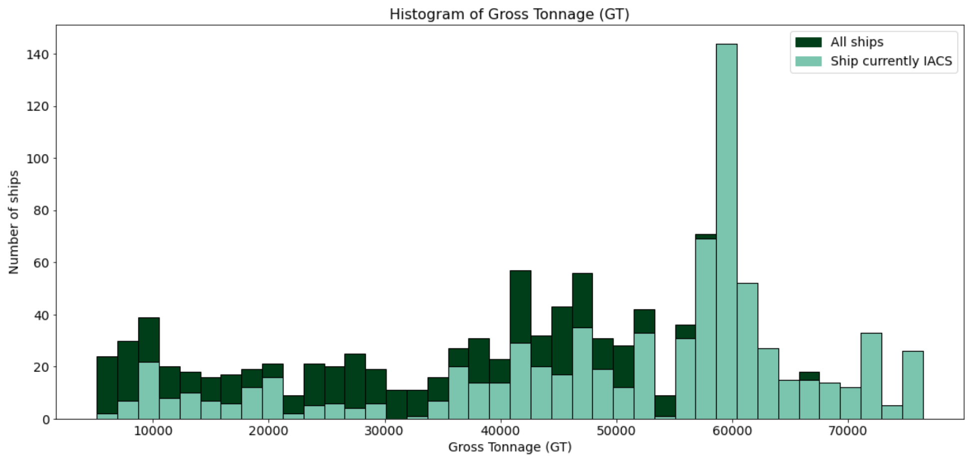

Figure 41. Gross tonnage distribution between IACS-classed ships and the whole vehicle carrier fleet.

Figure 42 shows the median gross tonnage evolution at delivery over the years for the whole fleet (solid line), the first and third quartile (green zone) as well as the median moving average over seven years (dashed line). The moving average median makes it clear that the median gross tonnage produced each year is increasing over the years, going almost linearly from 10 000 GT in 1975 to 60 000 GT in 2015. This can be linked to the democratisation of Post-Panamax ships from the year 1990, which allow bigger ships.

The low values between 1988 and 1992 in Figure 42 (as well as Figure 44 and Figure 46) is discussed further in section 10.6.

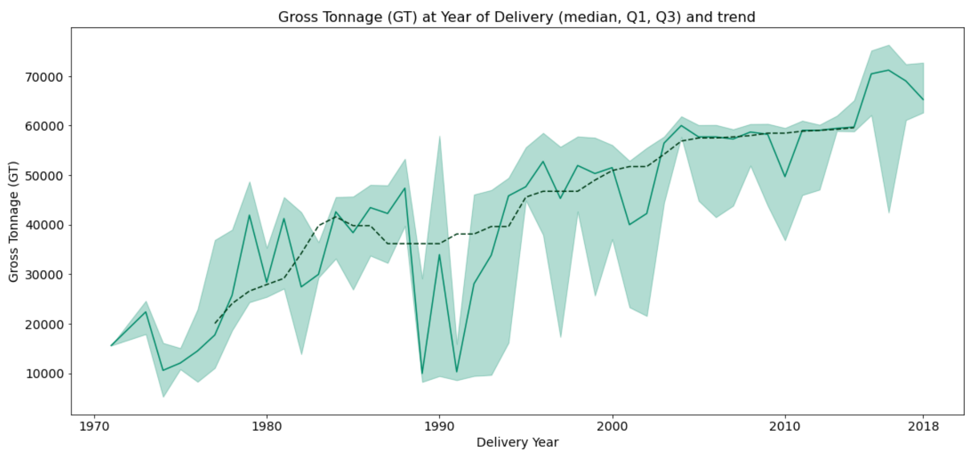

Figure 42. Evolution of median gross tonnage at delivery over the years – Vehicle carriers.

10.5.3 Car Equivalent Unit

Figure 43 shows the car equivalent unit distribution amongst the whole vehicle carrier fleet, as well as amongst IACS-classed ships (same remark as above, the two graphs are superimposed, thus the "all ships" part corresponds to the addition of both light and dark part). Amongst the ships below 6 000 CEU, there is no noticeable evolution for the ratio between IACS-classed and "all ships". Above 6 000 CEU, however, all but about ten ships are classed by an IACS member. The high quantity of ships between 6 000 and 7 000 CEU is again linked to the Panamax category of the ships built during this period.

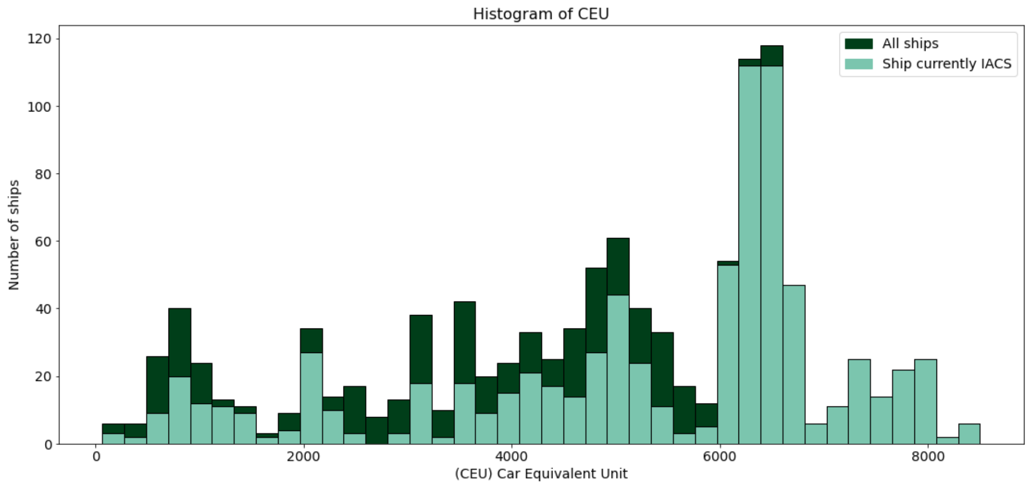

Figure 43. CEU distribution between IACS-classed ships and the whole vehicle carrier fleet.

Figure 44 shows the median gross tonnage evolution at delivery over the years (solid line), the first and third quartile (green zone) as well as the median moving average over seven years (dashed line). There are too few data before 1977 to analyse this period, but one can notice the clear augmentation in median car equivalent unit delivered each year despite some highs and lows (between 1988-1992 in particular).

Figure 43 and Figure 44 can be superimposed almost perfectly on Figure 41 and Figure 42, respectively. It is not unreasonable to assume that there is a correlation between gross tonnage and car equivalent unit, as the more volume (hence the more cars or trucks) a vehicle carrier can contain, the more length it needs to carry them.

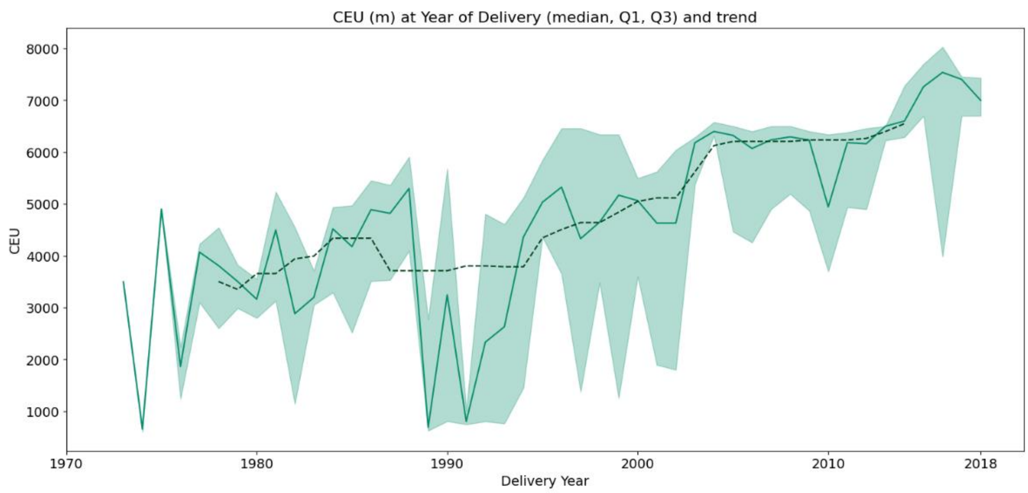

Figure 44. Evolution of median CEU at delivery over the years – Vehicle carriers.

10.5.4 Length between perpendiculars

Figure 45 shows the distribution of the LPP amongst the whole vehicle carrier fleet, as well as amongst IACS-classed ships. It is clear that the majority of the ships (both for IACS-classed and non IACS-classed) has a LPP between 160 m and 200 m (more precisely, according to Table 18, 50% of the vehicle carriers have a LPP between 163 m and 190 m). Historically the 200 m is related to some ports in Japan and has emerged to a deep sea vehicle carrier standard length (before 2008).

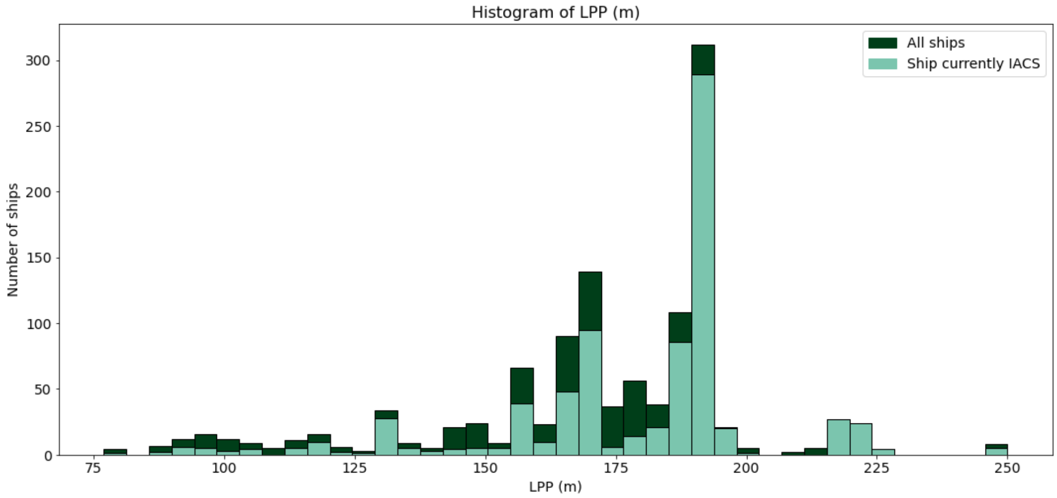

Figure 45. LPP distribution between IACS-classed ships and the whole vehicle carrier fleet.

Figure 46 shows the median LPP evolution at delivery over the years for the whole fleet (solid line), the first and third quartile (green zone), as well as the median moving average over seven years (dashed line). This graph can be divided into two zones; there are two periods during which the median moving average is almost constant (LPP of about 165 m from 1975 to 1997 and LPP of about 190 m from 2002 to 2018). Unlike LPP, it was previously stated that car equivalent unit and gross tonnage were increasing over the years. From Figure 42 and Figure 46, one can deduce that during these two periods, ships were getting bigger, but not longer.

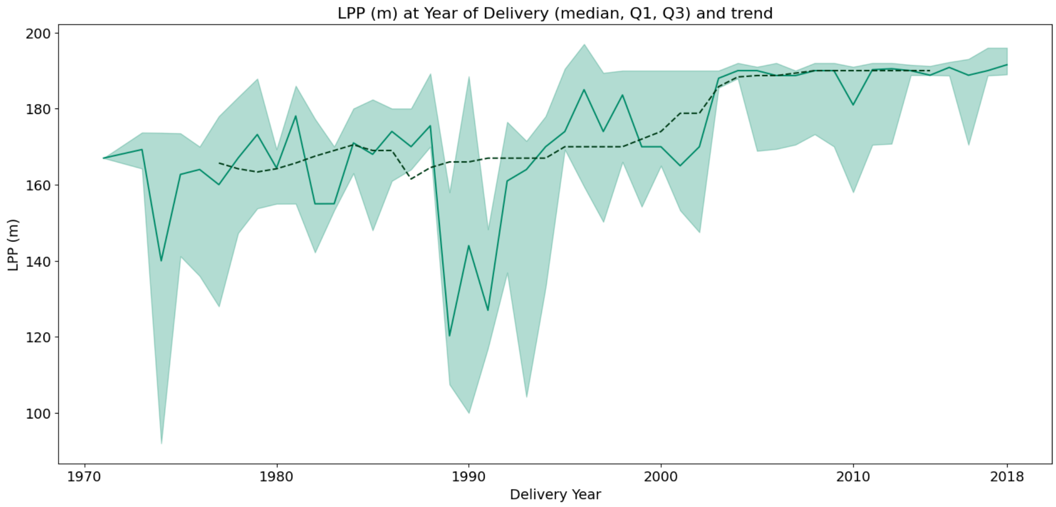

Figure 46. Evolution of median LPP at delivery over the years – Vehicle carriers.

10.6 Vehicle carriers shipyears Analysis

10.6.1 Delivery year and ship age

Figure 47 shows the number of ships delivered each year, amongst the whole vehicle carrier fleet. The number of ships delivered decreases strongly between 1988 and 1992. It can be related to what has been discussed in the previous part. Between 1988 and 1992, not only fewer boats were built, but they were also smaller (see Figure 40). This should therefore perhaps not be interpreted as a trend, but rather as a decrease in large ships construction.

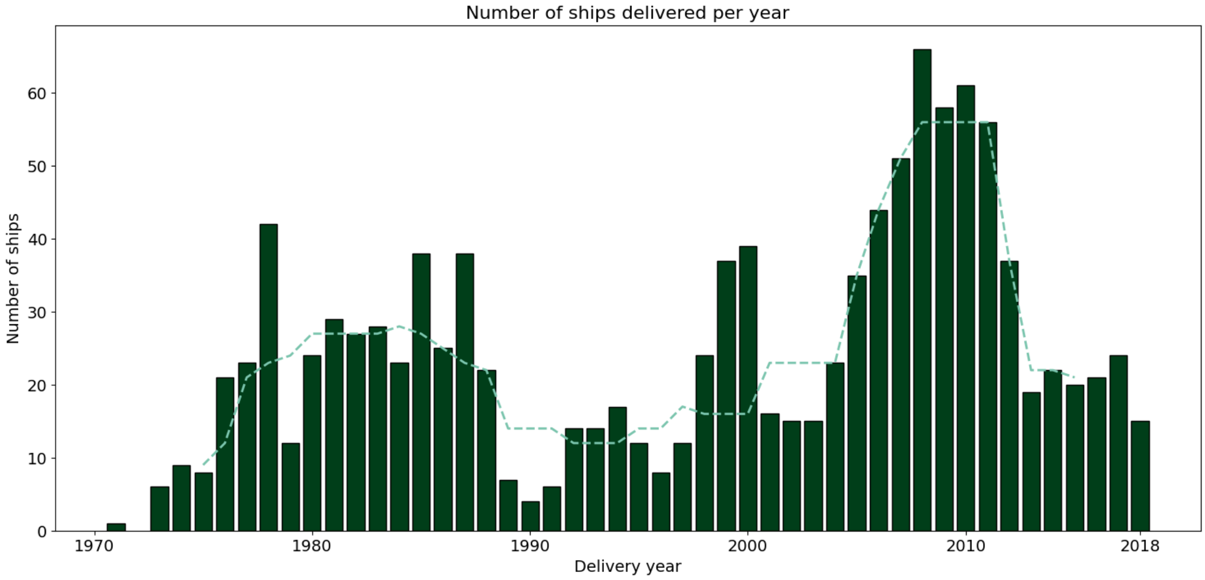

Figure 47. Number of vehicle carriers delivered each year.

Figure 48 shows the distribution of ship ages for vehicle carriers, for the whole fleet as well as IACS-classed ships. As expected, Figure 48 is almost a replicate of Figure 47. It can be noted that the proportion of IACS-classed ships decreases when the age increases.

Figure 48. Ship ages distribution between IACS-classed ships and whole vehicle carrier fleet.

In 2018, the average age of the fleet is 12.6 years old. The average life expectancy for the existing vehicle carriers over the 2016-2018 period was estimated to 17.0 years. The life expectancy for newbuildings over the 2016-2018 period was estimated to 28.8 years.

10.6.2 Closer look at shipyears for the period 2002-2018

During the period 2002-2018, there was a total of 11 703 shipyears for the whole vehicle carrier fleet.

10.6.2.1 Gross tonnage

Figure 49 shows the distribution of the total shipyears for the period 2002-2018, split between four gross tonnage categories.

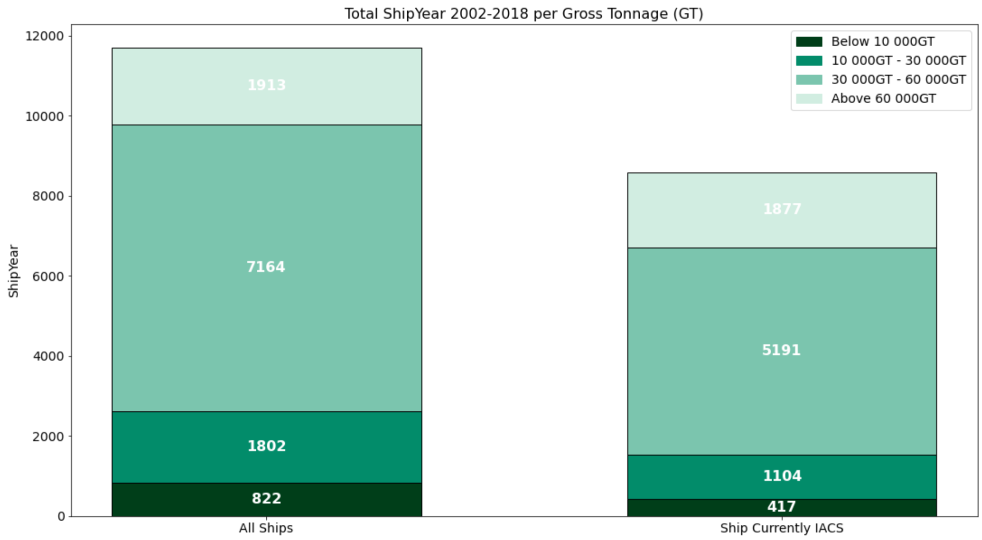

Figure 49. Total shipyears per gross tonnage for the whole vehicle carrier fleet as well as IACS-classed ships.

Figure 50 shows this distribution for the whole fleet for each year. It can be noted that almost all ships above 60 000 GT are IACS-classed ships, as it was stated in section 10.5.2. The proportion of ships above 30 000 GT has clearly increased over the years (from 66% to 85%, and from 4% to 28% for ships above 60 000 GT) and the number of ships below 10 000 GT has decreased.

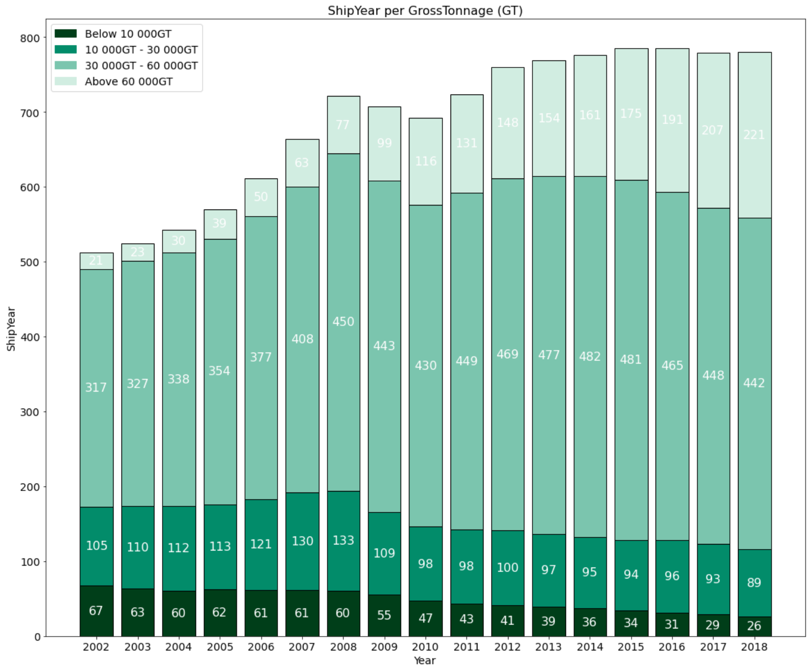

Figure 50. Evolution of shipyears per gross tonnage for the whole vehicle carrier fleet from 2002 to 2018.

10.6.2.2 Car Equivalent Unit

Figure 51 shows the distribution of the total shipyears for the period 2002-2018, split between four car equivalent unit categories.

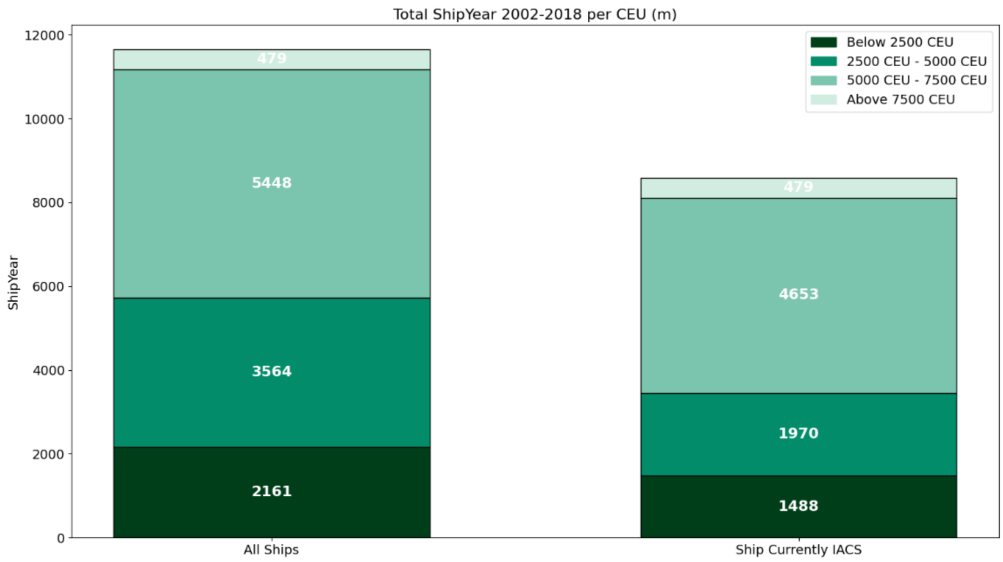

Figure 51. Total shipyears per CEU for the whole vehicle carrier fleet as well as IACS-classed ships.

Figure 52 shows this distribution for the whole fleet for each year. One can notice in Figure 51 that all ships above 7500 CEU are classed by an IACS member (which is coherent with the previous part). Figure 52 shows that over the years, as for gross tonnage, proportion (and number) of ships above 5 000 CEU has grown from 32% to 64%.

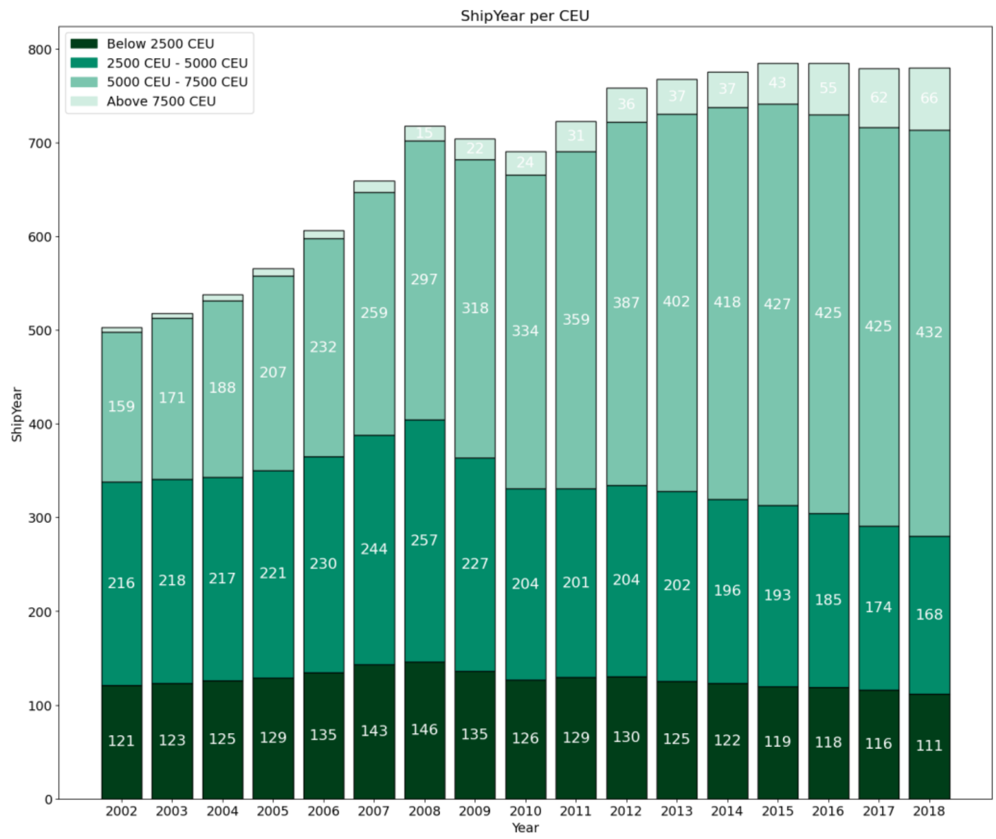

Figure 52. Evolution of shipyears per CEU for the whole vehicle carrier fleet from 2002 to 2018.

10.6.2.3 Length between perpendiculars

Figure 53 shows the distribution of the total shipyears for the period 2002-2018, split between four LPP categories.

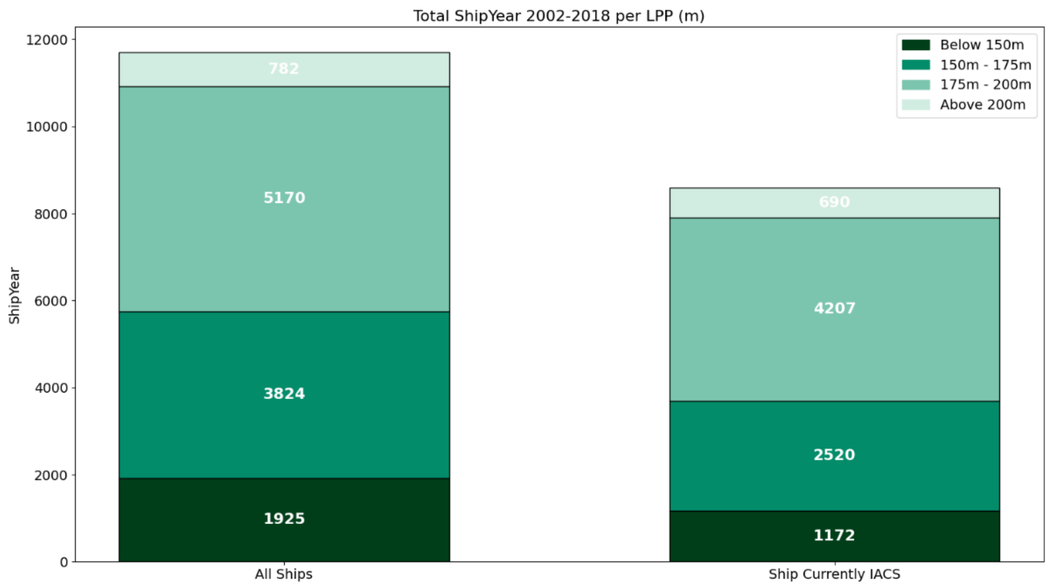

Figure 53. Total shipyears per LPP for the whole vehicle carrier fleet as well as IACS-classed ships.

Figure 54 shows this distribution for the whole fleet for each year. The vast majority of ships greater than 175 m are classed by an IACS member. As for the gross tonnage and the car equivalent unit, the number of shipyears amongst the fleet for ships longer than 175 m has been increasing over the years, while the number of shipyears for ships shorter than 150 m has been decreasing. The number of shipyears for ships between 150 m and 175 m has remained constant.

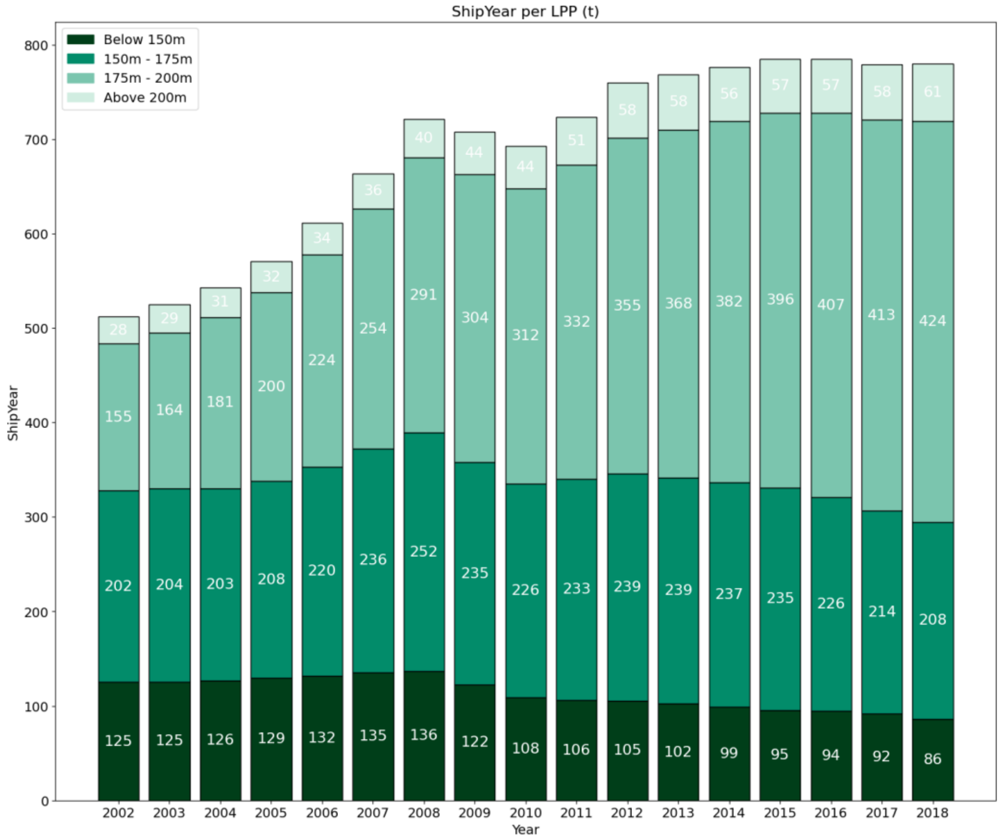

Figure 54. Evolution of shipyears per LPP for the whole vehicle carrier fleet from 2002 to 2018.

11 Casualty analysis

Main author of the chapter: Léon Lewandowski, BV.

This chapter provides information on fires that occurred in ro-ro spaces for the fleet described in the previous section (i.e. section 10). The fire casualties that took place on each type of ro-ro ship are further investigated, including the type of ro-ro space where the fires occurred, and their severity. Then, the frequencies of these casualties are determined, as a function of shipyears, lane meter-years and car equivalent unit-years.

An overview of events with lower severities, i.e. near-misses and marine incidents, is also given in order to find a link between these events and marine casualties.

11.1 Analysis of fires in ro-ro spaces

11.1.1 Fires in ro-ro spaces of ro-ro passenger ships

Figure 55 provides the number of fire casualties in ro-ro spaces for the ro-ro passenger fleet from 2002 to 2018. Figure 56 depicts the 'LASH FIRE serious' casualties in the ro-ro passenger fleet (for further details on the definition of 'LASH FIRE serious', see section 9.3.4). Figure 57 shows the distribution of these casualties between the different types of ro-ro spaces.

There has been a total of 30 casualties during the period considered, or an average of 1.76 per year and the median is 2.00 per year. Of the 30 casualties, 22 (i.e. 73%) were considered 'LASH FIRE serious' and 24 (80%) occurred in a closed ro-ro space.

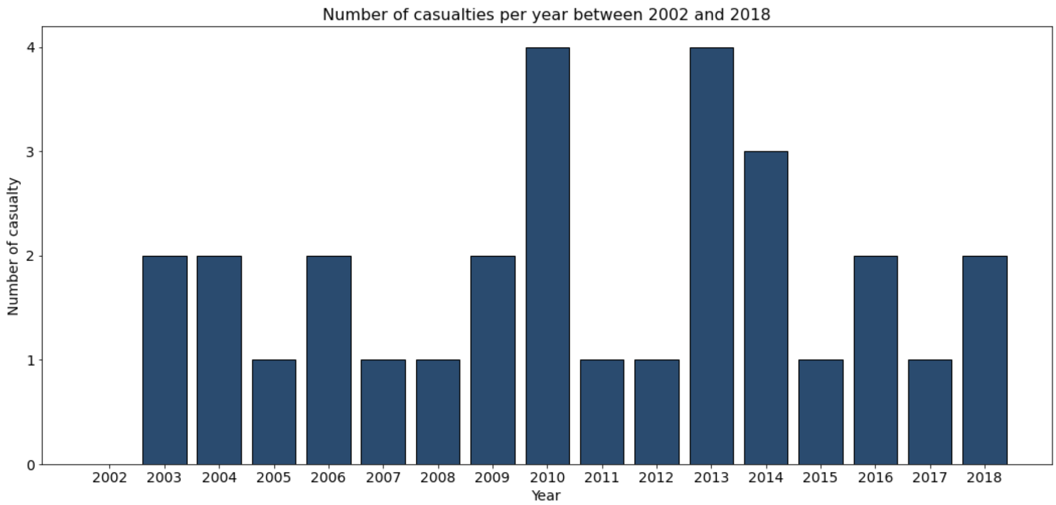

Figure 55. Number of fire casualties per year in ro-ro spaces for ro-ro passenger ships from 2002 to 2018.

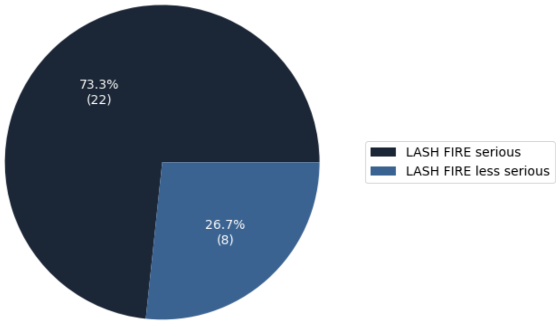

Figure 56. Severity of fire casualties in ro-ro spaces of ro-ro passenger ships.

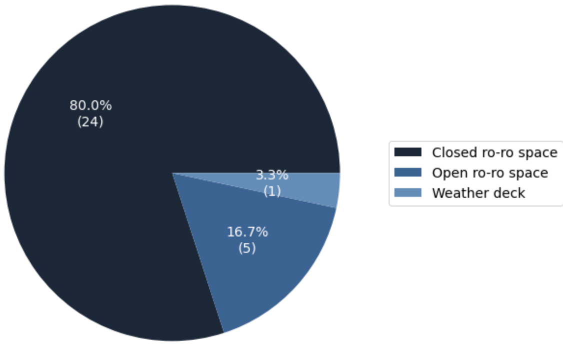

Figure 57. Distribution of casualties per type of ro-ro space for ro-ro passenger ships.

Figure 58 shows the location of these casualties around the world. This map is for information purposes only. A ro-ro passenger ship traffic density map would be necessary to further interpret this map (shipyear/unit area) as well as information on potential geographical discrepancies in the reporting of casualties.

Figure 58. Location of LASH FIRE compliant casualties for ro-ro passenger ships.

11.1.2 Fires in ro-ro spaces of ro-ro cargo ships

Figure 59 provides the number of fire casualties for each year during the studied period in ro-ro spaces of ro-ro cargo ships. Figure 60 depicts the 'LASH FIRE serious' casualties in the ro-ro cargo fleet, and Figure 61 shows the distribution of these casualties between the different types of ro-ro spaces.

There has been a total of 12 casualties, an average of 0.71 per year, and a median of 1.00 per year. Amongst these 12 casualties, 10 (i.e. 83%) were considered as 'LASH FIRE serious', 8 (i.e. 67%) occurred in a closed ro-ro space, and 3 (i.e. 25%) occurred on a weather deck.

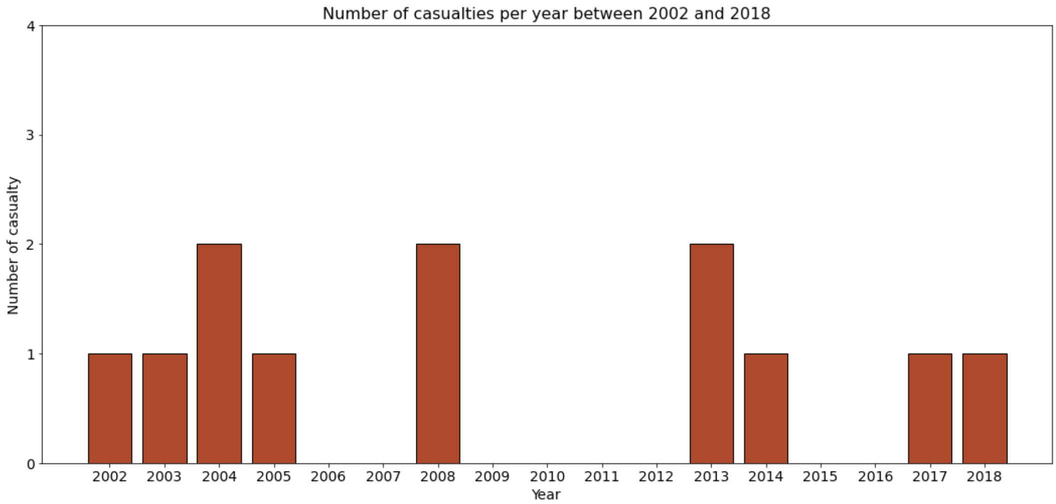

Figure 59. Number of fire casualties per year in ro-ro spaces for ro-ro cargo ships between 2002 and 2018.

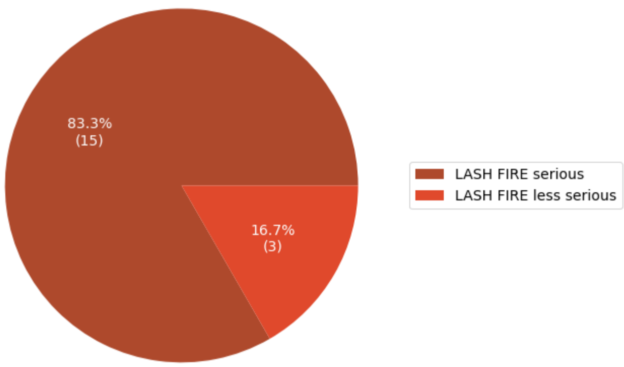

Figure 60. Severity of fire casualties in ro-ro spaces of ro-ro cargo ships.

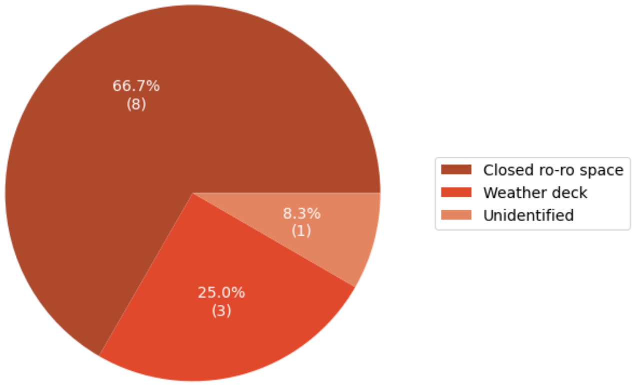

Figure 61. Distribution of casualties per type of ro-ro space for ro-ro cargo ships.

Figure 62 shows the location of these casualties around the world. This map is for information purposes only and has not been interpreted by the authors of this report.

Figure 62. Location of LASH FIRE compliant casualties for ro-ro cargo ships.

11.1.3 Fires in ro-ro spaces of vehicle carriers

Figure 63 provides the number of fire casualties that have occurred in ro-ro spaces of vehicle carriers for each year, from 2002 to 2018. Figure 64 depicts the proportion of 'LASH FIRE serious' casualties in the vehicle carrier fleet. As all these casualties are assumed to occur in closed ro-ro spaces (see section 8.4.5), no graph detailing their space origin has been displayed.

There has been a total of 18 casualties over the studied period, an average of 1.06 per year, and a median of 1.00 per year. Amongst these casualties, 14 (i.e. 78%) were considered as 'LASH FIRE serious'.

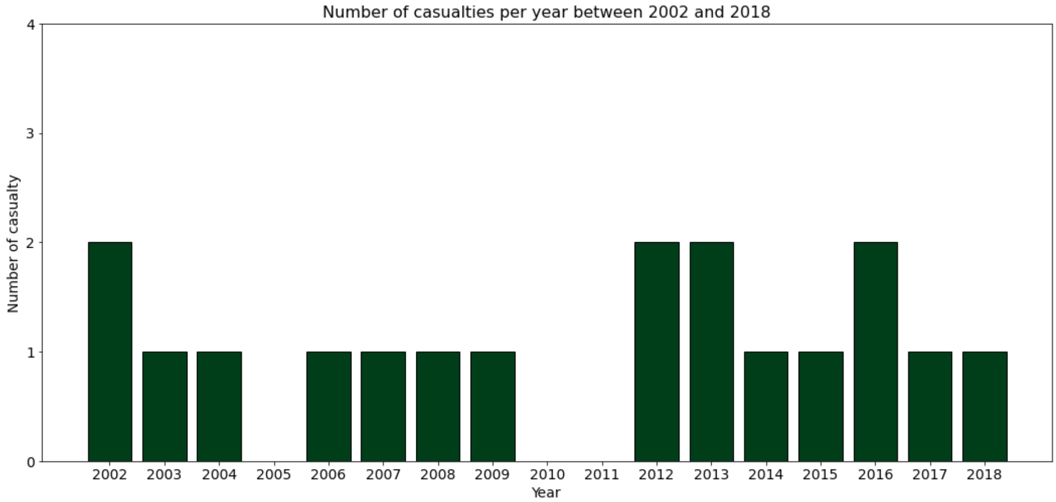

Figure 63. Number of fire casualties per year in ro-ro spaces for vehicle carriers between 2002 and 2018.

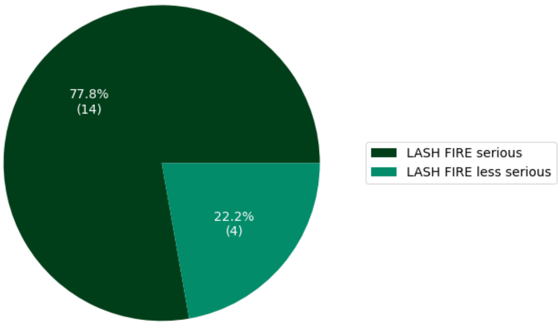

Figure 64. Severity of fire casualties in ro-ro spaces of vehicle carriers.

Figure 65 shows the location of these casualties around the world. This map is for information purposes only and has not been interpreted by the authors of this report.

Figure 65. Location of LASH FIRE compliant casualties for vehicle carriers.

11.1.4 Summary of fires in ro-ro spaces for the whole LASH FIRE fleet

Table 20 summarises the casualties reported for the whole ro-ro fleet, from 2002 to 2018 and that complies with the criteria set in LASH FIRE. A total of 60 casualties were identified in this study, and 46 of them (77%) were considered as 'LASH FIRE serious'. Ro-ro passenger ships account for half of the casualties recorded and for almost half of the serious casualties.

Table 20. Summary of fires in ro-ro spaces in the whole LASH FIRE fleet

	Ro-pax ships	Ro-ro cargo ships	Vehicle carriers	TOTAL
Number of casualties	30	12	18	60
Number of 'LASH FIRE serious' casualties	22	10	14	46
Proportion of 'LASH FIRE serious' casualties	73%	83%	78%	77%

Figure 66 shows the location of LASH FIRE compliant casualties for all three types of ro-ro ships around the world. As stated above, this map is for information purposes only and has not been interpreted by the authors of this report.

Figure 66. Location of LASH FIRE compliant casualties for all ro-ro ships.

11.2 Analysis of marine incidents and near-misses

Based on the 107 events provided by the ship operators (see section 6.7), qualitative and quantitative analyses were performed in order to draw some conclusions on fire events other than marine casualties, i.e. on the marine incidents and the near-misses. It shall be noted that, by definitions in MSC-MEPC.3/Circ.3 [5], the near-misses are included in the marine incidents, themselves included in the less serious casualties. However, for the purpose of the below analyses:

- When referring to the dataset "marine casualties", "marine incidents" and "near-misses" are excluded from this dataset; and
- When referring to the dataset "marine incidents", "near-misses" are excluded from this dataset.

Hence, they are considered as disjoint datasets.

11.2.1 Marine incidents

The marine incidents (38 events) from the dataset describe situations where a fire was detected and first response (e.g. by use of fire extinguisher/s) was carried out in most of the cases. For 5 events, first response was not attempted and the fire was directly handled by the fixed fire-extinguishing system or by manual firefighting (e.g. by use of fire hose/s).

The two tables below provide the proportion of success and failure of the first response for marine incidents. The column "self-extinguishment" reports the number of events where the fire self-extinguished after the disconnection of the power supply cable (and without the need of fire extinguishment). In Table 21, the self-extinguished fires are excluded from the success of first response, whereas in Table 22 they are included.

Table 21. Proportion of success and failure of the first response for marine incidents – Self-extinguishment excluded

Marine incidents	Total	First response						Self-extinguishment	
		Success		Failure		Unknown			
All ro-ro ships	**37**	**19**	**51%**	**12**	**32%**	**3**	**8%**	**3**	**8%**
Ro-pax	23	11	48%	7	30%	2	9%	3	13%
Ro-ro cargo	1	0	-	1	-	0	-	0	-
Vehicle carrier	13	8	62%	4	31%	1	8%	0	0%

Table 22. Proportion of success and failure of the first response for marine incidents – Self-extinguishment included

Marine incidents	Total	First response						Self-extinguishment	
		Success		Failure		Unknown			
All ro-ro ships	**37**	**22**	**59%**	**12**	**32%**	**3**	**8%**	**-**	**-**
Ro-pax	23	14	61%	7	30%	2	9%	-	-
Ro-ro cargo	1	0	-	1	-	0	-	-	-
Vehicle carrier	13	8	62%	4	31%	1	8%	-	-

The proportion of failure of first response for marine incidents is found to be in the order of 30% for ro-ro passenger ships and vehicle carriers. This is a much lower failure rate that what was derived in the FIRESAFE I study [11] (i.e. 70%). Indeed, the dataset from FIRESAFE I includes more severe fire events than marine incidents, and therefore the proportion of failure is higher.

11.2.2 Near-misses

The near-misses (61 events) from the dataset describe situations where:

- Smoke was detected (no flame) but the situation returned to the normal without the need for first response (e.g. using fire extinguisher/s); and
- A deviation that could have started a fire (ignition) or jeopardised the chain of the fire response (detection, first response, decision, extinguishment, containment and evacuation) was reported.

After a review of the events, it was found that all the deviations were brought back to normal by an action of the crew.

Only the near-misses reported on ro-ro passenger ships were further considered because of insufficient details for the other types of ro-ro ships.

Table 23 provides the number of deviations related to the collected near-misses per main area of the chain of events. One near-miss can be associated with deviations to different areas of the chain of events, e.g. too narrow passage between cargo would jeopardise the use of fire extinguisher(s), the fire confirmation and the manual firefighting. Deviations related to fire ignition were either presence of smoke (see the first bullet point above) or situations that could have started a fire (no smoke).

Table 23. Number of deviations related to collected near-misses per area – Ro-ro passenger ships

Area of deviation	Number of deviations
Ro-pax	**68**
Ignition	47
Detection	1
Faulty detection system	1
First response	5
Access to fire extinguisher blocked	1
Missing fire extinguisher	2
Too narrow passage between cargo	2
Decision	3
Faulty portable communication means	1
Too narrow passage between cargo	2
Extinguishment	5
Faulty portable communication means	1
Access to fire equipment blocked	2
Too narrow passage between cargo	2
Containment	1
Fire door in open position	1
Evacuation	6
Escape route blocked	1
Passenger in ro-ro space	5

A large proportion of the deviations are related to fire ignition. Table 24 provides the number of deviations related to ignition per potential cause of ignition. It highlights that the most reported deviations that would lead to a fire ignition are associated with vehicles (heater running and fuel leak), reefer connections, dangerous goods and presence of passenger(s) in ro-ro space. This is consistent with the findings in the FIRESAFE [11] and the LASH FIRE Hazard Identification workshops [37].

Table 24. Number of deviations related to ignition per potential cause of ignition – Ro-ro passenger ships

Potential cause of ignition	Number of deviations	Contribution
Ignition	**47**	**100%**
Ship equipment	2	4%
Faulty or damaged cable (non-connected)	2	-
Vehicle	18	38%
Engine running	1	-
Heater running	9	-
Fuel leak	6	-
Unknown	2	-
Reefer	10	21%
Reefer connection (presence of smoke, faulty, damaged, etc.)	9	-
Other	1	-
Cargo not reefer	11	23%
Dangerous Good (error in DG handling, undeclared, etc.)	8	-
Other	3	-
Passenger in ro-ro space	5	11%
Unknown	1	2%

11.3 Ratios between marine casualties, incidents and near-misses

In the past, there were several attempts to show the relationship between accidents, incidents and near-misses. For example, the "accident triangles" were developed by Heinrich (1931) and Bird (1966) [38], highlighting the link between the number of accidental events with a decreasing level of severity.

For the purpose of LASH FIRE, an accident triangle was developed in the form of Table 25.

Table 25. Accident triangle – LASH FIRE

Type of ships	Level of severity	Number of events	Ratio
All ro-ro ships	**Marine casualty**	**12**	**1**
	Marine incident/near-miss	**99**	**8**
Ro-pax	Marine casualty	7	1
	Marine incident/near-miss	80	11
Ro-ro cargo	*Not sufficient data for assessment*		
Vehicle carrier	*Not sufficient data for assessment*		

The ratios between the number of marine casualties and marine incidents/near-misses were calculated for 'all ro-ro ships' and 'ro-pax ships' based on the same set of ships (given the fact that the ships were anonymised in the dataset provided by the LASH FIRE MOAG). A ratio of about 1/10 between marine casualties and marine incidents/near-misses was found, which is in the same order of magnitude of what was found in the FIREPROOF project [39], and by Heinrich and Bird [38] in other safety domains.

11.4 Frequency of fires in ro-ro spaces

All the frequencies calculated in this section are given uniformly with three significant digits. These results should be interpreted with caution, and considering the errors given in ANNEX E: Calculation of distribution of ro-ro spaces.

11.4.1 Selection of time period

As explained in section 9.3.3, this analysis will focus on the period 2002-2018.

11.4.2 Frequency of fires in ro-ro spaces per ship type

11.4.2.1 Frequency of fires per shipyear

With data available from previous sections, it is possible to establish the frequencies of fires in ro-ro spaces for the three different types of ro-ro ships. Table 26 provides the exposure time (i.e. total shipyears) considered for each type of ro-ro ships.

Table 26. Exposure time (in shipyears) for each ro-ro ship type, for the period 2002-2018

	Ro-pax ships	**Ro-ro cargo ships**	**Vehicle carriers**	**TOTAL**
Exposure time	9 359	8 073	11 703	29 135

Table 27 provides the fire frequencies for all accidents and only serious accidents, i.e. 'LASH FIRE serious', in ro-ro spaces amongst the whole LASH FIRE fleet. Ro-ro passenger ships is the ship type where fires in ro-ro spaces are most frequent (3.21E-3 accidents per shipyear, and 2.35E-3 serious accidents per shipyear, i.e. more than twice as frequent as the accidents in the rest of the fleet).

Table 27. Fire frequencies in ro-ro spaces per type of ro-ro ships, per shipyear

Ships type	**Exposure Time (shipyears)**	**Number of accidents**	**Number of serious accidents**	**Fire frequency – All accidents ($shipyear^{-1}$)**	**Fire frequency – Serious accidents ($shipyear^{-1}$)**
Ro-pax ships	9 359	30	22	3.21E-3	2.35E-3
Ro-ro cargo ships	8 073	12	10	1.49E-3	1.24E-3
Vehicle carriers	11 703	18	14	1.54E-3	1.20E-3
TOTAL	29 135	60	46	2.06E-3	1.58E-3

11.4.2.2 Comparison between LASH FIRE results and previous studies

Table 28 summarises the frequencies for ro-ro ship fires obtained by other studies. The results obtained by the LASH FIRE study are in the same order of magnitude as those of previous studies. There are nevertheless some slight differences, which except from the different time periods studied can be explained by:

- The studies did not focus on the same type of casualties (for instance SAFEDOR focused on fire or explosion, not only fire); and
- The parameters chosen for each study were different (for instance, DNV-GL chose to focus on ships with gross tonnage above 4 000 GT, while LASH FIRE chose to focus on ships with gross tonnage above 5 000 GT; they also use different databases).

Table 28. Summary of studies addressing ro-ro ship fires

Description of casualty	Study	Data	Ship category	Frequency (fire/shipyear)	Period analysed
Ro-ro passenger ships					
Fire or explosion	SAFEDOR (2008)	Lloyds Maritime Information Unit (LMIU)	Ro-pax above 1 000 GT	8.28E-03	1994-2004
Serious accident due to fire or explosion	SAFEDOR (2008)	Lloyds Maritime Information Unit (LMIU)	Ro-pax above 1 000 GT	3.23E-03	1994-2004
Fire or explosion in ro-ro space	SAFEDOR (2008)	Lloyds Maritime Information Unit (LMIU)	Ro-pax above 1 000 GT	0.99E-03	1994-2004
Serious accident due to fire or explosion	Papanikolaou et al. (2015)	IHS Seaweb	Ro-pax	3.49E-03	1990-2012
Ship fire	FIRESAFE II (2018)	EMSA data	Ro-pax	1.89E-02	2002-2016
Ship fire in ro-ro space	FIRESAFE II (2018)	EMSA data	Ro-pax	5.28E-03	2002-2016
Ship fire in ro-ro space	DNV GL (2016)	a)	Ro-pax above 4 000 GT	2.0E-03	2005-2016
Ship fire in ro-ro space	**LASH FIRE**	**LASH FIRE database**	**Ro-pax above 5 000 GT**	**3.21E-3**	**2002-2018**
Ro-ro cargo ships					
Serious accident due to fire or explosion	Papanikolaou et al. (2015)	IHS Seaweb	Ro-ro cargo	3.32E-03	1990-2012
Ship fire in ro-ro space	DNV GL (2016)	a)	Ro-ro cargo above 4 000 GT	1.19E-03	2005-2016
Ship fire in ro-ro space	**LASH FIRE**	**LASH FIRE database**	**Ro-ro cargo above 5 000 GT**	**1.59E-3**	**2002-2018**
Vehicle carriers					
Ship fire in ro-ro space	DNV GL (2016)	a)	Vehicle carrier above 4 000 GT	0.91E-03	2005-2016
Ship fire in ro-ro space	**LASH FIRE**	**LASH FIRE database**	**Vehicle carrier above 5 000 GT**	**1.54E-3**	**2002-2018**

a) International databases, class records, EMSA marine casualty reports, incident reports, interviews with owners.

11.4.2.3 Frequency of fires per lane meter-year

For ro-ro passenger ships and ro-ro cargo ships, it is also interesting to take a look at the frequency of fires per lane meter-year. Table 29 summarises these exposure times.

Table 29. Exposure time (in lane meter-years) for ro-ro passenger and ro-ro cargo ships, for the period 2002-2018

	Ro-pax ships	Ro-ro cargo ships	TOTAL
Exposure time	13 347 728	16 278 603	29 626 331

Table 30 provides the fire frequencies for all accidents and only serious accidents in ro-ro spaces amongst ro-ro passenger ships and ro-ro cargo ships, per lane meter-year. Again, it is amongst the ro-ro passenger ships that the frequency is the highest (fires in ro-ro spaces are three times more frequent amongst them than amongst ro-ro cargo ships).

Table 30. Fire frequencies in ro-ro spaces per type of ro-ro ships, per lane meter-year

Ships type	Exposure Time (LMyears)	Number of accidents	Number of serious accidents	Fire frequency – All accidents ($LMyear^{-1}$)	Fire frequency – Serious accidents ($LMyear^{-1}$)
Ro-pax ships	13 347 728	30	22	2.25E-6	1.65E-6
Ro-ro cargo ships	16 278 603	12	10	7.37E-7	6.14E-7
TOTAL	29 626 331	42	32	2.03E-6	1.55E-6

11.4.2.4 Frequency of fires per car equivalent unit year

For vehicle carriers, the frequency of fires in ro-ro spaces per car equivalent unit-year is also pertinent to study. This exposure time is indicated in Table 31.

Table 31. Exposure time (in car equivalent unit-years) for vehicle carriers, for the period 2002-2018

	Vehicle carriers
Exposure time	54 052 801

Table 32 provides the fire frequency for all accidents and only serious accidents in ro-ro spaces amongst the vehicle carrier fleet, per car equivalent unit-year.

Table 32. Fire frequencies in ro-ro spaces per type of ro-ro ships, per car equivalent unit-year

Ships type	Exposure Time (CEUyears)	Number of accidents	Number of serious accidents	Fire frequency – All accidents ($CEUyear^{-1}$)	Fire frequency – Serious accidents ($CEUyear^{-1}$)
Vehicle carriers	54 052 801	18	14	3.33E-7	2.59E-7

11.4.3 Frequency of fires in ro-ro spaces per ro-ro space type

11.4.3.1 Ro-ro passenger ships

It is also pertinent to study the distribution of the accidents that took place in ro-ro passenger ships per type of ro-ro space. Figure 67 provides the number of lane meter-years for each type of ro-ro space amongst the ro-ro passenger fleet. Table 33 summarises the fire frequencies. Even though the number of fires in closed ro-ro spaces is the highest of the three numbers (24 fires listed), when the fire frequencies for each type of ro-ro spaces were computed, the fire ignition for one unit of lane meter is as frequent in open ro-ro space as in closed ro-ro spaces.

The frequency of fire on weather decks is lower than for the two other types of ro-ro spaces. This may be because of its particular arrangement and the environment making fire development more difficult. During a fire, heat and smoke are more likely to dissipate into the air, hence the fire will have less serious consequences and its severity may be lower than 'LASH FIRE less serious' defined in section 9.3.4. However, the result could also be a consequence of the sample size.

In a preliminary study, using a less fine distribution of the different types of ro-ro spaces, the orders of magnitude obtained for the frequencies were the same, i.e. about 1E-06 per lane meter-year (even though the ignition frequency for open ro-ro spaces varies from single to double). However, it is likely that the use of a smaller dataset of ship characteristics and arrangements would lead to a variation in these frequencies.

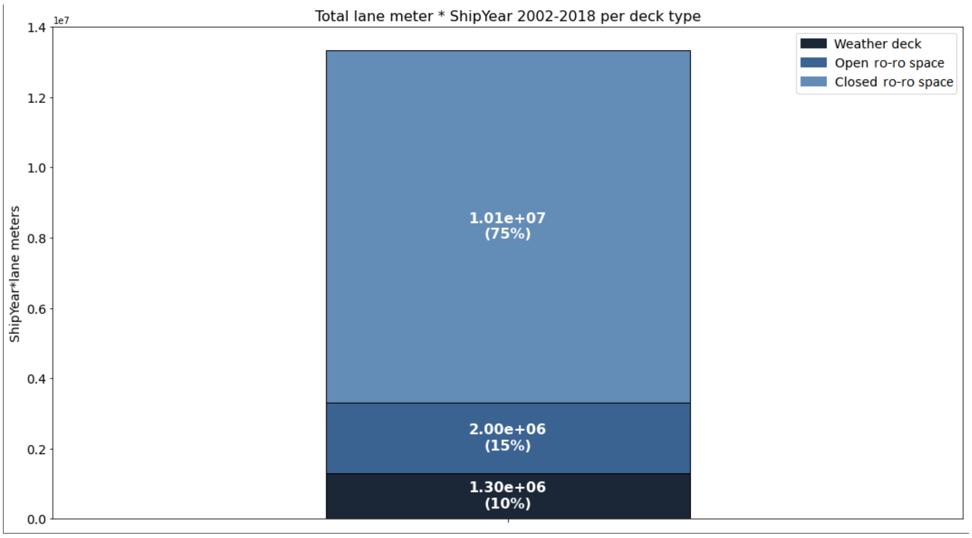

Figure 67. Distribution of lane meter-years for the three types of ro-ro spaces in the ro-ro passenger fleet.

Table 33. Frequency of fires per type of ro-ro space in ro-ro passenger ships, per lane-meter-year

Type of space	Exposure time (LMyears)	Number of accidents	Space dependent-fire frequency – All accidents (LMyear^{-1})
Closed ro-ro space	1.01E7	24	2.38E-6
Open ro-ro space	2.00E6	5	2.50E-6
Weather deck	1.30E6	1	7.69E-7

11.4.3.2 Vehicle carriers

For the vehicle carriers, all accidents were assumed to occur in closed ro-ro spaces. The fire frequency is summarised in Table 34 (Table 34 contains the same information as Table 32).

Table 34. Frequency of fires per type of ro-ro space in vehicle carriers, per car equivalent unit-year

Type of space	Exposure time (CEUyears)	Number of accidents	Space dependent-fire frequency – All accidents (CEUyear^{-1})
Closed ro-ro space	54 052 801	18	3.33E-7

12 Conclusion

Main author of the chapter: Eric De Carvalho, BV.

A methodology, based on data quality assessment, was developed to build a homogeneous and unbiased database which meets the FSA requirements. The WP04 database was built following this methodology.

Different case by case studies were performed on datasets provided by the ship operators in the LASH FIRE Maritime Operators Advisory Group (MOAG) and by EMSA. Those studies enabled to refine the scope of the FSA study and to build additional key features for the risk model construction. Several regression models were developed to define key features.

As a result, one database related to fires in ro-ro spaces and one related to fleet and ship characteristics were built by aggregating the different pools of information. They consist of four MS Excel files:

- WP04 Fleet database:
  - WP04 Fleet General database: ship level information with no imputed data;
  - WP04 Fleet Imputed database: ship level information for features with imputed data;
  - WP04 Fleet ShipYear database: ship level information with shipyears; and
- WP04 Casualty database: casualty level information with data from an aggregation of databases.

The databases form what in this deliverable are referred to as the **WP04 database**. This WP04 comprehensive database will be used only in the context of the LASH FIRE project and will not be used nor maintained after the project. As per the consortium agreement [2], access to raw data is restricted to LASH FIRE beneficiary Bureau Veritas only.

The initial objective of transparency and openness, i.e. to as much as possible use “public” database(s) without any “entrance fee”, was not fully achieved. However, all the different steps of the WP04 database construction were detailed and made transparent. Provided the availability of data used in the project, anyone should be able to review or redo this work.

The WP04 database and other relevant information collected but not included in the database were processed to draw statistics for the LASH FIRE fleet and fires in ro-ro spaces.

The ro-ro ships constituting the LASH FIRE fleet were described. Those fleet statistics provide an extensive overview of the fleet considered for the FSA study. The distributions of key parameters can later be used in the risk model.

The frequency of fire ignition in ro-ro spaces were drawn per ship type but also per ro-ro space type (when possible). This frequency is a prerequisite to the development of the risk model. The fire frequency per type and unit of ro-ro space, i.e. lane meter-year and car equivalent unit-year, should pave the way for a risk model that better matches the space-type categorisation in the SOLAS Convention, and it better reflects the effectiveness of solutions depending on ship size.

This deliverable is the summary and conclusion of task T04.3 ‘Comprehensive ro-ro space fire database and statistical analysis’. Its results will be used for the next WP04 tasks, i.e. the development of the ro-ro fire risk model and in particular its quantification.

It contributes to the strategic objective:

> “To provide a **recognized technical basis** for the revision of international **IMO regulations**, which greatly **enhances fire prevention** and **ensures independent management of fires** on ro-ro ships in current and **future** fire safety challenges”;

and to specific objective 3:

> “LASH FIRE will provide a **technical basis** for future revisions of regulations by **assessing risk reduction and economic properties of solutions**”.

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14 Indexes

14.1 Index of tables

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15 ANNEXES

15.1 ANNEX A: List of public accident investigation reports

Table 35. List of public accident investigation reports related to fires originating in ro-ro spaces

Ship Name	IMO No.	Ship Type	Casualty Date	Author	Available on	Downloadable on GISIS MCI?
JOSEPH AND CLARA SMALLWOOD	8604797	Ro-pax	12/05/2003	Canada (TSB)	http://www.tsb.gc.ca/eng/rapports-reports/marine/2003/m03n0050/m03n0050.pdf	Yes
VINCENZO FLORIO	9144732	Ro-pax	19/12/2004	Italy	-	Yes
AMORELLA	8601915	Ro-pax	19/05/2005	Finland	http://www.turvallisuustutkinta.fi/material/attachments/otkes/tutkintaselostukset/en/vesiliikenneonnettomuuksientutkinta/2005/b12005m_tutkintaselostus/b12005m_tutkintaselostus.pdf	No(1)
AL SALAM BOCCACCIO 98	6921282	Ro-pax	03/02/2006	Panama	-	Yes
COMMODORE CLIPPER	9201750	Ro-pax	16/06/2010	The United Kingdom (MAIB)	https://assets.digital.cabinet-office.gov.uk/media/547c6fb0e5274a428d000037/CommodoreClipperReport.pdf	Yes
LISCO GLORIA	9212151	Ro-pax	09/10/2010	Germany (BSU) / Lithuania	http://www.bsu-bund.de/SharedDocs/pdf/EN/Investigation_Report/2012/Investigation_Report_445_10.pdf?__blob=publicationFile	Yes

Ship Name	IMO No.	Ship Type	Casualty Date	Author	Available on	Downloadable on GISIS MCI?
PEARL OF SCANDINAVIA	8701674	Ro-pax	17/11/2010	Denmark (DMAIB)	https://dmaib.dk/media/9155/pearl-of-scandinavia-fire-on-17-november-2010.pdf	Yes
MECKLENBURG-VORPOMMERN	9131797	Ro-pax	19/11/2010	Germany (BSU)	http://www.bsu-bund.de/SharedDocs/pdf/EN/Investigation_Report/2012/Investigation_Report_515_10.pdf?__blob=publicationFile	Yes
KRITI II	7814058	Ro-pax	19/11/2012	Greece (HBMCI)	http://www.hbmci.gov.gr/js/investigation%20report/final/01-2012%20KRITI%20II.pdf	Not available for download(2)
VICTORIA SEAWAYS	9350721	Ro-pax	23/04/2013	Lithuania	http://www.bsu-bund.de/SharedDocs/pdf/EN/Investigation_Report/2014/Investigation_Report_MARINE_SHIP_ACCIDENT.pdf?__blob=publicationFile	Yes
URD	7826855	Ro-pax	04/03/2014	Denmark (DMAIB)	https://dmaib.com/media/9102/urd-fire-on-4-march-2014.pdf	Yes
NORMAN ATLANTIC	9435466	Ro-pax	28/12/2014	Italy (MIT)	http://hbmci.gov.gr/js/investigation%20report/Final%20as%20Interested%20Authority/2014-NORMAN%20ATLANTIC.pdf	Yes
SORRENTO	9264312	Ro-pax	28/04/2015	Italy (MIT)	https://www.mitma.es/recursos_mfom/comodin/recursos/sorrento_final_investigation_report_en_def.pdf	Yes
STENA SPIRIT	7907661	Ro-pax	31/08/2016	Bahamas / Poland (SMAIC)	https://www.bahamasmaritime.com/wp-content/uploads/2017/12/M.v-Stena-Spirit-Marine-Safety-Investigation-Report-Published.pdf	No

Ship Name	IMO No.	Ship Type	Casualty Date	Author	Available on	Downloadable on GISIS MCI?
SCHIEBORG	9188233	Ro-ro cargo	08/01/2005	The Netherlands	https://zoek.officielebekendmakingen.nl/stcrt-2006-86-URS452.pdf	No
UND ADRIYATIK	9215488	Ro-ro cargo	06/02/2008	Turkey	http://www.ubak.gov.tr/BLSM_WIYS/KAIK/en/en_Doc/20180629_110537_76347_2_64.pdf	Not available for download
BRITANNIA SEAWAY	9153032	Ro-ro cargo	16/11/2013	Denmark (DMAIB)	https://dmaib.com/media/9120/britannia-seaways-fire-on-16-nov-2013.pdf	Yes
CORONA SEAWAYS	9357597	Ro-ro cargo	04/12/2013	The United Kingdom (MAIB)	https://assets.digital.cabinet-office.gov.uk/media/547c6f1f40f0b60244000005/CoronaSeaways.pdf	Yes
REPUBBLICA DI ROMA	9009504	Ro-ro cargo	10/04/2014	Italy (MIT)	-	Yes
PYXIS	8514083	Vehicle carrier	14/10/2008	Japan	https://www.mlit.go.jp/jtsb/eng-mar_report/2011/2008tk0006e.pdf	Yes
ALLIANCE NORFOLK	9332547	Vehicle carrier	10/03/2012	The United States of America (NTSB)	https://www.ntsb.gov/investigations/AccidentReports/Reports/MAB1305.pdf	No
GOLDEN FAN	8511263	Vehicle carrier	22/06/2013	Panama	-	Yes

Ship Name	IMO No.	Ship Type	Casualty Date	Author	Available on	Downloadable on GISIS MCI?
COURAGE	8919922	Vehicle carrier	02/06/2015	The United States of America (NTSB)	https://www.ntsb.gov/investigations/AccidentReports/Reports/MAB1724.pdf	No
SILVER SKY	8519722	Vehicle carrier	19/10/2016	Panama	-	Yes
HONOR	9126297	Vehicle carrier	24/02/2017	The United States of America (NTSB)	https://www.ntsb.gov/investigations/AccidentReports/Reports/MAB1807.pdf	No
AUTO BANNER	8608066	Vehicle carrier	21/05/2018	Republic of Korea	-	Yes

(1) "No" = Casualty event not found in GISIS MCI or casualty event found but with no accident investigation report.

(2) "Not available for download" = accident investigation report found in GISIS MCI but not available for download with a public access at the time of the search (31-10-2020).

15.2 ANNEX B: List of data fields – WP04 databases

Table 36. List of data fields – WP04 Fleet General database

Feature	Type	Data source
LRIMOShipNo	numerical	IHS
ShipName	text	IHS
ShiptypeLevel5	categorical	IHS
StatCode5	categorical	IHS
ShiptypeGroup	categorical	IHS
ShipStatus	categorical	IHS
ShipStatusCode	categorical	IHS
ShipStatusEffectiveDate	date	IHS
ShipStatusEffDate	date	IHS
Deadweight	numerical	IHS
GrossTonnage	numerical	IHS
FlagCode	categorical	IHS
FlagName	categorical	IHS
AlterationsDescriptiveNarrative	text	IHS
AuxiliaryGeneratorsDescriptiveNarrative	text	IHS
BoilersDescriptiveNarrative	text	IHS
BollardPull	numerical	IHS
BreadthExtreme	numerical	IHS
BreadthMoulded	numerical	IHS
CargoCapacitiesNarrative	text	IHS
Crew	numerical	IHS
CargoTankHeatExchangerMaterial		IHS
ClassificationSocietyCode	categorical	IHS
ClassNarrative	text	IHS
ConstructionDescriptiveNarrative	text	IHS
ConsumptionSpeed1	numerical	IHS
ConsumptionSpeed2	numerical	IHS
ConsumptionValue1	numerical	IHS
ConsumptionValue2	numerical	IHS
DateOfBuild	date	IHS
DateOfB	date	IHS
DeathDate	date	IHS
DeaDate	date	IHS
DeliveryDate	date	IHS
DelDate	date	IHS
Depth	numerical	IHS
DischargeDiameterofCargoManifold	numerical	IHS
Displacement	numerical	IHS
Draught	numerical	IHS
FlashPointOver60c		IHS
FlashPointUnder60c		IHS

Feature	Type	Data source
FuelType1Capacity	numerical	IHS
FuelType1Code	categorical	IHS
FuelType1First	categorical	IHS
FuelType2Capacity	numerical	IHS
FuelType2Code	categorical	IHS
GearDescriptiveNarrative	text	IHS
HatchesDescriptiveNarrative	text	IHS
HoldsDescriptiveNarrative	text	IHS
HullMaterialCode	categorical	IHS
HullMaterial	categorical	IHS
HullShapeCode	categorical	IHS
HullType	categorical	IHS
IceCapabilityDescriptiveNarrative	text	IHS
InsulatedCapacity	numerical	IHS
KeelLaidDate	date	IHS
KeelLDate	date	IHS
LanesDoorsRampsNarrative	text	IHS
LengthBetweenPerpendicularsLBP	numerical	IHS
LengthOverallLOA	numerical	IHS
MaritimeMobileServiceIdentityMMSINumber	numerical	IHS
NewbuildPriceUSD	numerical	IHS
NumberOfAuxiliaryEngines	numerical	IHS
NumberofHolds	numerical	IHS
NumberofMainEngines	numerical	IHS
Operator	categorical	IHS
OperatorCompanyCode	categorical	IHS
RegisteredOwner	categorical	IHS
RegisteredOwnerCode	categorical	IHS
PrimeMoverDescriptiveNarrative	text	IHS
PrimeMoverDescriptiveOverviewNarrative	text	IHS
PropellerManufacturer	categorical	IHS
PropellerType	categorical	IHS
PropulsionTypeCode	categorical	IHS
PropulsionType	categorical	IHS
ReeferPoints	numerical	IHS
SalePriceUSD	numerical	IHS
Shipbuilder	categorical	IHS
ShipbuilderCompanyCode	categorical	IHS
Speedmax	numerical	IHS
Speedservice	numerical	IHS
TempMaximum		IHS
ThrustersDescriptiveNarrative	text	IHS
VapourRecoverySystem	categorical	IHS
AuxiliaryEnginesNarrative	text	IHS
DeliveryDateComp	date	IHS

Feature	Type	Data source
SpeedAggregate	numerical	LASH FIRE
LengthAggregate	numerical	LASH FIRE
Froude	numerical	LASH FIRE
Ship has been IACS	categorical	LASH FIRE
Ship currently IACS	categorical	LASH FIRE
Lanes (l,w,h)	text	IHS
L lanes	numerical	LASH FIRE
w lanes	numerical	LASH FIRE
h lanes	numerical	LASH FIRE
Passengers Narrative	text	IHS
Passengers	numerical	LASH FIRE
berths	numerical	LASH FIRE
unberthed	numerical	LASH FIRE
Total Passengers	numerical	LASH FIRE
CEU	numerical	LASH FIRE
AgeYear	numerical	LASH FIRE

Table 37. List of data fields – WP04 Fleet Imputed database

Feature	Type	Data source
LRIMOShipNo	numerical	IHS
ShipName	text	IHS
StatCode5	categorical	IHS
L_lane_imputed	numerical	LASH FIRE
TotalPassengers_imputed	numerical	LASH FIRE
CEU_imputed	numerical	LASH FIRE
WeatherDeckPercent	numerical	LASH FIRE
OpenDeckPercent	numerical	LASH FIRE
ClosedDeckPercent	numerical	LASH FIRE

Table 38. List of data fields – WP04 Fleet Shipyear database

Feature	Type	Data source
LRIMOShipNo	numerical	IHS
ShipName	text	IHS
StatCode5	categorical	IHS
SY_2002	numerical	LASH FIRE
SY_2003	numerical	LASH FIRE
SY_2004	numerical	LASH FIRE
SY_2005	numerical	LASH FIRE
SY_2006	numerical	LASH FIRE
SY_2007	numerical	LASH FIRE
SY_2008	numerical	LASH FIRE
SY_2009	numerical	LASH FIRE
SY_2010	numerical	LASH FIRE

Feature	Type	Data source
SY_2011	numerical	LASH FIRE
SY_2012	numerical	LASH FIRE
SY_2013	numerical	LASH FIRE
SY_2014	numerical	LASH FIRE
SY_2015	numerical	LASH FIRE
SY_2016	numerical	LASH FIRE
SY_2017	numerical	LASH FIRE
SY_2018	numerical	LASH FIRE
TotalShipYears	numerical	LASH FIRE

Table 39. List of data fields – WP04 Casualty database

Feature	Type	Data source
CasualtyID	numerical	IHS
IncidentDate	date	IHS
LRIMOShipNo	categorical	IHS
Severity (IHS)	categorical	IHS
Severity (LASHFIRE)	categorical	LASH FIRE
DangerousCargo	categorical	IHS
MarsdenGridRef	numerical	IHS
KilledIndicator	categorical	IHS
MissingIndicator	categorical	IHS
OwnerAtTimeOfIncident	text	IHS
PollutionDetails		IHS
PollutionUnitsCode		IHS
PrecisText	text	IHS
ComplimentaryText (IHS)	text	IHS
TotalLossIndicator	categorical	IHS
CargoText1	text	IHS
CargoText2	text	IHS
CargoText3	text	IHS
PollutionOccured	categorical	IHS
PollutionQuantity		IHS
PollutionTypeCode		IHS
IACS AtTimeOfIncident	categorical	IHS
IncidentYear	numerical	IHS
Ship has been IACS	categorical	LASH FIRE
Ship currently IACS	categorical	LASH FIRE
IACS AtTimeOfIncident from ShipHist	categorical	LASH FIRE
WeatherAtTimeOfIncident	categorical	IHS
Zone	text	IHS
CargoStatus	categorical	IHS
DetailStatus	categorical	IHS
LocationType	categorical	IHS
RemovalFromScene	categorical	IHS

Feature	Type	Data source
ShipName	text	IHS
StatCode5	categorical	IHS
Class_Aggregated	Categorical	LASH FIRE
Flag_Aggregated	Categorical	LASH FIRE
GrossTonnage_Aggregated	numerical	LASH FIRE
Deadweight_Aggregated	numerical	LASH FIRE
GeneralCargo_Aggregated	text	LASH FIRE
NumberKilled_Aggregated	numerical	LASH FIRE
NumberInjured_Aggregated	numerical	LASH FIRE
Latitude_Aggregated	latitude	LASH FIRE
Longitude_Aggregated	longitude	LASH FIRE
TypeOfShipLASHFIRE	categorical	LASH FIRE
Fire_Origin	categorical	LASH FIRE
Severity (IMO)	categorical	GISIS
Location	text	GISIS
SummaryOfEvents (GISIS)	text	GISIS
Location_GISIS	categorical	LASH FIRE
Cause_GISIS	categorical	LASH FIRE
CauseDetailed_GISIS	categorical	GISIS
Consequences1	categorical	GISIS
CrewOnboard1	numerical	GISIS
PassengersOnboard1	numerical	GISIS
OthersOnboard1	numerical	GISIS

15.3 ANNEX C: SOLAS vs non-SOLAS classification

Main author of the chapter: Matthieu Gadel, BV.

15.3.1 Context

As the information on the SOLAS or non-SOLAS status of a ship is not available in most databases, in most FSA studies, a threshold on the gross tonnage is used as a way to separate international, SOLAS compliant ships from domestic, non-SOLAS compliant ships (SAFEDOR, GOALDS, EMSA 3, and FIRESAFE).

As the EMSA provided the LASH FIRE project with a dataset of domestic and international ships, different thresholds on the gross tonnage have been studied to challenge this approach and classify ships into:

- SOLAS ships (i.e. international and EU domestic class A ships); and
- Non-SOLAS ships (i.e. domestic class B, C, and D).

In order to stay in line with other FSA studies, only models with a threshold on the gross tonnage have been studied. Moreover, it is to be noted that the EMSA dataset is only populated by ro-ro passenger ships but that the results of this study have been extended to ro-ro cargo ships and vehicle carriers (as for other filtering criteria used for LASH FIRE fleet definition).

15.3.2 Description of dataset

The data used for the study has been provided by the EMSA and is only populated by ro-ro passenger ships.

The main data source used in this study comes from the REFIT project. This source provides a list of EU domestic ships with indication of their class A, B, C or D. A list of international ships has also been added to the dataset, to limit the potential bias, i.e. in the case of the existence of an important number of international ships with a small gross tonnage.

Below is a description of the different data sources used to build the dataset:

- A list of domestic ships from the REFIT project, with indication on their domestic class. The list has been built by an EMSA algorithm, which identifies the status “domestic” or “international” of a ship based on its last recorded voyage. Ships tagged domestic are ships which have not been called in a distinct country since at least one year, considering the years between 2011 and 2015.
- A list of domestic ships provided by the EU Member States. It is to be noted that, from an expert point of view, this list of ships does not provide a reliable picture, as some ships flagged domestic in that database can also have international certificate.
- The list of Port State Control (THETIS), which provides a reliable picture of all ships sailing on the European waters.

After discussions with EMSA experts, it was decided to tag as international ship, ships that are in the THETIS database, but not in the Member State database. This ensures that the ships most probable to be international are added to the database.

15.3.3 Data preparation

The dataset was filtered with the LASH FIRE fleet criteria (8.3), except from gross tonnage.

Two classes have been defined for the classification problem:

- Class 0: SOLAS ships (international and domestic class A); and
- Class 1: Non-SOLAS ships (domestic class B, C, and D).

15.3.4 Dataset analysis

The distribution of gross tonnage, for the two classes of SOLAS ships and non-SOLAS ships are presented in Figure 68 below.

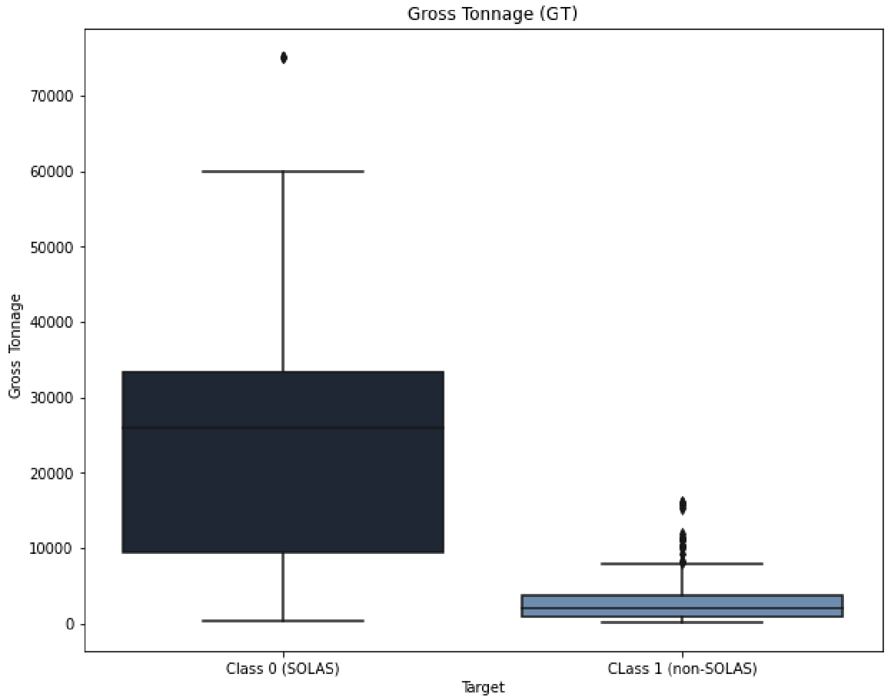

Figure 68. Distribution of gross tonnage for Class 0 and 1.

The boxplots underline an important difference between distributions of the two classes, with non-SOLAS ships having a significantly smaller gross tonnage. In Table 40 below, a description of the main statistical values of the two classes is presented.

Table 40. Gross tonnage statistics for Class 0 and 1

	Class 0 – SOLAS	Class 1 – non-SOLAS
Mean	23000 GT	3000 GT
25%	9500 GT	990 GT
50%	26000 GT	2000 GT
75%	33000 GT	3800 GT

An important number of non-SOLAS ship appears to be above 1 000 GT (only 25% are below 1 000 GT), which confirms the presumption to study different thresholds for classification.

15.3.5 Model definition and classification error

A simple threshold model has been defined for this binary classification problem, setting *y* as the target value:

$$y = \begin{cases} 0, & if\ GT\ \geq thres \\ 1, & if\ GT < thres \end{cases}$$

For a binary classification problem, results are commonly presented in the form of a confusion matrix. Below, the confusion matrices for different thresholds are presented (Table 41). Each row represents the instance of a predicted class and each column represents the instance of an actual class:

Table 41. Confusion matrices for each classification threshold

Threshold : 1 000 GT	Predicted values	
Trues values	**0**	**1**
0	178	9
1	165	73

Threshold : 4 000 GT	Predicted values	
Trues values	**0**	**1**
0	155	32
1	34	204

Threshold : 5 000 GT	Predicted values	
Trues values	**0**	**1**
0	149	38
1	16	222

Threshold : 6 000 GT	Predicted values	
Trues values	**0**	**1**
0	147	40
1	8	230

Threshold : 7 000 GT	Predicted values	
Trues values	**0**	**1**
0	145	42
1	0	238

F1-score score are calculated for the different thresholds:

$$F_1 = 2.\frac{precision\ .\ recall}{precision + recall}$$

Where the *precision* is the fraction of relevant instances among the retrieved instances and the *recall* is the fraction or relevant instances that were retrieved.

F1-score is a metrics commonly used to estimate the pertinence of a classifier taking into account the trade-off between *precision* and *recall*. The highest F1 score is 1 indicating perfect *precision* and *recall*, and the lowest possible value is 0.

In the Table 41 below, the F1-scores of each classification threshold are presented:

Table 42. F1-scores for each classification threshold

Threshold	1 000 GT	4 000 GT	5 000 GT	6 000 GT	7 000 GT
F1-score	0.61	0.84	0.87	0.88	0.90

The 1 000 GT threshold has a low F1-score compared to the other thresholds. Starting from 5 000 GT and above the performance of classifiers can be considered equivalent. To remains in line with other FSA studies where a threshold of 1000 GT was considered, the smallest threshold for equivalent F1 score (i.e. 5 000 GT threshold) is considered for the remaining of the study.

15.3.6 Impact on the LASH FIRE study

The impact of the modification of the gross tonnage threshold on the risk frequency has been investigated, and it is to be noted that the number of casualties remains the same for thresholds of 1 000 GT, 5 000 GT, 6 000 GT, 7 000 GT.

In Figure 69 below, the impact on total number of shipyears for the ro-ro passenger fleet is presented. A decrease in the number of shipyears of 12% from 1 000 GT to 2 000 GT, 9% from 2 000 GT to 3 000 GT and 5-6% for the other GT can be observed.

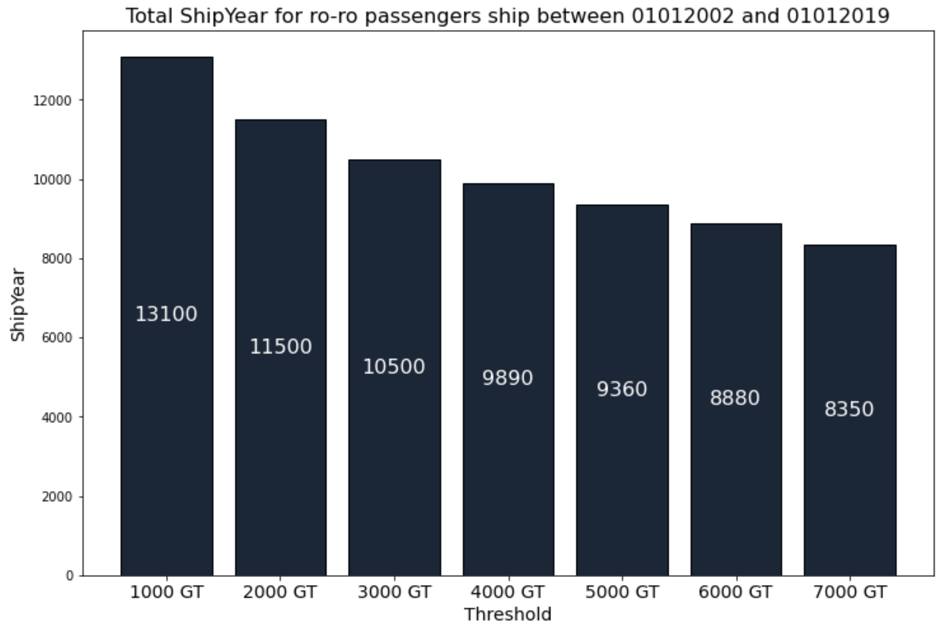

Figure 69. Impact on the different classification thresholds on the total number of shipyears for ro-ro passenger ships from the LASH FIRE fleet.

15.3.7 Limitation and empirical estimation on world fleet

As this study was based on an EU fleet dataset, this approach might be biased when applied to the world fleet of ro-ro ships. Experts were asked for their judgement, but no definitive statement was received.

To have an empirical idea of the error, a random sampling of ships with a GT between 1 000 GT and 5 000 GT was made from the LASH FIRE world fleet. Then, the general behaviour of the ship was estimated on the last port visited (Table 43).

Table 43. Last port visited by the ships from the random sampling

National	Close regional water	Long Mediterranean
13	4	1

It appeared that most of the sampled ships were actually domestic ships during their last voyage. Other ships were not performing strictly domestic voyages but were working in close regional waters, such as ferries between neighbouring countries (Red Sea ferries, American Great Lakes, close Mediterranean countries...).

As the classification is based only on ship gross tonnage, it seems difficult, without any information on the ships real voyage, to conclude on the nature international or domestic of a ship. Moreover, it appears that an important number of ships performing domestic voyages also have an international certificate.

Therefore, the LASH FIRE position is to set a threshold on gross tonnage in order to separate the international ships from ships having a domestic-behaviour (i.e. regional voyage), as the second category of ships are not strictly homogeneous with the LASH FIRE fleet.

Based on the above, a threshold of 5 000 GT is considered in WP04.

15.4 ANNEX D: Data imputation

Main author of the chapter: Matthieu Gadel, BV.

15.4.1 Context

Amongst features of the WP04 Fleet General database, some of them have a significant amount of missing values. This is an issue when those features are to be used as input data to the risk model.

Table 44. Key features for risk model with missing values in the WP04 database

LASH FIRE category	Feature	Missing values
Ro-ro passenger ship	L lanes	21.5%
	Total Passengers	1.7%
Ro-ro cargo ship	L lanes	7.4%
Vehicle Carrier	CEU	5.1%

The easiest solution to handle missing values is to not include them in the dataset. This approach was not considered as LASH FIRE aims at presenting an accurate representation of shipyears. Therefore, considering the relatively high amount of missing data, different data imputation technics were studied and used. For the sake of reproducibility, the missing data were imputed through regression techniques.

15.4.2 Description of dataset

The WP04 Fleet General database was used for the study.

15.4.3 Ro-ro passengers ships

15.4.3.1 Dataset analysis

For ro-ro passenger ships, target features were ‘Total Passengers’ and ‘L lanes’.

In the matrix (Figure 70) below, scatterplots between targets ‘Total Passengers’ and ‘L lanes’, and other features are presented; the features univariate distribution is presented in plots along one of the matrix’ diagonals.

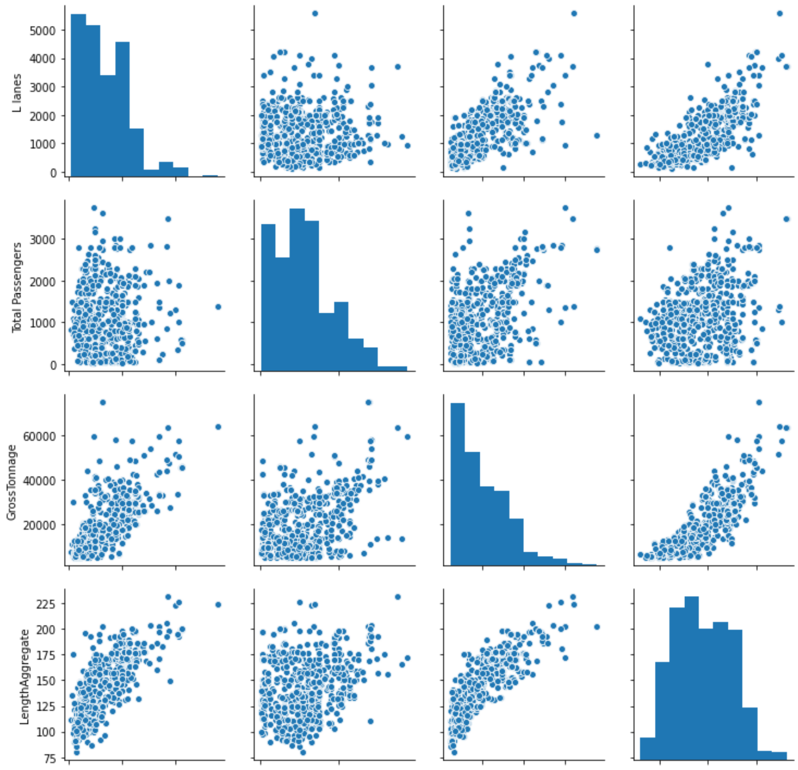

Figure 70. Scatterplots between 'L lanes', 'Total Passengers', 'GrossTonnage', LengthAggregate' – Ro-ro passenger ships.

'Total Passengers' does not seem to be correlated with other features.

Some correlations between target feature 'L lanes' and other features 'Gross Tonnage', 'LengthAggregate' and 'BreadthMoulded' were identified and further investigated. Nevertheless 'L lanes' seems to present an important dispersion for all correlated features.

15.4.3.2 Data preparation

Outliers were identified with boxplots and withdrawn from the dataset (Figure 71).

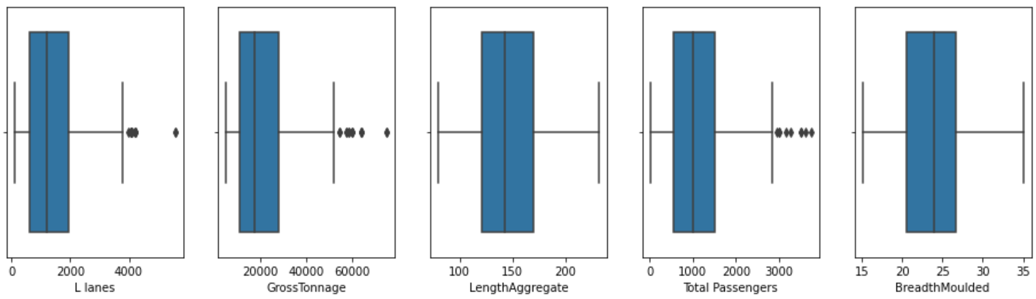

Figure 71. Boxplots of lane meters, gross tonnage, length aggregate, total passengers and breadth moulded – Ro-ro passenger ships.

All data have been standardised.

15.4.3.3 Model for 'L lanes'

Based on the consideration above (see section 15.4.3.1), polynomial models built on features 'Gross Tonnage', 'LengthAggregate', 'Total Passengers' and 'BreadthMoulded' were studied.

Ridge regression was performed on the polynomial transformation of input features in order to avoid overfitting of the dispersed input data, and the hyperparameter “lambda” was tuned by cross validation. A threshold was set at the minimum ‘L lanes’ value of the training set.

Coefficients were estimated with *sklearn RidgeCV* [40]:

$$\begin{cases} L\ lanes_{missing} = 190 * GT_s - 210 * Pax_s + 300\ Lpp_s + 210 * B_s + 1300 \\ L\ lanes \geq 100 \end{cases}$$

Where features have been standardised and are defined as:

$$GT_s = \frac{GrossTonnage - 19000}{10000}$$

$$LPP_s = \frac{LengthBetweenPerpendiculars - 140}{27}$$

$$Pax_s = \frac{Total\ Passengers - 1100}{680}$$

$$B_s = \frac{BreadthMoulded - 23}{3.6}$$

15.4.3.4 Model validation

Model errors have been estimated by Leave-One-Out (LOO) cross validation to prevent overfitting and estimate the model’s ability to predict new data. This means that for a sample of size n, where y is the target and X the features, the model is fitted on (n-1) samples and the remaining value of X is used to predict y_pred. The L2 error of the model is then evaluated by the error between y_pred and the true y value. The process is then repeated for the (n-1) samples remaining.

The RMSE and the coefficient of determination Q2, which indicates how well regression predictions approximate real data points, defined by LOO are presented below in Table 45.

Table 45. Estimation of model errors – Ro-ro passenger ships – ‘L lanes’

RMSE	Q2
454	0.66

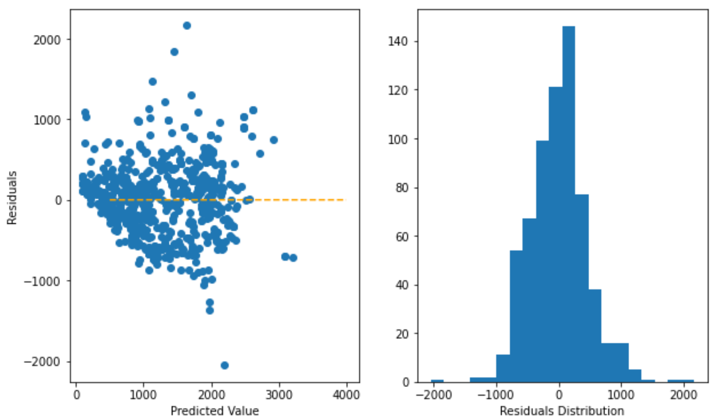

Figure 72. Model residuals – Ro-ro passenger ships.

Residuals (difference between predicted and true values) appeared to be normally distributed and to a lesser extent homoscedasticity (Figure 72).

15.4.3.5 Model for 'Total Passenger'

Given the fact that no direct correlation appeared and the small amount of data involved (1.7% of values missing), missing values have been imputed as the mean of the 'Total Passenger':

$$Total\ Passengers_{missing} = \overline{TotalPassengers} = 1080$$

The root of the mean square error (RMSE) defined by LOO is presented below in Table 46.

Table 46: Estimation of model errors – Ro-ro passenger ships – 'Total Passenger'

RMSE
692

15.4.4 Ro-ro cargo ship

15.4.4.1 Dataset analysis

For ro-ro cargo ships, the target feature was 'L lanes'.

In the matrix (Figure 73) below, scatterplots between target 'L lanes' and other features are presented.

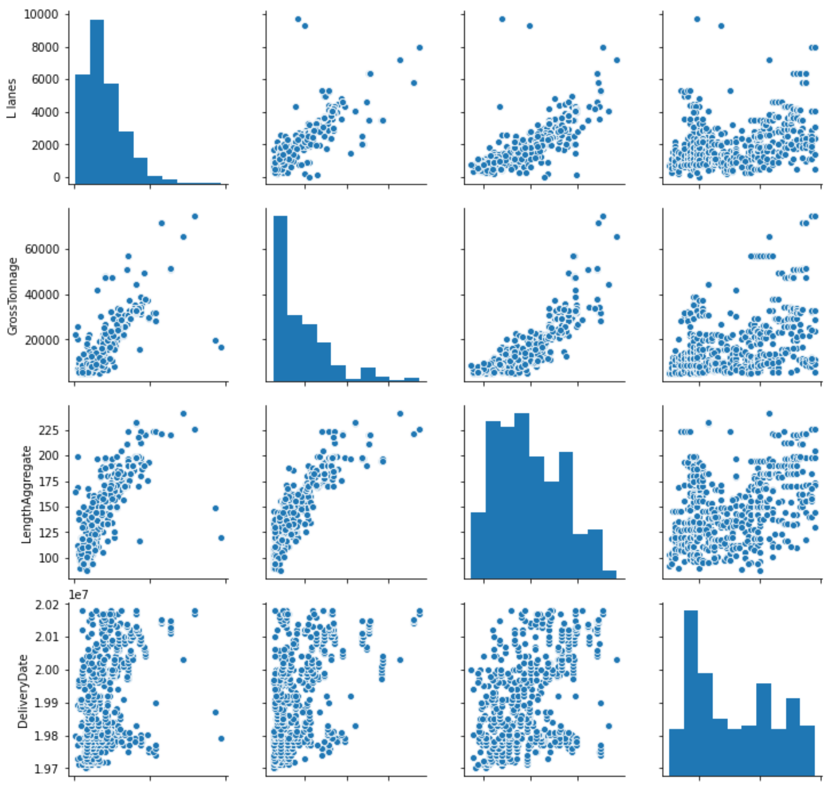

Figure 73. Scatterplots between 'L lanes', 'GrossTonnage', LengthAggregate', 'DeliveryDate' – Ro-ro cargo ships.

The scatterplots in Figure 73 underline some correlations between the target feature ‘L lanes’, and other features ‘GrossTonnage’ and ‘LengthAggregate’. ‘DeliveryDate’ and ‘SpeedAggregate’ show no correlation with the target value. The target feature ‘L lane’ presents a skewed distribution on the left.

A regression of features ‘GrossTonnage’ and ‘LengthAggregate’ has been studied in the following sections.

15.4.4.2 Data preparation

Outliers were identified using boxplots and withdrawn from dataset (Figure 74).

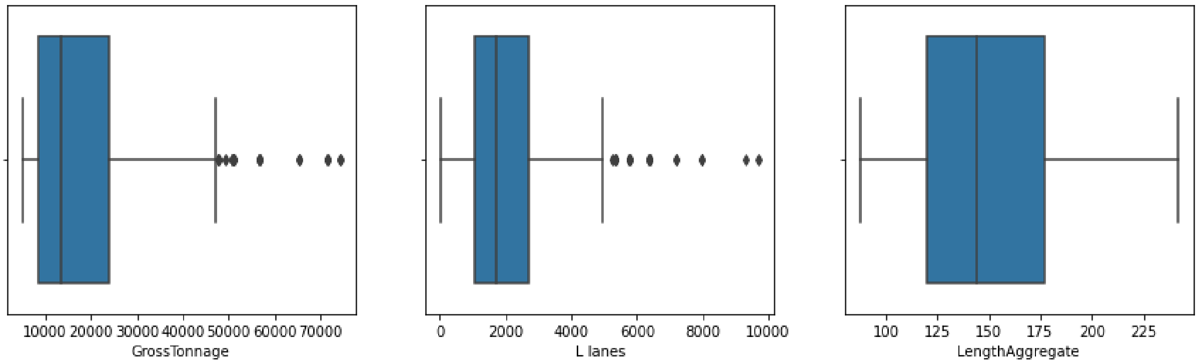

Figure 74. Boxplots of gross tonnage, lane meters and length aggregate – Ro-ro cargo ships.

A root square transform has been applied to ‘L lanes’ to reduce its skewness. All data have been standardised.

15.4.4.3 Model for ‘L lane’

Based on the consideration above (see section 15.4.4.1), polynomial models on ‘Gross Tonnage’ and ‘LengthAggregate’ were studied. A ridge regression (linear regression with L2 regularisation term) has been performed on the polynomial transformation of input features, in order to avoid overfitting of the dispersed input data. The hyperparameter lambda (coefficient of the penalty term) of the ridge regression has been tuned by cross validation.

Coefficients have been estimated with *sklearn RidgeCV* [40]:

$$L\ lanes_{missing} = (13 * GT_s + 4.7 * LPP_s - 8.8 * GT_s^2 + 41)^2$$

Where features are standardised and defined as:

$$GT_s = \frac{GrossTonnage - 16000}{11000}$$

$$LPP_s = \frac{LengthBetweenPerpendiculars - 150}{31}$$

$$GT_s^2 = \frac{GrossTonnage^2 - 3.9 * 10^8}{5.7 * 10^8}$$

15.4.4.4 Model validation

The RMSE and the coefficient of determination Q2, which indicates how well regression predictions approximate real data points, defined by LOO are presented below in Table 47.

Table 47. Estimation of model errors – Ro-ro cargo ships

RMSE	Q2
462	0.76

Residual values (difference between predicted and true values) were found to be dispersed (Figure 75). Residual points with values above 1 500 were further investigated. Most points were found to be old design (‘DeliveryDate’ before 1980) with small ‘L lanes’.

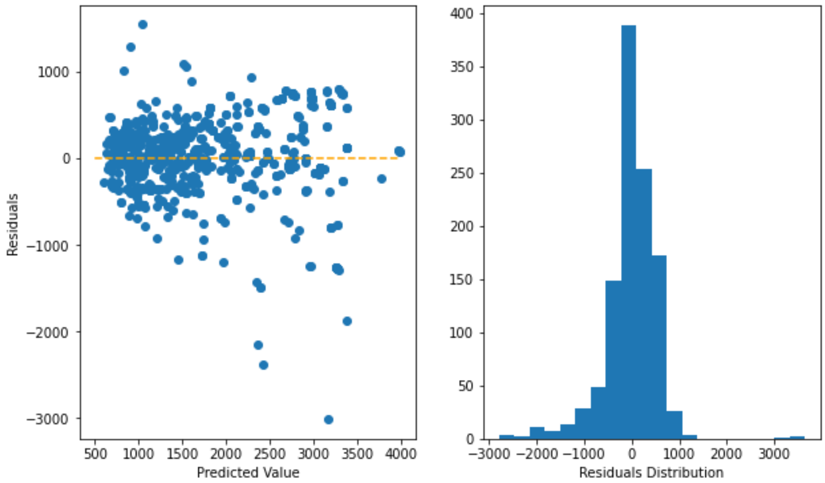

Figure 75. Model residuals – Ro-ro cargo ships.

Residuals are presenting a distribution close to normality.

15.4.5 Vehicle carrier

15.4.5.1 Dataset analysis

For vehicle carriers, the target feature was ‘CEU’.

In the matrix (Figure 76) below, scatterplots between target ‘CEU’ and the feature ‘GrossTonnage’ are presented. Scatterplots underline a high correlation between gross tonnage and car equivalent unit except for some points located around 5 000 CEU and 20 000 GT.

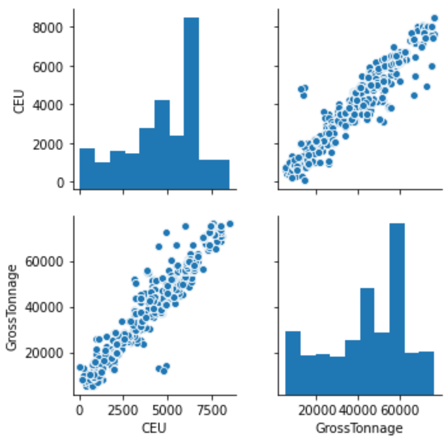

Figure 76. Scatterplots between ‘CEU’ and ‘GrossTonnage’ – Vehicle carriers.

Given above, a linear model on ‘GrossTonnage’ was studied.

15.4.5.2 Model for 'CEU'

A linear regression model on 'GrossTonnage' was used to estimate missing 'CEU' values. Coefficients in the linear expression were estimated with *sklearn LinearRegression* [40]:

$$CEU_{missing} = 0.11 * GT - 160$$

15.4.5.3 Model validation

The RMSE and the coefficient of determination Q2, which indicates how well regression predictions approximate real data points, defined by LOO are presented below in Table 48.

Table 48. Estimation of model errors – Vehicle carriers

RMSE	Q2
544	0.93

The residuals (difference between predicted and true values) are presented in Figure 77 below. Some values are outside of the x axis (see section 15.4.5.1); they are constituted of ships with an old design (low gross tonnage and high car equivalent unit) and can be considered as outliers. Distribution is close to normal and homoscedastic.

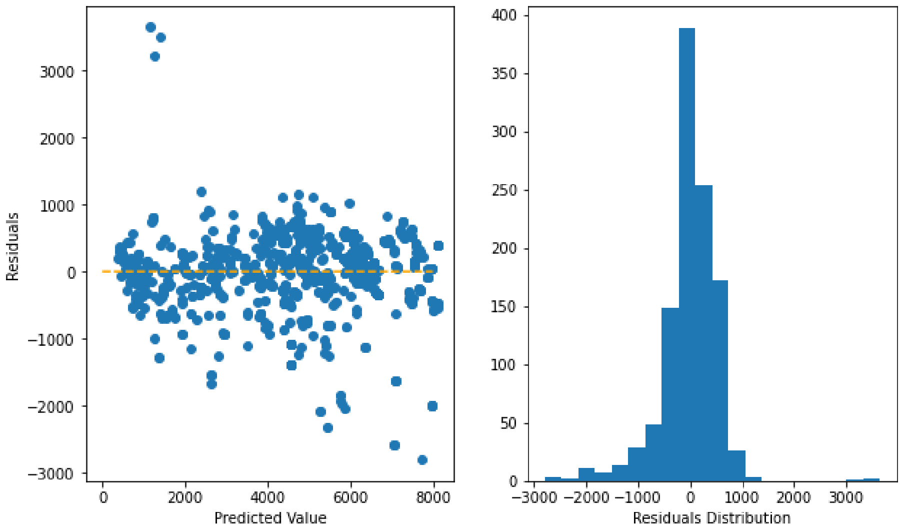

Figure 77. Model residuals – Vehicle carriers.

15.5 ANNEX E: Calculation of distribution of ro-ro spaces

Main author of the chapter: Matthieu Gadel, BV.

15.5.1 Context

In FIRESAFE II, the ignition frequency was calculated as the overall exposition of the ro-ro passenger fleet to fire casualties. This approach was then applied to a ship having average characteristics, and the model assumed that results would scale to the whole fleet characteristics and design, e.g. size. This is correct if ΔPLL and ΔCost ratio do not dramatically change with ship characteristics, e.g. the size, ratios of space type etc. This was covered in the FIRESAFE II sensitivity analysis; however, this assumption is likely not applicable to all different ship designs.

Because of that, one of the LASH FIRE objectives was to construct a risk model based on ro-ro space type and metrics. It also enables to align the outcomes of LASH FIRE with the regulations on ro-ro space type definitions (closed ro-ro space, open ro-ro space and weather deck). The exposition of risk has therefore been calculated based on some fleet key characteristics and on the type of ro-ro space.

Given the small number of casualties at identified for the study, only a limited number of ship characteristics defined by expert judgement have been considered to avoid overfitting:

- For ro-ro passenger ships: L lanes and Number of passengers;
- For ro-ro cargo ships: L lanes; and
- For vehicle carriers: CEU.

The objective of this study is to propose an approach to estimate, based on ship characteristics, the percentage of closed ro-ro space(s), open ro-ro space(s) and weather deck(s) in term of ro-ro lanes. Simple models were investigated and used because of the reduced availability of data and to enable reproducibility of the study.

15.5.2 Description of dataset

The dataset was provided by MOAG members: BALEARIA, BC FERRIES, CALMAC, CONDOR FERRIES, DFDS, SCANDLINES, STENA LINE, WALLENIUS, with following data fields (Table 49).

Table 49. Data fields of the dataset by MOAG members

Operator	ShipName	IMONumber	ShipType
SisterShip	TotalLaneMeters	CEU	PassengerMOAG
WeatherDeckPercent	OpenDeckPercent	ClosedDeckPercent	

This dataset was filtered using LASH FIRE fleet criteria. For each ship type, the total number of data is described in Table 50 below.

Table 50. Number of ro-ro ships of MOAG member's dataset

Type of Ship	Ro-ro passenger ship	Ro-ro cargo ship	Vehicle carrier
# Data	146	42	51

It should be noted that this dataset includes an important number of sisterships (or duplicate data), something that will be discussed in the next section.

15.5.3 Exploratory data analysis

15.5.3.1 Ro-ro passenger ships

The distribution of gross tonnage of dataset from MOAG ships is presented in Figure 78 below. An over-representation of ships with gross tonnage comprised between 15 000 GT and 35 000 GT can be underlined. Nevertheless, the training set provides an acceptable representation of the LASH FIRE ro-ro passenger fleet.

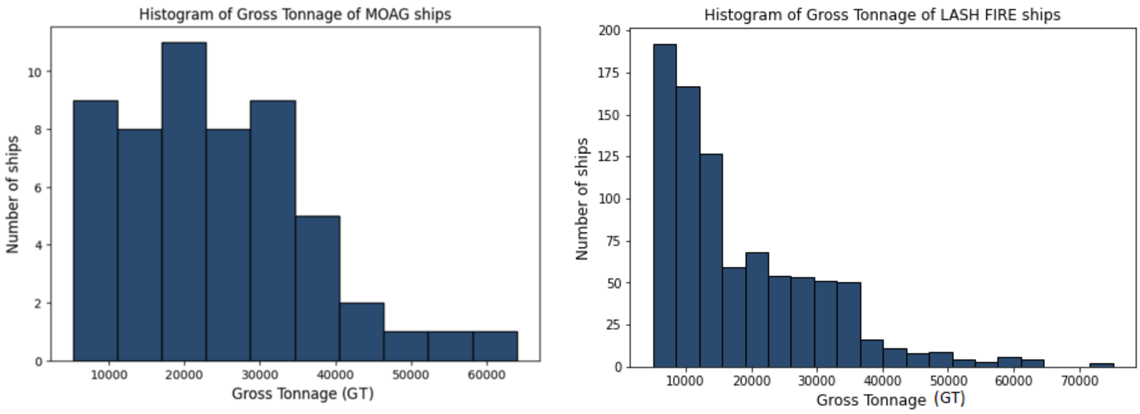

Figure 78. Distribution of gross tonnage for MOAG dataset versus the LASH FIRE fleet – Ro-ro passenger ships.

The distributions of the three percentages for each of the ro-ro space types are presented Figure 79 below. They appear to be highly unbalanced with a lot of 0% or 100% values.

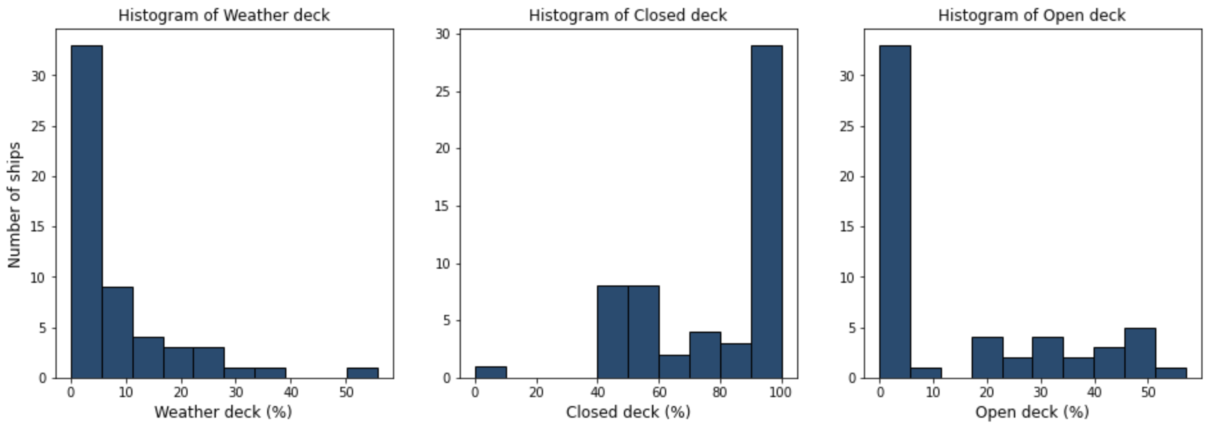

Figure 79. Distribution of percentage of ro-ro space for MOAG dataset – Ro-ro passenger ships.

Correlations between some interesting features were investigated and no clear correlations was found between the features and the target values.

15.5.3.2 Ro-ro cargo ships

The distribution of gross tonnage of dataset from MOAG ships is presented in Figure 80 below. The ships characteristics of the MOAG fleet show a different distribution than the LASH FIRE ro-ro cargo fleet; especially only one ship is present in the MOAG dataset for the range between 14 000 GT and 24 000 GT.

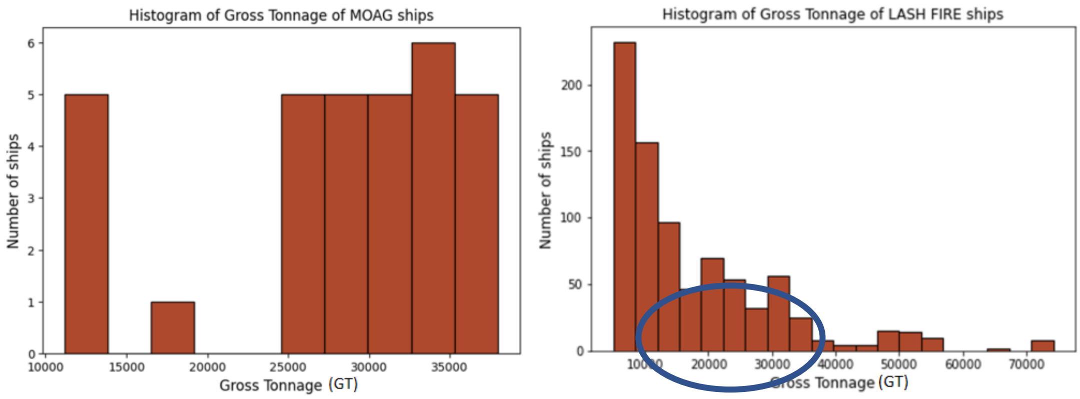

Figure 80. Distribution of gross tonnage for MOAG dataset versus the LASH FIRE fleet – Ro-ro cargo ships.

The dataset provided by the MOAG does not provide an acceptable representation of the LASH FIRE ro-ro cargo fleet and it was therefore not further investigated.

15.5.3.3 Vehicle carriers

All vehicle carriers of the MOAG dataset are defined as 100% closed ro-ro spaces.

15.5.4 Description of the approach

Given the results of the data analysis (see section 15.5.3), only the ro-ro passenger fleet was studied.

Different models were investigated. For each of the models described below, the error was estimated for each percentage. The overall error has been taken as the average of the prediction error for each of the three percentages. Here follows a summary of the studied models:

- Model 1: Subdivision of the data in K class with an unsupervised algorithm (K-means). The number of optimal class has been determined by elbow method (3 and 4 class are investigated). Then, a supervised classification algorithm is trained to predict the belonging in one of the K class (models studied are decision tree, random forest). For each ship, a class is predicted given its characteristics; then, the mean value of percentage of (closed-deck, open-deck, and weather-deck) is allocated for all ship of the class. The error estimated for this model is quite high compared to the other model (RMSE > 20%).
- Model 2: Regression models are studied. Two percentages are predicted given ship characteristics, and the 3rd percentage is deduced from the two others.

Model 2 is presented below.

15.5.5 Data preparation and feature selection

An important number of ships of the dataset are sisterships. When several ships share the same characteristics, only one of them was kept in the dataset to avoid any bias (duplicate data). After suppression of all sisterships, the size of the training set for ro-ro passenger ships is 55 ships.

Given the results of the correlation analysis where no clear correlation was identified, and the small size of the dataset, a simple model with the smallest number of parameters was considered to avoid over fitting. Features of importance were identified by expert judgement and are: 'GrossTonnage', 'L lanes', 'Total Passengers'. In addition, the features 'SpeedAggregate', ’LengthAggregate’, ’BreadthMoulded’ were investigated.

All data have been standardised.

15.5.6 Model comparison

Polynomial transformations were performed on the input features, and different hyperparameters (degree of polynomial transformation, set of input feature) were studied for the prediction of each percentage. A linear ridge regression was fitted for each of the three percentages to avoid overfitting.

To avoid overfitting, the model with the best results and the smallest number of input and polynomial degree has been considered. A polynomial model of degree 2 with input features 'GrossTonnage', 'L lanes', 'Total Passengers' provided the best result and was further investigated.

15.5.7 Model

Two independent models were considered for the percentage prediction, the third percentage being deduced from the two other. A polynomial transformation of degree 2 on input features 'GrossTonnage', 'L lanes', 'Total Passengers' was considered as a starting point, then possible variable reductions have been studied to limit overfitting while keeping an acceptable error.

The coefficients were estimated with *sklearn RidgeCV* [40]:

$$\begin{cases} p_{weather} = \begin{pmatrix} -0.62\ GT_s + 0.91\ Lane_s - 0.4\ Pax_s \\ +0.55\ GT_s.Pax_s - 0.64\ Lane_s.Pax_s - 0.18 \end{pmatrix} * 9.3 + 5.9 \quad \text{with} \quad 0 \leq p_{weather} \leq 100 \\ p_{open} = \begin{pmatrix} -0.77\ GT_s + 0.89\ Lane_s + 0.39\ Pax_s - \\ 0.64\ GT_s.Lane_s + 0.39\ Lane_s^2 \ - 0.34\ Pax_s^2 + 0.38 \end{pmatrix} * 18 + 12 \quad \text{with} \quad 0 \leq p_{open} \leq 100 \\ p_{closed} = 100 - p_{weather} - p_{open} \end{cases}$$

Where features are standardised and defined as:

$$GT_s = (GrossTonnage - 23000)/12000$$

$$Lanes_s = (L\ lanes - 1600)/880$$

$$Pax_s = (Tota\ Passengers - 1100)/600$$

15.5.8 Model validation

The error was estimated by Leave-One-Out (LOO) cross validation as the root of the mean square error (RMSE). The total error for the prediction of the three percentages is defined as the average of the mean square error of each models as:

$$RMSE_{total} = \sqrt{\frac{1}{3}\sum_{deck} MSE_{deck}}$$

The errors for each model are presented in Table 51.

Table 51. Estimation of model errors – Ro-ro passenger ships

	RMSE
Weather deck	6.25
Open deck	13.5
Closed deck	15.7
Total	12.5

Which means that, in average, the error performed by the total model of the three percentage prediction when performing on new, unseen data (LOO error) is 12.5%.

The distributions of the errors calculated by Leave-One-Out (LOO) are given in Figure 81.

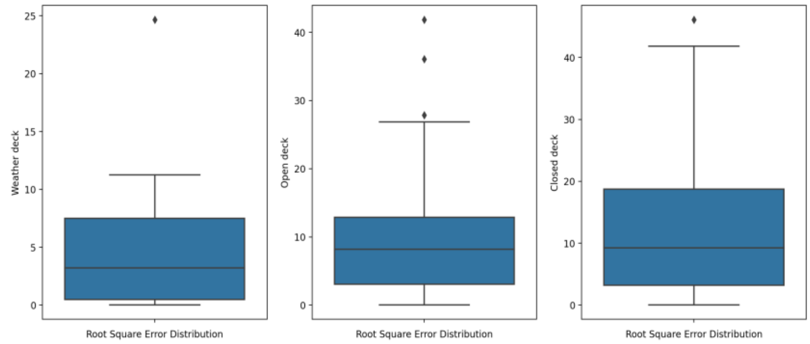

Figure 81. Distribution of the LOO errors for percentage of ro-ro space prediction– Ro-ro passenger ships.