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Study investigating cost effective measures for reducing the risk from fires on ro-ro passenger ships (FIRESAFE)

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Abstract

This is a study commissioned by the European Maritime Safety Agency, EMSA. It consists of two parts, investigating risk control options (RCOs) for mitigating the risk from fires on ro-ro decks. The first part considers RCOs in relation to *Electrical Fire as ignition risk* and the second part considers RCOs to mitigate the risk of *Fire Extinguishing Failure (with focus on drencher systems)*. The study considers both newbuildings and existing passenger ships, and has been done per the instructions and limitations in the Tender Specifications (EMSA /OP/01/2016).

The ships included in the analysis were selected based on criteria as agreed by EMSA and the fleet at risk consisted of 490 ships. EMSA provided information about which ships were engaged in international trade.

Historical risks and hazards have been found and complemented with two fire hazard identification (HazId) workshops. The project developed three risk models to be used to investigate the effects of RCOs on the PLL and costs.

Six RCOs were selected for quantitatively analysis in the risk models for the risk of electrical fire ignition and six for drencher failure. Many other RCOs are very promising and could be further analysed in the future. The selected RCOs for this study were:

Electrical faults:	Drencher failure:
- Robust connection boxes - Only ship cables - IR camera - Training for awareness - Only crew connections - Cable reeling drums	- Remote control - Rolling shutters - Efficient activation routines - Fresh water activation/flushing - CCTV - CCTV + Remote control

These RCOs were analysed in a cost benefit analysis which calculated the GCAF and NCAF values for the different RCOs. After analysing the outcome of the cost benefit assessment, the following conclusions could be drawn:

- Training solutions are the most cost effective RCO.
- In this study A-0 shutters were investigated but other solutions exist. More inexpensive shutters will likely be available in the near future.
- Robust connection boxes have the highest risk reduction for fires ignited by electrical failures.
- The number of accident cases was not sufficient for a full statistical study, (however it was higher than the statistics used in some other FSAs).
- Input values are not definitive; they will improve with more statistics and more assessment.
- Quick response to fire is the most important safety precaution.
- The outcome is also dependent on other aspects e.g. detection.
- RCOs are also influencing other aspects. If this had been considered in the analysis, some of the RCOs that were not selected for quantitative analysis might have been found to be cost effective.

Summary
This is a study commissioned by the European Maritime Safety Agency, EMSA. It consists of two parts, investigating risk control options (RCOs) for mitigating the risk from fires on ro-ro decks. The first part considers RCOs in relation to *Electrical Fire as ignition risk* and the second part considers RCOs to mitigate the risk of *Fire Extinguishing Failure*. With regards to extinguishing failure the focus has been on failure of drencher systems (as requested by the tender specifications). Both fire extinguishing and fire suppression have been analysed. The study considers both newbuildings and existing passenger ships, and has been done per the instructions and limitations put forward by EMSA in the Tender Specifications (EMSA /OP/01/2016) and during the work.

To define the problem, possible fire development has been investigated. Factors that affect the fire growth on ro-ro spaces include ventilation and available fuel. Ro-ro spaces are categorized as either open, closed or weather decks. An open ro-ro space is generally a space with more than 10% openings in the sides. A ro-ro space is defined as a closed space if it is not an open or a weather deck. This way of defining a closed space leads to some difficulties in a fire analysis since also a closed deck could have openings that cover 9.5% of the sides. The implications of large openings were discussed and calculations of the rate of fire growth have been done with different sizes of openings.

A fire on an open deck could grow to several hundred MW while fires on spaces with smaller openings are restricted by the available oxygen. Also in closed spaces the fire could continue for some time before it becomes ventilation controlled. Some calculations were done in this study to get an understanding of possible fire growth and fire developments. If the ventilation is kept on with 10 air changes per hour the fire will grow to about 60-70 MW after 40 minutes and continue to burn with 60 MW until the fuel is consumed (up to 7 hours). These calculations were done on a generic ship which was defined as an average of the ships covered by the study. Even with such small openings as 1% (with natural ventilation) the fire could continue to burn with about 40 MW. In a completely closed space the fire will consume all available oxygen and self-extinguish. This will not happen until after 30 minutes due to the large size of the ro-ro spaces.

The study has been done in accordance with the "Revised Guidelines for FSA for Use in the IMO Rule-Making Process FSA" (MSC-MEPC.2/Circ.12/Rev.1). In particular, it is step 2, step 3 and parts of step 4 that have been considered. Step 1, identification of the hazards that should be analysed was done by EMSAs Group of Experts prior to this study. The outcome was an instruction for this study to focus on the risk of electrical fire ignition and the risk of suppression failures of drencher systems.

A thorough analysis of the fleet at risk has been done based on the information and instructions from EMSA. The ships that have been included in the analysis were selected based on the following criteria:

- classed as Passenger/Ro-Ro Ship;
- engaged on international voyages or EU domestic class A;
- gross tonnage equal or greater than 1,000;
- with a keel laying date on or after 25/05/1980;
- Froude number less than 0.5; and
- Classed or having been classed by one the IACS members.

After applying the above selection criteria, the fleet at risk consisted of 490 ships. It was difficult to determine which ships were engaged in international trade. Information about this was provided by EMSA based on information available to them. The characteristics of the fleet at risk has also been analysed and described. This information was used to define a generic ship which was used as basis for the calculations regarding loss of life, costs of fires and costs of RCOs.

The next step was to determine the historical risks of the selected ships. This was done by analysing available casualty statistics and on a review of historical data. The effects of some characteristics (e.g. age or ship size) on the accidents and incidents frequency have also been investigated. Furthermore, this analysis provided more insight about fires on ro-ro decks on ro-ro passenger ships and could thus serve as inputs for quantifying the risk models. The resulting outcomes of the analysis were estimation of historical Potential Loss of Life (PLL) and initial accident frequency of fires on ro-ro decks.

The data sources that have been used in the study were:

- FSI 21/5
- MARINFO Database (EMSA)
- IHS Casualty Database
- EMCIP Database (EMSA)
- GISIS (IMO)

Historical data is however not enough to find all possible hazards and risks. Consequently, two fire hazard identification (HazId) workshops have been organised. One was held prior to this study by STENA and SP as part of an internal fire safety project in the STENA Rederi AB. The focus on that HazId was to investigate all possible risks and hazards regarding fire safety on ro-ro spaces. This HazId was then complemented by comments and views from the project team including BV and EMSA experts.

This project has also developed three risk models to investigate the effects of RCOs on the PLL and costs. First a main risk model was developed based on the work by EMSAs GoE. This consists of an event tree starting from ignition of a fire. All possible accident scenarios were identified and described leading to 21 branches of the event tree. Each branch represents a possible accident scenario.

Two sub-models were also developed to provide input to the main model. One is a fault tree that will give the probability of ignition of a fire. The aim of this model is to determine the effects of the RCOs concerned with the probability of ignition from electrical failures. The model also considers other fire causes than electrical faults since it is necessary to estimate probabilities of all types of fires to analyse the effect of the RCOs. The model could be further developed to include more details about other fire causes.

The second sub-model is also a fault tree. This tree gives the probability of failure of fire suppression/extinguishing with a focus on drencher systems. It includes manual firefighting but this is only analysed generally since it was out of the scope of the study. The success of a drencher system is dependent on both the time of activation in relation to the fire growth and on the type of ro-ro space (open or closed). This made it necessary to develop four separate fault trees. The structure of the trees is identical but the input values are different.

The consequences and the costs of fires could now be determined for the generic ship without any RCO. The input values to the models were based on statistics from the historical data, reliability data and expert judgement. It should be noted that the number of accidents in the FIRESAFE fleet of risk are limited in a statistical point of view. It has thus been necessary to rely on expert judgement which could introduce additional uncertainties. The input data used in the study shall thus not be treated as fixed or absolute and it should instead be adjusted as more statistical and expert information are obtained.

The costs of fires have been determined based on the accident scenarios and experience from STENA. The fatality rates or number of fatalities for each accident scenario have been extracted from a previous FSA study on RoPax and compared with historical data.

In the HazIds a large number of RCOs were proposed. This list was complemented with proposed RCOs from other projects and accident investigations. A coarse selection was then done in three sessions with the project team, BV and STENA experts and EMSA. Six RCOs were selected for quantitatively analysis in the risk models for the risk of electrical fire and six for drencher failure. There are many other RCOs that are very promising and these could be further analysed in the future. The selected RCOs are:

Electrical faults:

- Robust connection boxes
- Only ship cables
- IR camera
- Training for awareness
- Only crew connections
- Cable reeling drums

Drencher failure:

- Remote control
- Rolling shutters
- Efficient activation routines
- Fresh water activation/flushing
- CCTV
- CCTV + Remote control

These RCOs were analysed in a cost benefit analysis. The RCOs influence different nodes in the sub-models and in some cases also nodes in the main model. Since some of the benefits from the RCOs include both precautions against human and technical errors the effect of a RCO on a node had to be estimated by expert judgement. In a cost benefit assessment, the GCAF and NCAF values were calculated for the different RCOs.

Conclusions

Fires on board ships are a complex problem and many different fire developments could be expected. In most cases a fire starts as a small smouldering fire and after an incipient phase it will start to grow. When it starts to grow it usually grows very quickly. The development of fires is highly dependent on ventilation and available fuel.

After analysing the outcome of the cost benefit assessment, the following conclusions could be drawn:

- Training solutions are the most cost effective RCO.
- Fire shutters is the most risk reducing RCO for suppression failures. In this study A-0 shutters were investigated but other solutions exist. More inexpensive shutters will likely be available in the near future.
- Robust connection boxes have the highest risk reduction for the electrical model.
- The number of accident cases was not sufficient for a full statistical study, (however it was higher than the statistics used in some other FSAs).
- Input values are not definitive, they will improve with more statistics and more assessment.
- Quick response to fire is the most important safety precaution.
- The outcome is also dependent on other aspects e.g. detection.
- RCOs are also influencing other aspects. If this had been considered some of the RCOs that were not selected for quantitative analysis might have been cost effective.

Disclaimer

"*The information and views set out in this report are those of the author(s) and do not necessarily reflect the official opinion of EMSA. EMSA does not guarantee the accuracy of the data included in this study. Neither EMSA nor any person acting on EMSA's behalf may be held responsible for the use which may be made of the information contained therein.*"

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Acronyms

BEV: Battery Electric Vehicle
CI: Confidence Interval
EMCIP: European Marine Casualty Information Platform
EMSA: European Safety Maritime Agency
FC: Fuel Cell
FSA: Formal Safety Assessment
FSI: Flag State Implementation
GCAF: Gross Cost of Averting a Fatality
GDP: Gross Domestic Product
GISIS: Global Integrated Shipping Information System
GoE: Group of Experts
HEV: Hybrid Electric Vehicle
HGV: Heavy Goods Vehicle
HSC: High Speed Craft
IACS: International Association of Classification Societies
IMO: International Maritime Organization
LBP: Length between perpendiculars
LOA: Length overall
LQI: Life Quality Index
LSA: Life Saving Appliances
MAIB: The United Kingdom's Marine Accident Investigation Branch
NCAF: Net Cost of Averting a Fatality
NPV: Net Present Value
OECD: Organisation for Economic Co-operation and Development
PLC: Potential Loss of Cargo
PLL: Potential Loss of Life
PLS: Potential Loss of Ship
POB: Persons on Board
RCO: Risk Control Option
RU: Refrigerating Unit
SOLAS: Safety of Life at Sea
SRtP: Safe Return to Port
VPF: Value for Preventing a Fatality

Definitions

Classes of passenger ships as defined in Article 4 of Directive 2009/45/EC of the European Parliament and of the Council of 6 May 2009 on safety rules and standards for passenger ships. Passenger ships are divided into the following classes per the sea area in which they operate:

'Class A' means a passenger ship engaged on domestic voyages other than voyages covered by Classes B, C and D.

'Class B' means a passenger ship engaged on domestic voyages in the course of which it is at no time more than 20 miles from the line of coast, where shipwrecked persons can land, corresponding to the medium tide height.

'Class C' means a passenger ship engaged on domestic voyages in sea areas where the probability of exceeding 2,5 metres significant wave height is smaller than 10 % over a one-year period for all-year-round operation, or over a specific restricted period of the year for operation exclusively in such period (e.g. summer period operation), in the course of which it is at no time more than 15 miles from a place of refuge, nor more than 5 miles from the line of coast, where shipwrecked persons can land, corresponding to the medium tide height.

'Class D' means a passenger ship engaged on domestic voyages in sea areas where the probability of exceeding 1,5 metres significant wave height is smaller than 10 % over a one-year period for all-year-round operation, or over a specific restricted period of the year for operation exclusively in such period (e.g. summer period operation), in the course of which it is at no time more than 6 miles from a place of refuge, nor more than 3 miles from the line of coast, where shipwrecked persons can land, corresponding to the medium tide height.

Closed ro-ro (vehicle) spaces are ro-ro (vehicle) spaces which are neither open ro-ro (vehicle) spaces nor weather decks (SOLAS II-2/3.12 and SOLAS II-2/3.13).
Open ro-ro (vehicle) spaces are those ro-ro (vehicle) spaces which are either open at both ends or have an opening at one end, and are provided with adequate natural ventilation effective over their 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-2/3.35 and SOLAS II-2/3.36).
Weather deck is a deck which is completely exposed to the weather from above and from at least two sides (SOLAS II-2/3.50).

Casualty types

The following definition of casualty types are considered in IHS:

- Foundered (FD) – includes ships which sank as a result of heavy weather, leaks, breaking into two, etc., and not as a consequence of other categories such as collision etc.
- Fire/explosion (FX) – includes ships where fire/explosion is the first event reported, or 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.
- Collision (CN) – includes ships striking or being struck by another ship, regardless of whether under way, anchored or moored. This category does not include ships striking underwater wrecks.

- Contact (CT) – includes ships striking or being struck by an external object, but not another ship or the sea bottom. This category includes striking drilling rigs/platforms, regardless of whether in fixed position or in tow.
- Wrecked/stranded (WS) – includes ships striking the sea bottom, shore or underwater wrecks.
- Hull/machinery damage (HM) – includes ships where the hull/machinery damage is not due to other categories such as collision etc.

Severity

As reported in EMSA 3 (EMSA, 2015a), in the IHS database, an event is categorized as serious if it fulfils one of the following conditions:

- Structural damage, rendering the ship unseaworthy, such as penetration of hull underwater, immobilization of main engines, extensive damage, etc.
- Breakdown
- Actual Total Loss
- Any other undefined situation resulting in damage or financial loss which is considered to be serious.

As reported in (EMSA, 2015b), EMSA defines the severity categories as follows:

- VERY SERIOUS CASUALTIES are marine casualties involving the total loss of the ship or a death or severe damage to the environment.
- SERIOUS CASUALTIES are marine casualties to ships which do not qualify as very serious casualties and which involve for example a fire, collision, grounding, heavy weather damage, suspected hull defect, etc., which result in the ship being unfit to proceed or pollution.
- LESS SERIOUS CASUALTIES are marine casualties that don't qualify as very serious or serious casualties.

1. Introduction

This is a study commissioned by the European Maritime Safety Agency, EMSA. It consists of two parts, investigating risk control options (RCOs) for mitigating the risk from fires on ro-ro decks in relation to *Electrical Fire as ignition risk* and *Fire Extinguishing Failure*. The study considers both newbuildings and existing passenger ships. Information from other research projects has been used to avoid duplication of the work.
The study has been done per the instructions and limitations put forward by EMSA in the Tender Specifications (EMSA /OP/01/2016) and during the work.

1.1. Background

The EMSA tender specifications background is recalled and completed below.

The IMO Correspondence Group on Casualty Analysis (FSI 21/5; 2012) reviewed a number of fires on vehicle decks of either ro-ro passenger or ro-ro cargo ships that took place in the period from 1994 to 2011. Their report of March 2013 noted:

- *"61 There have been a number of significant fire incidents on ro-ro passenger vehicle decks since 1994 and there is no sign of these diminishing. Since 2002 there has been a very serious incident every other year, resulting in six constructive total losses."*
- *"62 A significant number of the incidents have occurred as a result of electrical fires, particularly relating to refrigerated trailers, but also in some cases from the ship's own equipment."*
- *"63 Many of the findings of the casualty investigation reports studied reiterate well-known problems, e.g. the need to deploy drencher systems early in the fire, problems associated with water accumulating on the vehicle decks, structural fire integrity and fire containment."*

The report was brought to the attention of MSC at its 92nd session and the relevant recommendations were forwarded to the SDC 1 and the SSE 1 sub-committees ((SDC 1/24/1; 2013) and (SSE 1/20; 2013)). However, in the absence of any intervention, SDC decided to invite "*interested Member Governments and international organizations to submit proposals for new outputs to the Committee*" ((SDC 1/26; 2014), §24.6).

EMSA has further analysed this type of accident using the in-house EMCIP database (European Marine Casualty Information Platform which is managed by EMSA), as well as the MARINFO database which is populated with data from four commercial providers. This analysis has shown that the number of fires on ro-ro decks remains at high levels, including very serious accidents of which the NORMAN ATLANTIC and the SORRENTO are the most recent.

Statistics on this issue present a compelling need to consider whether any practicable solutions could be found to reduce the risk posed by fires on ro-ro decks.

Further on the subject, the European Commission and associated countries have proposed at MSC 97 that the Maritime Safety Committee establishes a new output on its work programme, for action by the Sub-Committee on Ship Systems and Equipment, with support as required from the Sub-Committees on Ship Design and Construction and Human Element, Training and Watchkeeping, with three sessions required to complete it (MSC 97/19/3; 2016).

1.2. EMSA initiative

In September 2015, EMSA held a workshop on fires on ro-ro decks for maritime administrations and accident investigation bodies, together with relevant speakers from industry. Following this workshop, a Group of Experts (GoE) was formed to discuss and further analyse this issue. One of the first tasks of the group was to evaluate and score the different risk areas that were identified in the casualty analysis correspondence group of the IMO FSI sub-committee which led to the development of document FSI 21/5 (FSI 21/5; 2012). The results of this exercise showed that the experts consider that *Electrical Fire as ignition risk* and *Fire Extinguishing Failure* are the greatest risk contributors. Consequently, it was proposed that EMSA will initiate the present study to further investigate these two risks and potential risk control options.

1.2. Electrical fire as ignition risk (first part)

1.2.1. Objective and scope

The main objective of the first part of the study is to identify a range of RCOs and assess those most likely to be cost beneficial in relation to cabling and electrical equipment faults leading to electrical fires on any ro-ro passenger ship, considering both open and enclosed ro-ro spaces. Other work dealing with the subject has been taken into consideration without being duplicated.

The study uses common tools for risk analysis as described in the Formal Safety Assessment (FSA) Guidelines of IMO (MSC-MEPC.2/Circ.12/Rev.1). Relevant accident data provided by EMSA has been used in combination with other available data.

The analysis addresses both newbuildings and existing ships and different types of ro-ro spaces (e.g. open or closed).

1.2.2. Description

This study is based on that the *Electrical Fire as ignition risk* has been identified as one of the main risk contributors by the Group of Expert on fires on ro-ro decks. Therefore, cabling and electrical equipment faults leading to electrical fires on any ro-ro spaces have been selected for further analysis. Other possible fire risks on ro-ro decks such as non-electrical cargo fire or arson are thus outside the scope of this section and has not been investigated into details. However, they are included in the risk model since the total probability needs to be assessed. The RCOs that are most likely to be cost beneficial for both newbuildings and existing ro-ro passenger ships has been analysed quantitatively.

For this study, the design of different ro-ro spaces has been analysed. One representative generic vessel representative of the world fleet was used as a base for the analysis.

1.3. Fire extinguishing failure (second part)

1.3.1. Objective and scope

The main objective of the second part of the study has been to identify a range of RCOs and assess those most likely to be cost beneficial in relation to fire extinguishing failure on board any ro-ro passenger ship, considering both open and enclosed ro-ro spaces. However, as requested by EMSA the work has focused on failure of drencher systems. Other work dealing with the subject has been taken into consideration without being duplicated.

The study uses common tools for risk analysis as described in the Formal Safety Assessment (FSA) Guidelines of IMO. Relevant accident data provided by EMSA has been used in combination with other available data.

The analysis has addressed both newbuildings and existing ships and different types of ro-ro spaces (e.g. open or closed).

1.3.2. Description

In this part of the study the risk of unsuccessful or partially successful deployment of drencher systems has been investigated. RCOs that decreases this risk has been proposed and the RCOs that are most likely to be cost beneficial for both newbuildings and existing ro-ro passenger ships has been analysed. The difference between open and closed ro-ro spaces has been considered. It should be noted that weather decks are only included in the general picture.

Furthermore, a space with large openings which are too small to classify the space as an open space is classified as a closed ro-ro space, e.g. a "garage" with only the whole aft part open. All spaces with less than 10% openings are classed as a closed ro-ro space. This has been considered when possible RCOs were investigated since the fire growth is dependent on if the space could be closed in a way that leads to a ventilation controlled fire. Also, the performance of detection and suppression systems is affected by this. A general discussion of this is included in the study as input for choosing fire scenarios, RCOs and evaluation methods.

1.4. Scope and limitations of the study

Based on the tender specification and discussions with EMSA it was decided that the study should only consider ro-ro passenger ships and that ro-ro cargo ships and pure car carrier should be excluded. It should be noted that ro-ro cargo ships and PCC could benefit from many of the RCOs discussed in the study.

The study will only look at SOLAS ships and EU category A ships and not on ships in domestic trade. In many countries, it is required that ships trading in sea area A shall fulfil the SOLAS requirements.

Only ships built to SOLAS 74 are included which means that ships built before 1980 are excluded. As discussed later in the report the expected life time for ro-ro ships is about 35 years even though there are many old ships sailing in European waters.

Ships built to the High Speed Craft code are excluded since the requirements in this code are based on another concept than SOLAS.
The tender specifications requests that the study shall focus on drencher systems and consequently other fixed systems, such as CO2 will not be discussed in detail.
Manual extinguishment has been included in the detailed model for fire suppression but has not been analysed in detail.
Electrical and hybrid vehicles are only included in part one, electrical fire causes.
Alternative fuel vehicles are not considered unless they make a significant impact on the results.

1.5. Regulations and rules

As seen in the scope above the study will only cover ships built to the SOLAS convention. In SOLAS it is mainly chapter II-1 "Construction - Structure, subdivision and stability, machinery and electrical installations" and chapter II-2 "Construction - Fire protection, fire detection and fire extinction" that are of interest for this study. The specific regulations and requirements that have been considered are described when the different issues are discussed in the report.

In general, the regulations only contain the main requirements while the technical details could be found in different codes, e.g. the Fire Safety Systems code and the Fire Test Procedures code. Furthermore, there are a large number of circulars and resolutions that also needs to be considered.

SOLAS chapter II-1 contains electrical requirements for ships. In regulation II-1/3-1 it is required that in addition to the requirements contained elsewhere in the present regulations, ships shall be designed, constructed and maintained in compliance with the structural, mechanical and electrical requirements of a classification society or with applicable national standards of the Administration which provide an equivalent level of safety.

> *Regulation 3-1 - Structural, mechanical and electrical requirements for ships.*
> *In addition to the requirements contained elsewhere in the present regulations, ships shall be designed, constructed and maintained in compliance with the structural, mechanical and electrical requirements of a classification society which is recognized by the Administration in accordance with the provisions of regulation XI-1/1, or with applicable national standards of the Administration which provide an equivalent level of safety.*

Part D of chapter II-1 contains the most of the requirements for the electrical installations on board ships. One important requirement is regulation 40.2 that requires that the administration shall take appropriate steps to ensure uniformity in the implementation and application of the provisions of this part in respect of electrical installations. A footnote is included which refers to the recommendations published by the International Electrotechnical Commission and, in particular, Publication IEC 60092 - Electrical Installations in Ships.

Footnotes in SOLAS are not mandatory but it is up to the administration to decide on this. Furthermore, all international conventions (e.g. SOLAS) need to be incorporated into the national legislation to be put into force. As an example, it could be mentioned that

Sweden has put this requirement into force with the regulations TSFS 2014:1 where it is required (Chapter 3 regulation 18 3§) that SOLAS ships shall fulfil a recognized classification society's rules and IEC 60092.

Consequently, it is not mandatory according to SOLAS to have a ship classed by a classification society. However, it is required by many Administrations that ships electrical systems shall be designed according to the requirements of a classification society. And if not the system shall be designed according to a national standard giving the same level of safety. Since the requirements of different classification societies differ somewhat it could not be assumed that all ships fulfil similar requirements, even though it is likely that IEC 60092 is applied with by most ships.

The requirements for fire safety of ro-ro spaces could be found in chapter II-2 regulation 20 in the SOLAS convention. The detailed requirements for the suppression system are regulated in MSC.1/Circ.1430.

1.6. Scientific studies/articles

A literature study was performed to study the critical factors that influence the fire development on a ro-ro deck to support fire load calculations, estimate the fire growth rate of a ro-ro fire and how to estimate the duration and intensity of an uncontrolled ro-ro deck fire at varying ventilation conditions.

The fire load and the potential fire growth rate on a ro-ro deck can, of course, vary significantly depending on the variety of cargo that can be found; cars, trucks, busses, caravans, general cargo and dangerous goods can all be transported on a ro-ro deck.
Many studies have been performed on the fire development of cars, typically to be used in assessing the fire safety of parking garages etc. which is relevant for ro-ro deck fires as well. Yuguang Li has studied and contemplated several of these reports (Li, Y.; 2004) and estimates on fire load and fire growth rates for single and multiple cars can be found. The fire load and expected fire growth rate of other relevant combustible materials such as wood pallets, hydrocarbons etc. can be found in fire dynamics handbooks (Karlsson, B. and J.G. Quintiere; 2000).

A series of model scale experiments representing vehicle deck fires was performed at SP in 2002 [Larsson, I. *et al;* 2002]. This study concluded that the degree of ventilation and supply and oxygen are decisive in determining the development of a fire on a vehicle deck. Even with all ventilation openings closed the fire can reach a large size and present a significant risk to crew and passengers. This risk increases with large ventilation openings.

Further, the study demonstrated that a two-zone model can represent a ro-ro deck fire regarding global gas temperatures, smoke layer height and oxygen concentration with satisfactory results. Hence, for a given fire growth rate (which is an input in the model) 2-zone models can be used to estimate the time to reach tenability limits and as an input for determining ship damages from a fire scenario.

Another important study regarding fire safety on ro-ro decks is the IMPRO project [Arvidson, M.; 2010] that investigated the efficiency of water based active firefighting systems for ro-ro spaces. This study concluded, in short, that drencher discharge densities must be increased to achieve sufficient efficiency in fire scenarios relevant on vehicle decks today. As a result of the IMPRO project the requirements for water based firefighting systems were revised (except for systems designed as alternative systems) with the development of (MSC.1/Circ.1430).

2. Problem definition

2.1. Ship designs

Ships have been designed with ro-ro spaces for many years with first roll-on roll-of ships being train carrier and invented in 1840 decade in UK, was extended to military purpose during World War I to cross the channel between UK and France and commercially adapted to all road vehicles after proven effectiveness with World War II landings.

The concept is very easy to understand, it is a space into which one could drive cars, trucks and cargo, roll on roll off. However, the definition has always been somewhat complicated. For ships built prior to 2002 the definitions and the requirements are a little bit different than for ships built after 2002. The explanation is that a comprehensive review of chapter II-2 of SOLAS was done which included the introduction of more performance based regulations.

As seen below there are in the present version some definitions on vehicle and ro-ro spaces:

> *SOLAS II-2/3*
> *12. Closed ro-ro spaces are ro-ro spaces which are neither open ro-ro spaces nor weather decks.*
> *13. Closed vehicle spaces are vehicle spaces which are neither open vehicle spaces nor weather decks*
> *35. Open ro-ro spaces are those ro-ro spaces that are either open at both ends or have an opening at one end, and are provided with adequate natural ventilation effective over their 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.*
> *36. Open vehicle spaces are those vehicle spaces which are either open at both ends, or have an opening at one end and are provided with adequate natural ventilation effective over their 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*
> *41. Ro-ro spaces are spaces not normally subdivided in any way and normally extending to either a substantial length or the entire length of the ship in which motor vehicles with fuel in their tanks for their own propulsion and/or goods (packaged or in bulk, in or on rail or road cars, vehicles (including road or rail tankers), trailers, containers, pallets, demountable tanks or in or on similar stowage units or other receptacles) can be loaded and unloaded normally in a horizontal direction.*
> *46. Special category spaces are those enclosed vehicle spaces above and below the bulkhead deck, into and from which vehicles can be driven and to which passengers have access. Special category spaces may be*

accommodated on more than one deck provided that the total overall clear height for vehicles does not exceed 10 m.
49. Vehicle spaces are cargo spaces intended for carriage of motor vehicles with fuel in their tanks for their own propulsion.
50. Weather deck is a deck which is completely exposed to the weather from above and from at least two sides.

With regards to fire safety and fire development it is sufficient to categorize the spaces into either open, closed or weather decks. A ro-ro space is defined as a closed space if it is not an open or a weather deck. This way of defining a closed space leads to some difficulties in a fire analysis since a closed deck could have openings that cover 9.5% of the sides. The implications of large openings will be discussed later in the report.

2.2. Ro-ro passenger ships fleet analysis

2.2.1. Introduction

The results of the evaluation of historical data of ro-ro passenger vessels are summarized in this section. Such analysis is part of the "Problem definition" step of the Formal Safety Assessment (FSA) Guidelines (MSC-MEPC.2/Circ.12/Rev.1). The objective of the analysis is to provide some insights on the characteristics of the fleet of ro-ro passenger ships and the fleet under consideration in this study (FIRESAFE fleet).
For the sake of clarity and transparency, assumptions taken during this study and data limitations are detailed in this section.
The information included in this part will be of use during the selection of an appropriate generic model.

2.2.2. Data sources

The investigations performed in this section have mainly been based on MARINFO[1] (EMSA) database. When relevant, additional data sources such as IHS World Fleet database or IMO GISIS Ships and Company Particulars module have been used for the purpose of obtaining complementary information on ships' characteristics.

2.2.3. Selection criteria for FIRESAFE fleet

The objective of FIRESAFE is to investigate cost efficient measures for reducing the risk from fires on ro-ro passenger ships, using the FSA methodology. A mostly homogenous group of ships is essential for this purpose. The focus will be put on SOLAS compliant ships.
The dataset is restricted to vessels:

- classed as Passenger/Ro-Ro Ship;
- engaged on international voyages or EU domestic class A;
- gross tonnage equal or greater than 1,000;
- with a keel laying date on or after 25/05/1980;
- Froude number less than 0.5; and
- Classed or having been classed by one the IACS members.

All of these filtering criteria are explained and justified in more detail in the following.

[1] Application developed by EMSA which combines data from four different commercial databases (Lloyds List Intelligence, IHS Maritime, Clarksons Research Services and AXSMarine).

Passenger/Ro-Ro Ship
For the analysis of the *Passenger/Ro-Ro Cargo Ship*, only the sub-types *Passenger/Ro-Ro Ship (Vehicles)*, coded as A36A2PR in IHS, and *Passenger/Ro-Ro Ship (Vehicles/Rail)*, coded as A36A2PT, have been considered. *Passenger/Landing Craft*, which sub-type is also part of the *Passenger/Ro-Ro Cargo Ship* category, has been excluded from the analysis since the architecture and types of voyages of such ships are likely to be different from the two previous sub-types considered.
For these sub-types, IHS provides the following definitions summarized in Table 2.2-1:

StatCode5	Name Description	Definition
A36A2PR	Passenger/Ro-Ro Ship (Vehicles)	A ro-ro cargo ship with accommodation for more than 12 passengers
A36A2PT	Passenger/Ro-Ro Ship (Vehicles/Rail)	A ro-ro cargo ship for the additional carriage of rail-vehicles and with accommodation for more than 12 passengers

Table 2.2-1: Definition of sub-types of Ro-Ro Passenger ships corresponding to StatCode5 (IHS)

These definitions are in accordance with the definitions included in the SOLAS Regulation II-2/3.
Changes of ship types have not been considered since ship type history recorded in MARINFO does not go as far back in time as desirable to analyse all ship's conversions. Moreover, based on the dates of the occurrences of recorded "conversions", these were judged more as data input errors and corrections than real "ship type conversions".

International voyages or EU domestic class A
This filtering criterion allowed considering only ships compliant with the SOLAS.
Vessels engaged on international voyages have been determined by an EMSA algorithm based on ship's last recorded voyages. Ships not having called in a distinct country since at least one year, considering the years between 2011 and 2015, are considered as Domestic. EMSA provided the project with an anonymised list of ships.

During an EU project (REFIT) carried out by EMSA, a list of EU domestic ships has been developed, therefore, it was possible to identify ships complying with the FIRESAFE criteria that fell under the category Domestic Class A, as defined in Article 4 of the Directive 2009/45/EC (Directive 2009/45/EC; 2009). According to Article 6: Safety requirements of this Directive, new passenger ships of Class A *shall comply entirely with the requirements of the 1974 SOLAS Convention, as amended, and with the specific relevant requirements specified in this Directive*; and existing passenger ships of Class A *shall comply with the regulations for existing passenger ships defined in the 1974 SOLAS Convention, as amended, and with the specific relevant requirements in this Directive*.
It should be noted that ships sailing in "Protected areas in Norway", as identified by EMSA, have been excluded from the fleet under consideration, as they should comply with specific regulations.

The impact of this filtering criterion is analysed into more details in the dedicated sub-section Analysis of International and Domestic Class A fleet versus Domestic other than EU Domestic Class A fleet*.*

Gross tonnage
It has been considered that most ships below GT 1,000 operate on non-international voyages, and therefore not likely to be SOLAS vessels, and not representative of the world fleet under consideration. This approach is common and has already been followed in previous FSA studies on ro-ro passenger ships (SAFEDOR (IMO, 2008); GOALDS (IMO, 2012a); EMSA 3 (EMSA, 2015)).

Keel laid date
Only ships which keel was laid on or after 25 May 1980 (date of entry into force of the SOLAS 1974) have been considered.
When the keel laying date was not recorded in the database, the above criterion has been applied to the build date as specified in MARINFO.

Froude number
Only ships with a Froude number less than 0.5 have been considered to exclude High Speed Craft (HSC) vessels, which should comply with specific regulations with regards to fire protection.
Froude number is not directly provided by databases and has been calculated based on the following formula:
$Fr = 0.3193.V.\frac{0.5144}{\sqrt{L_{BP}}}$,
where V is the service speed, and L_{BP} is the Length between perpendiculars (when not available, 0.9*L_{OA} (Length overall) has been used as equivalent).

IACS classed
In order to minimize the effect of under-reporting, ships that have never been classed by a classification society member of the International Association of Classification Societies (IACS) have been excluded from the analysis.
The following IACS members, in alphabetical order, have been considered, regardless of their actual membership status over time (IACS, 2016):

- American Bureau of Shipping (ABS);
- Bureau Veritas (BV);
- China Classification Society (CCS);
- Croatian Register of Shipping (CRS);
- Det Norske Veritas Germanischer Lloyd (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); and
- Russian Maritime Register of Shipping (RS).

Differences between "IACS" and "non-IACS" fleet of ro-ro passenger ships have been widely reported in the recent EMSA 3 FSA study (EMSA, 2014) and, therefore, will not be repeated here.
While the rationale for exclusion remains the same, the approach followed in this study slightly differs from the previous FSA projects where the "IACS criterion" has been applied to the classification status at the time of the study.
Selection and application of this filtering criterion is discussed in more details in the section Casualty data analysis.

2.2.4. Analysis of ro-ro passenger ships fleet

In MARINFO database, 872 ships have been found compliant with the above-mentioned criteria with the exception of the Domestic/International Status.
As the initial period of study considered is 1994-2015, all ships scrapped or lost before 01/01/1994 and delivered after 31/12/2015, as indicated in the databases, have been excluded from the analysis to keep only ships active between 1994 and 2015[2].
Among this fleet of 872 ships, 95% of the ships under consideration fall under the category *Passenger/Ro-Ro Ship (Vehicles)* and 56% of the recorded ships are fully compliant with FIRESAFE criteria (*i.e.* also satisfying the criterion "engaged in international voyages or EU Domestic Class A"). The number of ships per category, active between 1994 and 2015, is reported in Table 2.2-2.

	International and EU Domestic Class A	Domestic other than EU Domestic Class A	Total
Passenger/Ro-Ro Ship (Vehicles)	456	370	826
Passenger/Ro-Ro Ship (Vehicles/Rail):	34	12	46
Total	490	382	

Table 2.2-2: Number of RoPax ships compliant with the FIRESAFE filtering criteria with the exception of Domestic/International status broken down by category.

As discussed on the description of the fleet, due to data limitations[3], influence of ship type conversion has not been taken into account.

2.2.5. Analysis of International and Domestic Class A fleet versus Domestic other than EU Domestic Class A fleet

As shown in Table 2.2-2, two different fleets complying with the filtering criteria (RoPax, GT, Keel Laid, Froude, and IACS) can be identified based on the nature of their voyages.
These fleets are as follows:

- *International and EU Domestic Class A* fleet, which consists of 490 ships:
  - engaged on international voyages, as determined by the EMSA algorithm based on last ship's recorded voyages; and
  - identified as Domestic Class A, based on the list from REFIT.
- *Domestic other than Domestic Class A* fleet, which consists of 382 ships:
  - engaged on domestic voyages (EMSA algorithm);
  - identified as Domestic Class B/C/D (REFIT); and
  - sailing in "Protected areas in Norway".

Only the first fleet, *International and EU Domestic Class A*, is fully compliant with the FIRESAFE filtering criteria.
Analysis of some of the characteristics of the two fleets has been performed in order to show their differences and is reported as boxplots (with minimum, first quartile, median, third quartile, and maximum) in Figure 2.2-1, Figure 2.2-2, and Figure 2.2-3.

[2] This initial period of study has been chosen at the beginning of the project because 1994 is a starting point in most of the casualty data sources and in similar studies. Selection of the period of study is discussed in more details in the casualty data analysis section.
[3] Information on possible conversions based on ship type history available in MARINFO is actually not available for the whole period under consideration.

It should be noted that the *passenger capacity* is not always directly provided in the databases that have been used for this study. Therefore, the maximum between *Passenger*, and the sum of *Berths* and *Unberthed*, as indicated in IHS, has been taken to retrieve an estimation of the number of passengers.

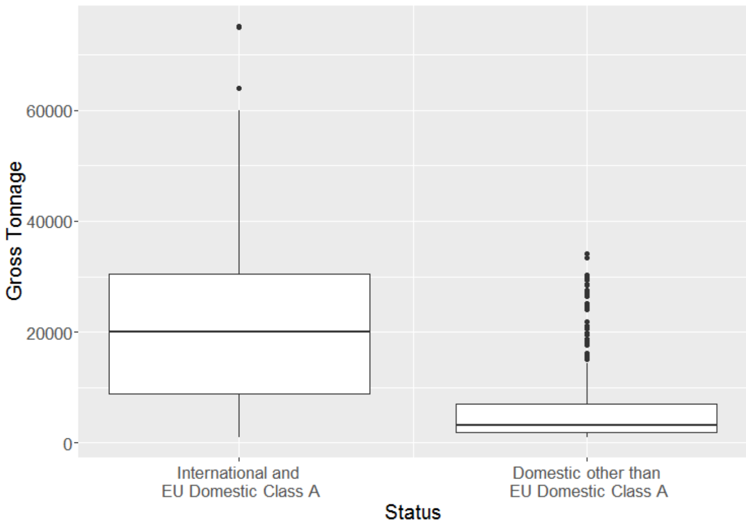

Figure 2.2-1: Gross Tonnage in the International and EU Domestic Class A fleet and Domestic other than EU Domestic Class A.

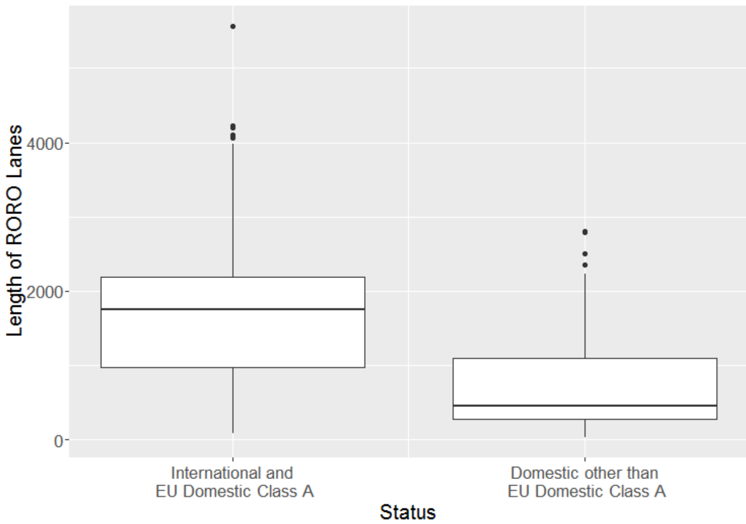

Figure 2.2-2: Length of ro-ro lanes in the International *and EU Domestic Class A fleet* and *Domestic other than EU Domestic Class A* [4]

[4] This figure does not provide a picture of the whole fleet as zeros (non-recorded length of ro-ro lanes) have been removed from the analysis. This boxplot has been computed based on the data for 503 out of 872 ships (368 *International and Domestic Class A*, and 135 *Domestic other than EU Domestic Class A*).

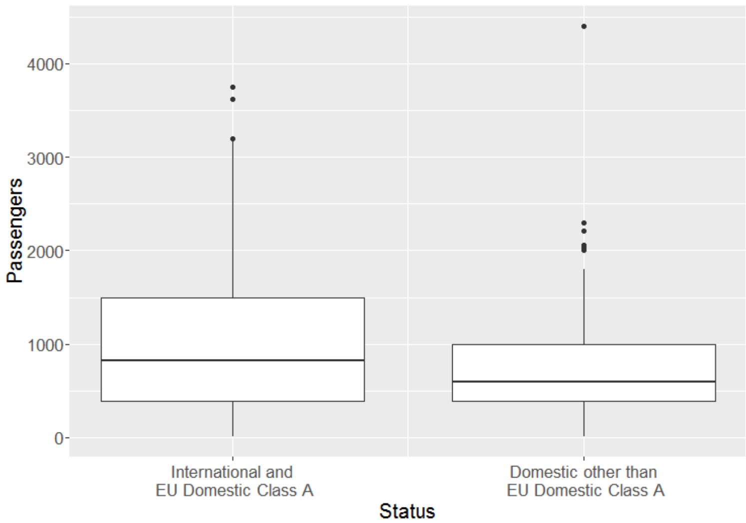

Figure 2.2-3: Passenger capacity in the *International and EU Domestic Class A fleet* and *Domestic other than EU Domestic Class A* [5]

The boxplots show that the *International and Domestic Class A* fleet and the *Domestic other than EU Domestic Class A* fleet are two distinct fleets that cannot be studied together, due to their intrinsic differences, in terms of size and capacity, even if both fleets were SOLAS compliant.
In accordance with paragraph 3.2.1 of the FSA Guidelines MSC-MEPC.2/Circ.12/Rev.1, which calls for "c*onsideration […] to potential improvements in those data in anticipation of an FSA implementation (e.g. a better specification for recording relevant data including the primary causes, underlying factors and latent factors associated with a casualty)"*, this analysis showed the need for a (better) reporting of *SOLAS* or *non-SOLAS* status of the ships in databases in order to avoid using alternative criteria that might not provide the right picture. This reporting is expected to improve the robustness of statistical analysis and FSA studies.

2.2.6. Analysis of the FIRESAFE fleet

After the exclusion of the domestic ships (except EU Domestic Class A), 490 ships active during the period 1994-2015 remain (488 during the period 2002-2015). In order to gain more insight into the fleet being looked at, its main characteristics are reported below.

Shipyears

In accordance with the methodology that has been used in previous projects, the number of shipyears was calculated, with a monthly precision, for the time between "delivery date" or "start of the period of study" and either one of the following:

- end of the period of study (31/12/2015);
- the scrap date; or
- the date of loss.

The Figure 2.2-4 shows the number of shipyears per year for the FIRESAFE fleet between 1994 and 2015. The number of shipyears is increasing over the entire period, starting

[5] This figure does not provide a picture of the whole fleet as zeros (non-recorded passenger capacity) have been removed from the analysis. This boxplot has been computed based on the data for 800 out of 872 ships (458 *International and Domestic Class A*, and 342 *Domestic other than EU Domestic Class A*).

from about 210 shipyears in 1994 to 460 shipyears in 2015. The cause of this increase can be attributed to the filtering criteria selected for the study. The fleet under consideration consists of the ships compliant with the above-mentioned criteria. Each year, new ships enter the fleet (newbuildings compliant with the criteria), and contribute for additional shipyears, while almost no ships leave the fleet (since conversions are not considered and almost no scrapped or lost are observed). It seems a fair assumption to consider that the ships characteristics remain unchanged over time.

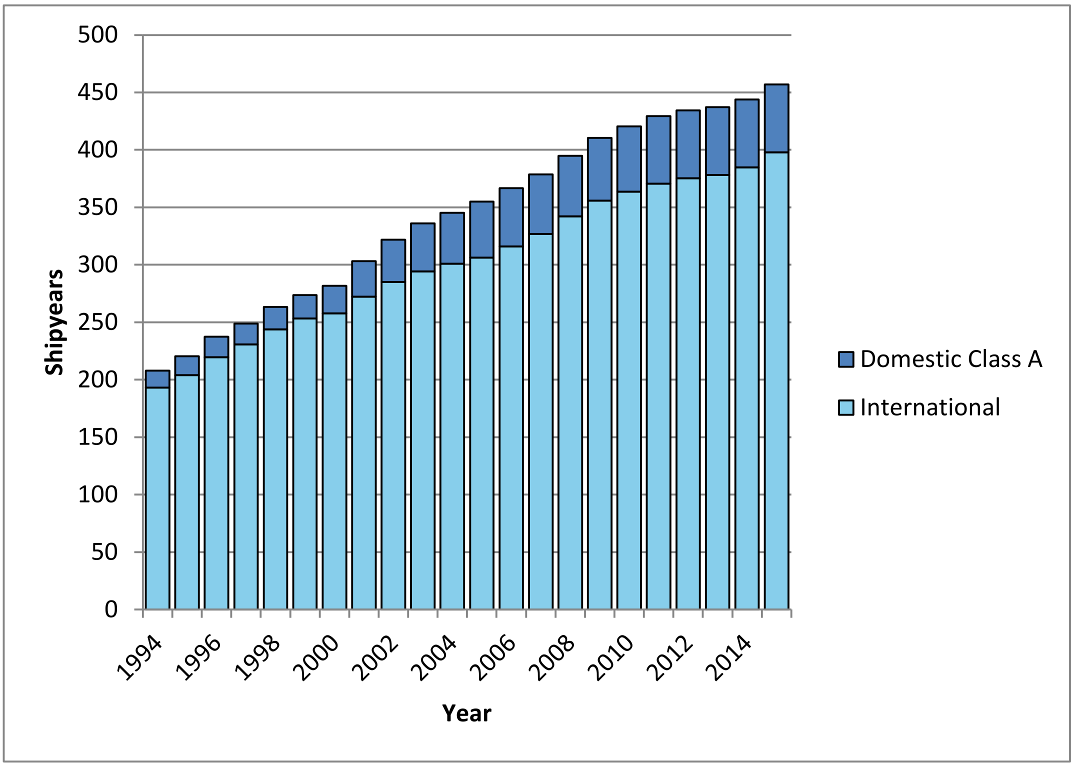

Figure 2.2-4: Number of shipyears per year for the FIRESAFE fleet between 1994 and 2015.

This led to a total of 7567 shipyears for the period 1994-2015, and 5530 shipyears for the period 2002-2015.

Delivery Date

Figure 2.2-5 shows the number of ships delivered per year. Due to the filtering criteria (keel laying date), only one ship FIRESAFE-compliant has been delivered in 1980. No trend can be determined over the period.

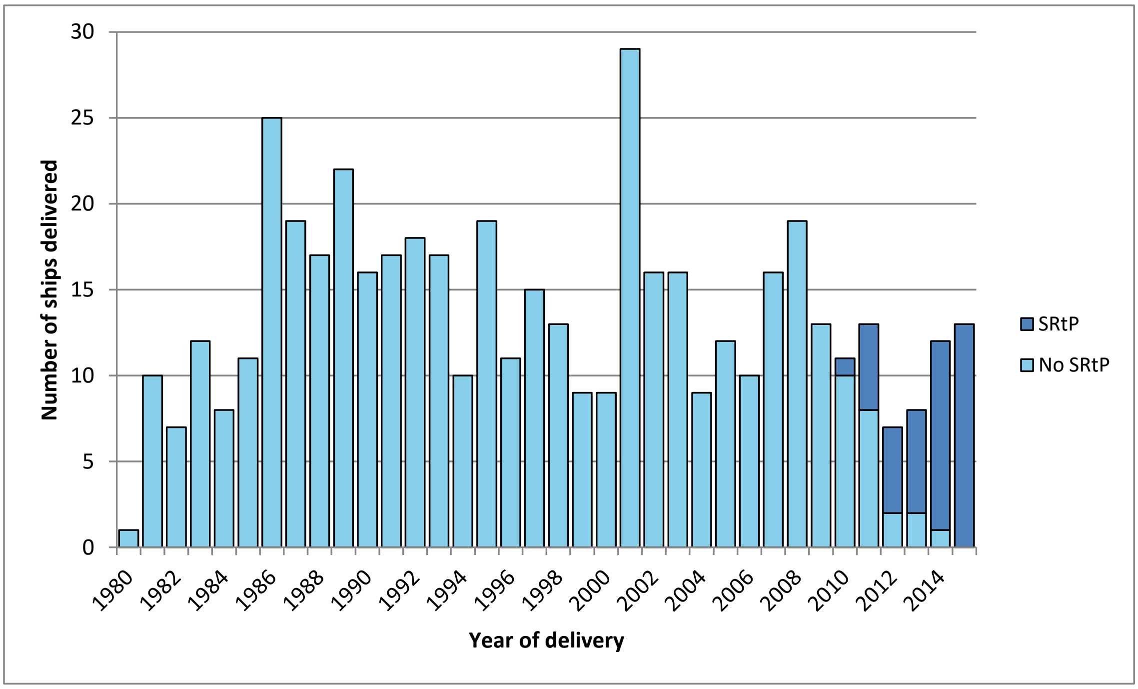

Figure 2.2-5: Number of ships delivered according to delivery date[6].

Age

Figure 2.2-6 shows the number of shipyears with respect to the age of ships over the period 2002-2015. This figure shows a slight increase up to around 18 years old (meaning more exposure for the youngest ships), then the number of shipyears decreases linearly with increasing age until the age of 30 years old and declines gradually until 35 years old, which is the maximum age that a ship can reach given the filtering criteria and the period of study being considered.

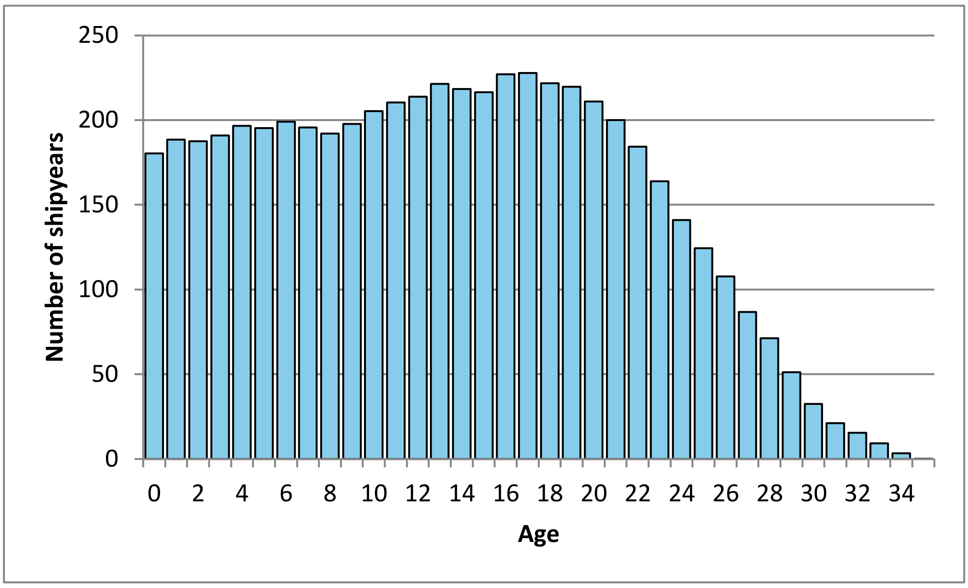

Figure 2.2-6: Number of shipyears for ships observing the given age during the period 2002-2015

[6] When keel laid date was not provided in the database – for 10 out of the 41 ships concerned, criterion has been applied to *built date*, as provided in MARINFO, therefore number of ships identified might be slightly over-estimated.

Figure 2.2-7 shows the average age of the fleet for the period 1994-2015. The age of a ship is calculated from the 31st of December of each year. The average age is increasing from year to year due to the filtering criteria (keel laid date). Each year, each ship takes one more year (with almost no scrap or lost ships) while only few ships enter in the fleet (as shown in Figure 2.2-5). In 2015, the average age of the fleet is 17.4 years old.

As an increase of the average age of the fleet over the investigated period is observed, it might be argued that the fleet selected is not homogenous and that it will affect the incident rate. By normalizing the number of accidents for each age with the exposure time (which has been plotted shown in Figure 2.2-6), it has been possible to determine the accident frequency as a function of the ship age. This has been investigated in the Casualty data analysis section.

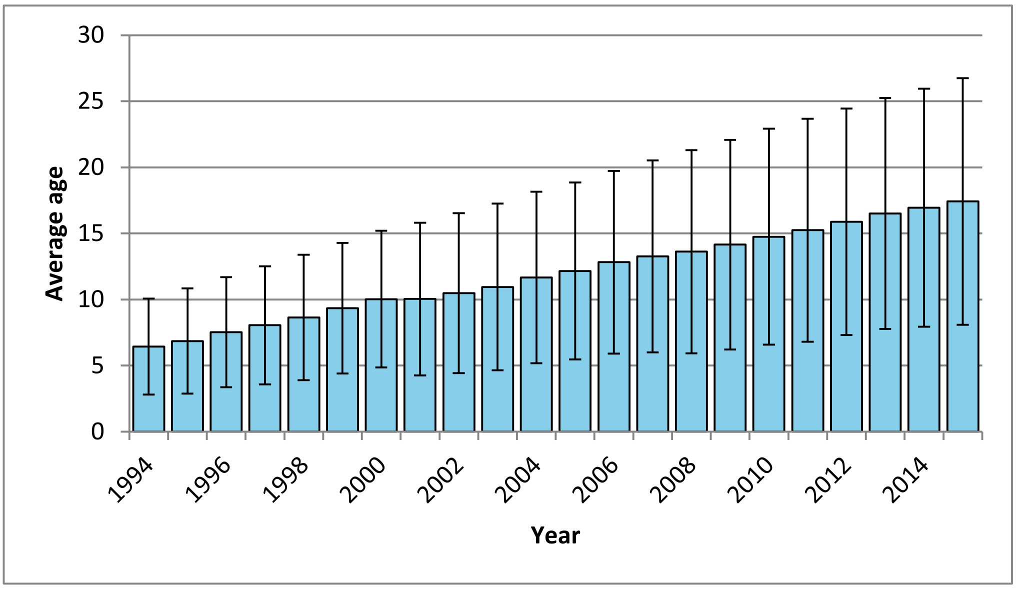

Figure 2.2-7: Average age of the fleet between 1994 and 2015 (+/- one standard deviation)

Life expectancy (at delivery) over the period 2002-2015 for the ships of the FIRESAFE fleet has been estimated to 33.2 years old. However, there is a high uncertainty on this value provided the size of the fleet.

Fleet evolution: gross tonnage

Figure 2.2-8 shows the evolution of the average gross tonnage of the fleet under consideration over the period 2002-2015. A slight increase can be observed between 2002 and 2012, followed by a slight decrease until 2015.

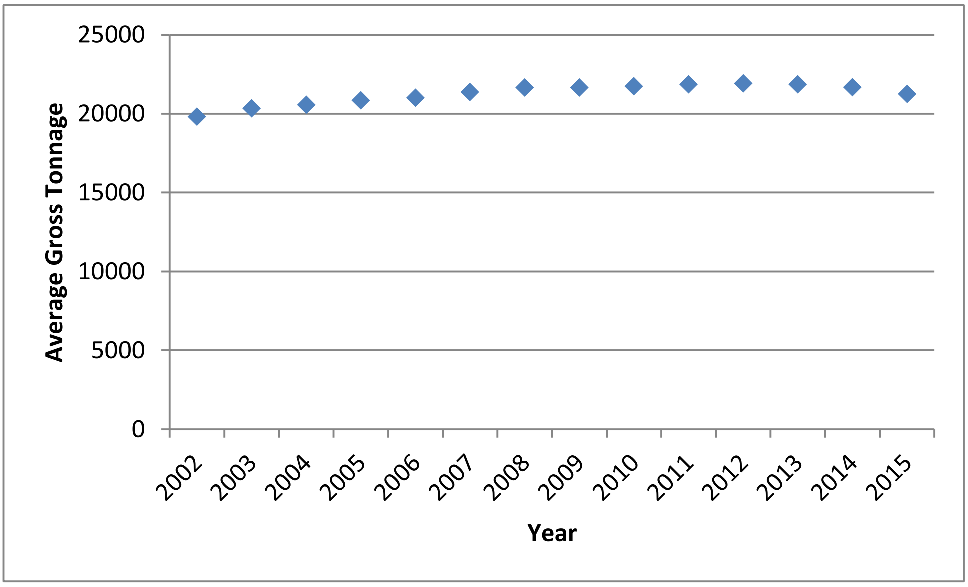

Figure 2.2-8: Evolution of the average gross tonnage of the FIRESAFE fleet over the period 2002-2015

Figure 2.2-9 provides the number of shipyears per year for the FIRESAFE compliant ships, over the period 2002-2015, broken down by GT category. It can be seen that the larger part of the operational fleet is coming from the ships below GT 30000.
Based on the 490 ships, median for the gross tonnage has been calculated to GT 20030 with an interquartile from GT 8790 to GT 30430.

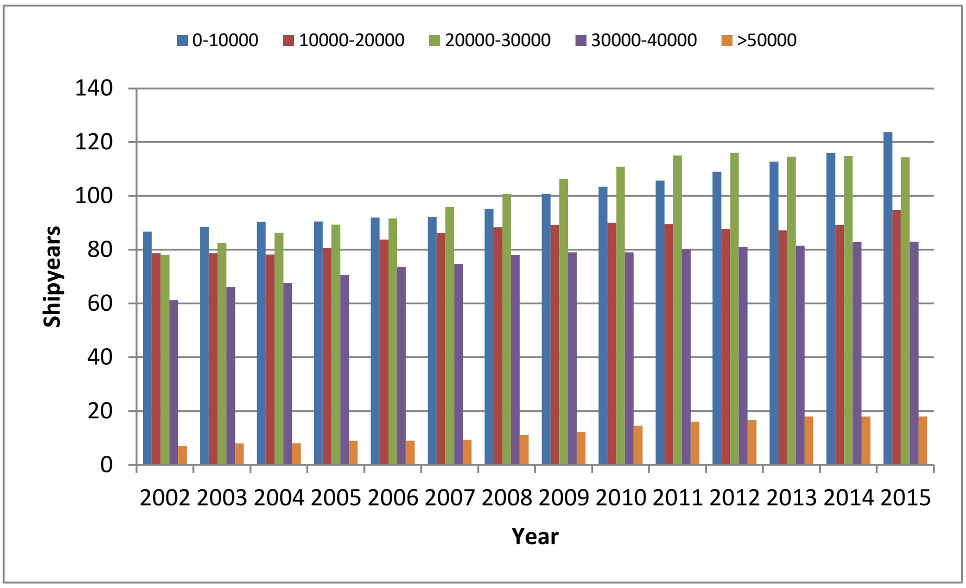

Figure 2.2-9: Number of shipyears per year for FIRESAFE fleet, over the period 2002-2015, broken down by size category (GT)

Fleet evolution: lane meters

Figure 2.2-10 shows the number of shipyears per year for 5 different categories of lane meters. It should be noted that the first category (0-1000m) is expected to be higher (data on the length of ro-ro length were missing for ships with low GT).

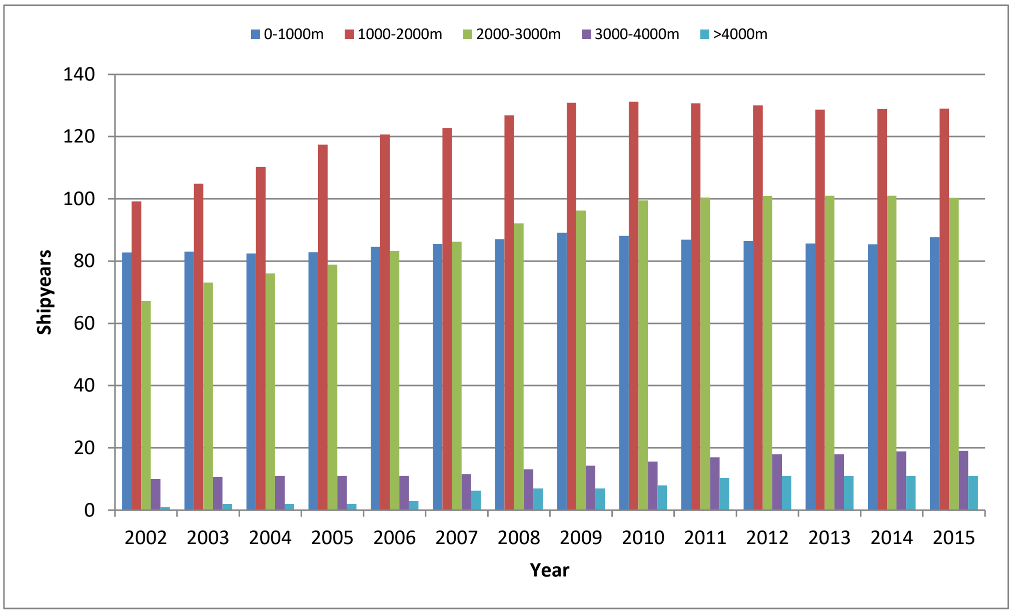

Figure 2.2-10: Number of shipyears per year for the FIRESAFE fleet over the period 2002-2015, broken down by lane meters categories.

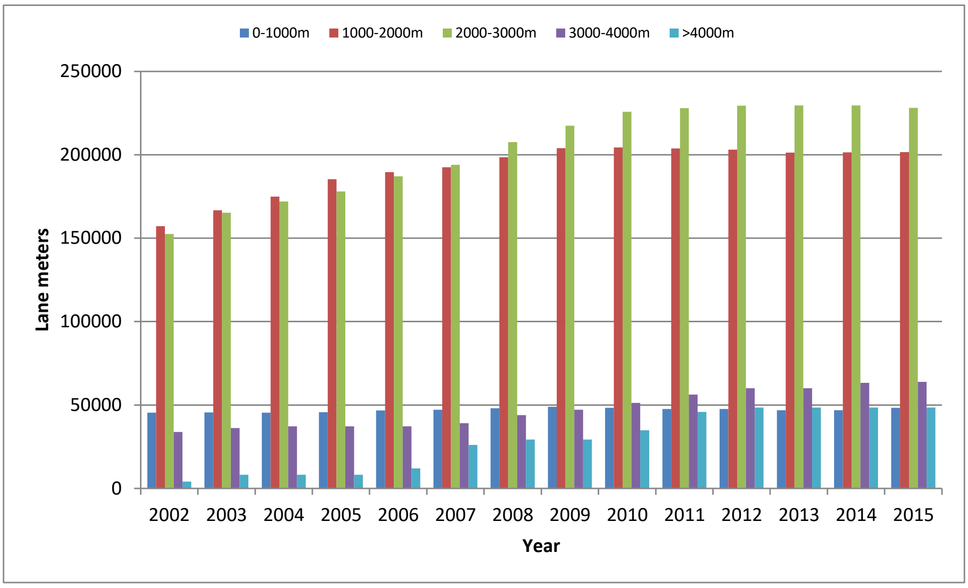

Figure 2.2-11: Total length of ro-ro lanes per year for the FIRESAFE fleet over the period 2002-2015, broken down by lane meters categories

Although the largest part of the fleet consist of ships with lane meters smaller than 2000m (taking into account missing data below 1000m), as shown in Figure 2.2-10, on annual basis, the largest total cargo capacity is provided by ships with length of ro-ro lanes comprised between 1000m and 3000m, as shown in Figure 2.2-11[7]. It should be noted that the total cargo capacity provided by ships with lane meters above 4000m has continuously increased over the period of study. The average length of ro-ro lanes on ro-ro passenger ships of the fleet has increased throughout the period of study.

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[7] Number included in Figure 2.2-11 and Figure 2.2-13 are provided for comparison purposes only and should not be interpreted as absolute number of passengers transported each year by the fleet under consideration.

Based on the 368 data available (out of 490), median for the length of ro-ro lanes has been estimated to 1750 meters with an interquartile from 970 to 2186.

Fleet evolution: passenger capacity

Although the ships having a passenger capacity below 750 persons represent the biggest part of the fleet (almost 50%, as shown in Figure 2.2-12), on annual basis, the largest total capacity of passengers is provided by ships with a passenger capacity between 750 and 2250 passengers (as shown in Figure 2.2-13). The average passenger capacity of the fleet has increased throughout the period.
Based on the 458 data available (out of 490), median for the passenger capacity has been estimated to 827 passengers with an interquartile from 387 to 1500.

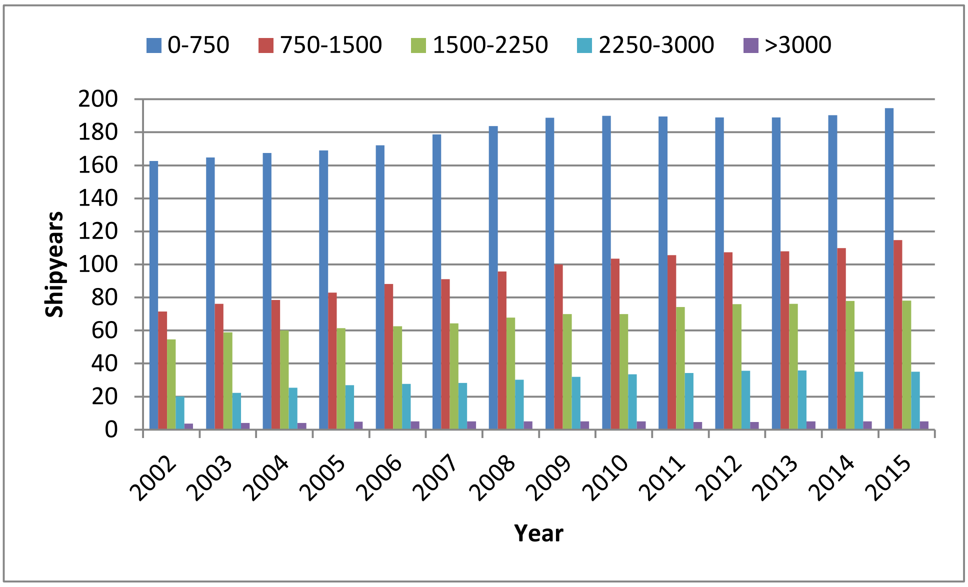

Figure 2.2-12: Number of shipyears per year for the FIRESAFE fleet over the period 2002-2015, broken down by passenger capacity categories

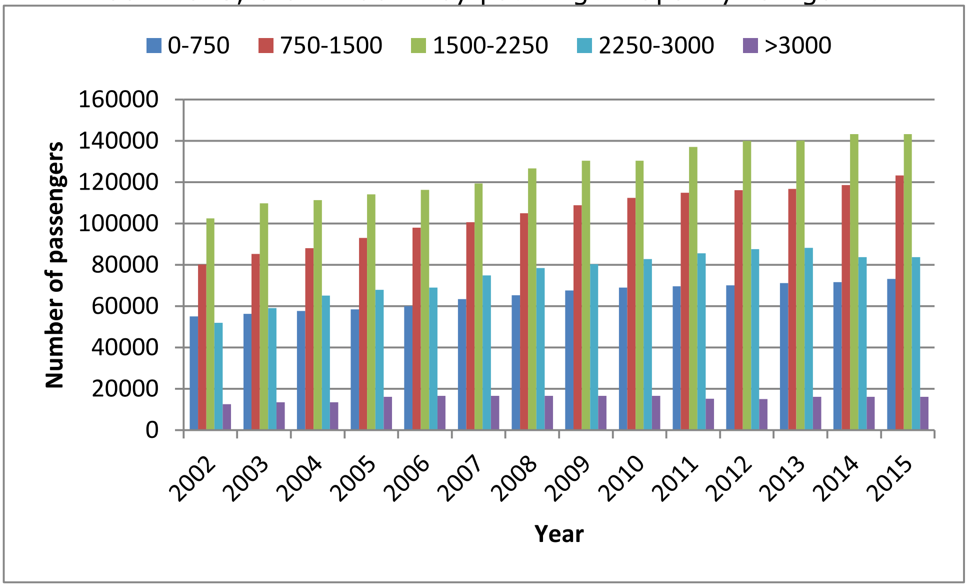

Figure 2.2-13: Total passenger capacity per year for the FIRESAFE fleet over the period 2002-2015, broken down by passenger capacity categories

2.3. Generic ship

A generic ship model was required to make assumptions on different numbers relative to the cost model and the capacity of the ship. The generic ship was selected for that purpose. The number of passengers of the generic ship is very close to the median, while the number of passengers is the main factor in the assessment. As exposed in section Analysis of the FIRESAFE fleet, generic ship's GT belongs to the 3rd quartile, and its length of lane meters is a little bit above the 3rd quartile.

Other fleet characteristics have been further processed in order to define median characteristics on Length, Breadth, Depth, Draught, Age, Speed and Froude.

A statistical metrics (relative difference to evaluate how far the ship characteristics are from the median ones) has been used. In the table below, the reader will find characteristics having a relative difference of less than 25% highlighted in green, else highlighted in red. The reference vessel is vessel no 3 in the Table 2.3-1.

Names	Passengers	Lanes meters	GT (tons)	Length (m)	Breadth (m)	Depth (m)	Draught (m)	Age (years)	Speed (knots)	Froude (-)
Median	827.0	1750.0	20026.0	161.0	24.4	9.7	6.2	17.4	20.4	0.3
STENA SHIP 1	+	+	+	+	+	+	+	+	+	+
STENA SHIP 2	+	+	-	+	+	+	+	-	+	+
STENA SHIP 3	+	-	-	+	+	+	+	-	+	+
STENA SHIP 4	+	-	+	+	+	+	+	-	+	+
STENA SHIP 5	-	+	-	-	+	+	+	+	+	+
STENA SHIP 6	+	+	-	+	+	-	+	-	+	+
STENA SHIP 7	+	+	-	+	+	-	+	-	+	+
STENA SHIP 8	-	+	-	+	+	-	+	+	+	+
STENA SHIP 9	-	+	-	-	+	+	+	+	-	+
STENA SHIP 10	-	+	-	-	+	-	+	+	+	+
STENA SHIP 11	-	+	-	+	-	+	+	-	+	+
STENA SHIP 12	-	+	-	+	-	+	+	-	+	+
STENA SHIP 13	-	-	-	+	+	-	+	+	+	+
STENA SHIP 14	-	-	+	+	+	-	+	-	+	+
STENA SHIP 15	-	-	-	-	+	+	+	-	+	+
STENA SHIP 16	-	-	-	-	+	+	+	-	+	+
STENA SHIP 17	-	-	-	-	+	+	+	+	+	+
STENA SHIP 18	-	-	-	-	+	-	+	-	+	+
STENA SHIP 19	+	-	-	-	+	+	+	-	+	+
STENA SHIP 20	-	-	-	-	-	-	+	-	+	+
STENA SHIP 21	-	-	-	-	-	-	+	-	+	+

Table 2.3-1: Table of possible generic vessel

2.3.1. Ship characteristics

DWT*	6 000 mt on 6.2m draft
Tonnage*	GT 27000 – NT 9000
Class	Ro-ro Passenger ship, SOLAS ship
Ship age	17.5 years
LOA*	190 m / 178 m
Beam*	25 m
Draft*	6m
Upper deck*	1100 lm (open deck)
Main deck*	900 lm (closed deck)
Lower hold*	250 lm (closed deck)
Total:*	2 250 lm + 200 cars (weather deck and under deck)

Passenger capacity 880 incl. crew

Reefer plugs 80 pcs, 40 pcs on main deck and 40 pcs on upper deck

*Approximate number

2.3.2. Fire safety equipment

Detection system	Smoke detection in cargo area
Drencher system	Drencher system on open/closed decks Drencher system manually operated from the drencher central on dk 3 One drencher pump Medium: Sea water Drencher zones in total: 20
Fire pumps	3 fire pumps + 1 emergency fire pump
Fire hoses/ hydrants	Weather deck: 10 Upper deck: 15 Main deck: 17 Lower hold: 21

2.3.3. Additional ship information

CCTV cameras	Weather deck: 2 Upper deck: 2 Main deck: 4 Lower hold: 3
Openings on open deck	2 large openings aft 6 open areas on each side (consisting of total 40 smaller openings) 14 large shutters needed to close all openings
Electrical connection boxes	20 pcs (IP class 56), No earth fault indication on individual sockets
Electrical cables	80 pcs + 10 spare No reeling drums
Electrical car charging station	None

2.4. Casualty data analysis

2.4.1. Introduction

The purpose of this section is to provide more insight about fires on ro-ro decks on RoPax ships.

The subsequent analysis is based on a review of historical data. To enhance transparency and allow repeatability, assumptions taken and limitations of inputs data are explicitly provided. The impacts of some of the assumptions that have been used as the basis for the study have been investigated and are reported.
Based on the historical data, the historical Potential Loss of Life (PLL) and initial accident frequency of fires on ro-ro decks have been estimated.
As mentioned in the EMSA III FSA study (EMSA, 2014), which focused on Cruise and RoPax ships, the fleet under consideration and therefore, the number of shipyears, is small compared to other ship types. Therefore, it is expected to have high uncertainty in some of the results.
The effect of some characteristics (e.g. the age or the size of the ships) on the accidents frequency has also been investigated.
Some of the results, such as the initial accident frequency of fires on ro-ro decks, have served as inputs for quantifying the risk models.

2.4.2. Data collection

2.4.2.1. Description of the data sources

Several different databases and data sources have been used to identify fire accidents and incidents on vehicle decks of ro-ro passenger ships. The main databases and data sources used are as follows:

- FSI 21/5;
- MARINFO Database (EMSA)[8];
- IHS Casualty Database[9];
- EMCIP Database (EMSA)[10]; and
- GISIS (IMO)[11].

2.4.2.1.1. FSI 21/5

Appendix 1 of Annex 6 of the document FSI 21/5 (IMO, 2012a) provides a list of "*73 fires on ro-ro passenger ships and six fires on ro-ro non-passenger ships from 1994 to 2011*". These accidents "*were identified [by the authors of the submission] from the information contained in investigations reports, GISIS and other sources, including Det Norske Veritas, the United Kingdom's Marine Accident Investigation Branch and the Maritime and Coastguard Agency, and Sweden's Lund University*". Although most of the accidents have been anonymised, the year of accident and a short description of its circumstances are provided for each event. Indication of the means of extinguishing is also mentioned when known.

2.4.2.1.2. MARINFO Database

An extract of MARINFO, complying with the FIRESAFE criteria apart from the Froude number criterion and Domestic/International status, has been used and it contains fires on ro-ro passenger ships between 1994 and 2015. For each accident, the date and a

[8] Application developed by EMSA which combines data from four different commercial databases (Lloyds List Intelligence, IHS Maritime, Clarksons Research Services and AXSMarine).
[9] IHS Casualty Database – Version of the 03/02/2016.
[10] EMCIP: European Marine Casualty Information Platform, managed by EMSA and populated by EU Member States on the basis of Directive 2009/18/EU.
[11] GISIS: Global Integrated Shipping Information System, database managed by IMO.

descriptive field containing detailed narrative of the circumstances of the accidents are provided. Additional fields such as the accident area, the number of fatality, missing, and injured, along with the type of loss (Actual Total Loss *i.e.* sank or Constructive Total Loss *i.e.* damaged beyond repair) are available. However, no information on the severity of the accident is reported.

2.4.2.1.3. IHS Casualty Database

Subset of fire accidents having occurred from 1994 to 2015 on ships selected based on Gross Tonnage and Ship Types (i.e. including FIRESAFE and non-FIRESAFE compliant RoPax), has been extracted from the entire IHS Casualty database. As for MARINFO, for each accident, the date of the event and two descriptive fields containing detailed narrative of the circumstances of the accidents are provided. Fields such as the accident area, the number of fatalities and missing are also included in IHS database. Number of injured can be retrieved sometimes from the accident description. In addition to those ones, ship characteristics at time of incident (such as Owner, Flag, or Class) are given. Severity Indicator is also available.

2.4.2.1.4. EMCIP Database

Subset of fire accidents and incidents having occurred on the FIRESAFE compliant ships from 2010 to 2016 has been provided by EMSA as anonymised data. Date and descriptions of the accidents are available and severity indicator is recorded, as defined in the IMO Code for the Investigation of Marine Casualties and Incidents (IMO, 2008a).

2.4.2.1.5. GISIS Marine Casualties and Incidents module

Fires on ro-ro passenger ships were extracted from the GISIS Marine Casualties and Incidents module, and a search on a ship by ship basis, using ship name or IMO number, has been performed to obtain more detailed information on the accidents (related to the causes). This approach has already been followed in other FSA studies such as the FSA of General Cargo Ships (IMO, 2010) and GOALDS (IMO, 2012b), and has been highlighted in the document III 3/4/5 (IMO, 2016a): "*[GISIS] available reports do provide information on the underlying accident causes which can be readily used in FSA studies*".

2.4.2.2. Data sources exploitation

In IHS Casualty database, initial query for the selection of the subset of fire accidents was not only limited to accidents categorized under Fire/Explosion (FX). Consideration has been given to other accident types that could have led to fire in ro-ro decks, such as collision.

Amongst the non-anonymised fires on ro-ro passenger ships included in the document FSI 21/5, 3 accidents were identified as having occurred on ro-ro cargos or pure car and carriers (Und Adriyatik, Scheiborg and Silver Ray). These have been removed from the initial list of 73 accidents.

In most databases, except for EMCIP, the precise origin of fire is not directly provided. Short descriptions of accidents provided by MARINFO and IHS were analysed individually to identify fires on ro-ro decks.

When available, accident investigation reports, GISIS, and press articles from local newspapers or technical papers on 'Fires on ro-ro decks' have been consulted to obtain additional information on the events.

By construction, there were overlaps between databases (*i.*e. one single accident could be included in more than one dataset). However, as the accident details and descriptions were not provided with the same level of details depending on the database, this allows having validation of the description of accidents or obtaining additional details for one single accident.

2.4.2.3. Results of data collection

For the sake of clarity and transparency, the number of records found in the databases is reported in the Table 2.4-1:

	FSI 21/5	MARINFO	IHS Casualty	EMCIP
Total records (RoPax Fires)	70[12]	176	261	27[13]
Fires on ro-ro decks (including non-FIRESAFE compliant RoPax ships)	70	46	37	27
Fires on ro-ro decks (FIRESAFE compliant RoPax ships) 2002-2015	17	30	18	22

Table 2.4-1: Number of total records for fires on RoPax ships and relevant records for fires on ro-ro decks, according to the data source.

Unless indicated otherwise, same filtering criteria as the ones selected for the determination of the FIRESAFE fleet have been used for the casualty analysis over the period 2002-2015. When relevant, broader fleets might have been investigated (*i.e.* ship selection using slightly different criteria). Analyses considering other fleets have been clearly identified in the following of the report and the criteria selected have been justified.

Based on the FIRESAFE filtering criteria, and gathering/merging the information contained in the MARINFO and IHS databases, which both cover the whole period 2002-2015, this led to a list of 32 fires on decks on ro-ro passengers ships compliant with FIRESAFE criteria between 2002 and 2015[14]. If data from all the above-mentioned databases are merged, this led to a list of 50 fires on ro-ro decks on FIRESAFE compliant ships.

2.4.3. Casualty statistics

Although EMCIP represented the most complete database, in terms of number of accidents and incidents per year (with 27 records between June 2010 and June 2016,

[12] The list of accidents included in FSI 21/5 focused on fires on ro-ro decks, therefore the number of records for RoPax Fires and Fires on ro-ro decks are identical.
[13] Due to the way EMCIP subset was selected, the number of total records and number of fires on ro-ro decks are very similar.
[14] The period of interest considered is further discussed in section: *Period of Study*.

and an average number of 4 records per year between 2012 and 2015), the fleet at risk can be hardly determined since EMCIP only records marine casualties or incidents:

- involving a ship flying its flag, irrespective of the location of the casualty;
- occurring within its territorial sea and internal waters as defined in UNCLOS, irrespective of the flag of the ship or ships involved in the casualty; or
- involving a substantial interest of the Member State, irrespective of the location of the casualty and of the flag of the ship or ships involved.

Since FSI 21/5 and EMCIP did not cover the full period of study and given their specific reporting channels, in order to have a consistency of the reporting, in particular regarding severity throughout the period, only data from MARINFO and IHS have been merged and used for deriving casualty statistics such as accident frequencies and dependent probabilities of the main risk model (32 accidents).

However, FSI 21/5 and EMCIP are very valuable sources of information. For some specific analyses, data from these sources have been merged with IHS and MARINFO to compute ratios and statistics.

2.4.3.1. High-level historical data investigation

In order to gain more insight on accidents occurring on RoPax ships, the number of records per casualty types on the FIRESAFE compliant ships between 2002 and 2015 has been investigated and results are shown in **Fel! Hittar inte referenskälla.**2.4-1.

This analysis has been performed using the IHS Casualty Database. For the purpose of the analysis, the fields "killed" and "missing", as reported in IHS, are merged into the group "fatalities".

For the purpose of the study, the category Fire/Explosion (FX) has been divided into two sub-categories: FX (ro-ro decks) for fires originating from ro-ro decks and FX (others) for fires not originating from ro-ro decks, irrespective of their specific origin (*i.e. engine room, accommodation* or *others*).
451 accidents have been reported in IHS during the period 2002-2015 leading to a total number of 2116 fatalities. The proportion of accidents caused by fire/explosion represents 12.9% of the total number of accidents, with about one third of them originating from ro-ro decks.
While the relative *all accidents* frequency and *serious accidents* frequency of the category "Fires on ro-ro decks" are comparatively low in comparison to the others, the relative frequency of fatal accidents is comparable for each accidents category.

Except for the Fire/Explosion accidents (and other accident types that had led to fires on ro-ro decks as identified during the data collection process), accident reports have not been reviewed, therefore the results presented in **Fel! Hittar inte referenskälla.**2.4-1 might differs from previous FSA studies. The number of fatalities for the "Fires on ro-ro decks" fatal accidents corresponds to the ones reported in IHS. This number might vary in the following of the report as it depends on the source.[15]

[15] Number of fatalities from accident investigation reports or official sources has been used in the following for the calculation of historical PLL.

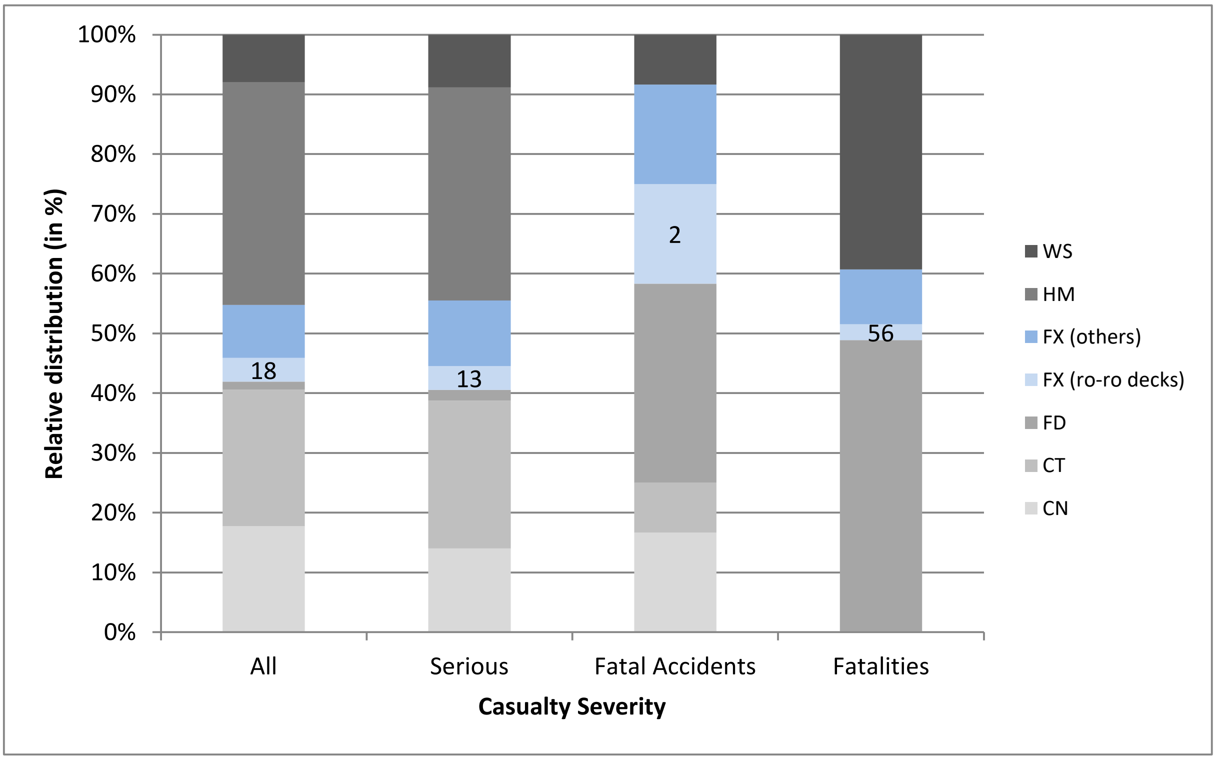

Figure 2.4-1: Relative distribution of casualty reports over the different accident categories on the FIRESAFE fleet between 2002 and 2015. Number of records for FX (ro-ro decks) provided by IHS. (WS: Wrecked/stranded, HM: Hull/machinery damage, FX: Fire/explosion, FD: Foundered, CT: Contact, CN: Collision)

2.4.3.2. Fires on ro-ro decks

2.4.3.2.1. Fires on ro-ro decks: Severity discussion

The ratio between *Serious* and *Non-Serious*[16] (which could be derived from **Fel! Hittar inte referenskälla.**2.4-1 looking at the difference between *All* and *Serious* accidents) might be biased by the reporting process depending on the database provider.

However, due to the obligations provided for by the Directive 2009/18/EU (EU, 2009), it is expected that incidents are well represented in the EMCIP database, contrary to what is usually observed in other accident databases as identified in the document MSC 93/15/2 (IMO, 2014).

Therefore, statistics based on EMCIP database have been produced to give a picture that is considered to be closer to the reality, in terms of severity level ratios, than what is reported in **Fel! Hittar inte referenskälla.**. These results are shown in Figure 2.4-2.

[16] Definitions for the different levels of severity differ from database to database. Definitions for IHS Casualty database and EMCIP have been reported in Annex.

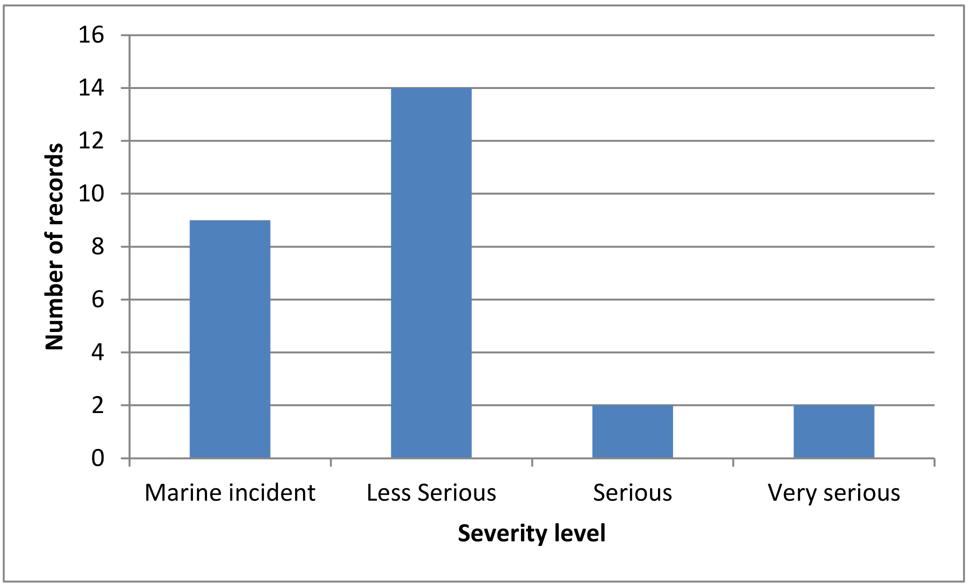

Figure 2.4-2: Number of occurrences according to severity, based on EMCIP database.

85% of the 27 fires on ro-ro decks occurrences on FIRESAFE compliant ships recorded in EMCIP databases between June 2010 and June 2016 have been classified as *Marine incident* or *Less Serious Casualty*. Only 28% of the records were classified as *Non-Serious* in IHS.

Contrary to the approach followed in some FSA studies, where only *Serious* accident were considered (*e.g.* EMSA III - to consider only accident that could have endangered the stability of the ship), no discrimination on the severity of the accident will be made in the sample of 32 accidents that were reported in IHS/MARINFO. This approach is consistent with the one followed in SAFEDOR FSA on RoPax (IMO, 2008b). It is believed that all accidents were susceptible to have caused significant damages to the ship, but were in some cases, detected and fought early enough to avoid any (serious) damage.

2.4.3.2.2. Fires on ro-ro decks: Effect of database

As different data sources, have been used for that study, the effect of the data source has been investigated. This investigation also allows comparison with previous FSA study on ro-ro passenger ships (SAFEDOR).

A more recent FSA study on ro-ro passenger ships (EMSA III) has been published, however, this FSA mainly focused on damaged stability. Therefore, while the initial accident frequency for fires has been updated, the accident reports related to fires have not been reviewed and the relative distribution of fires on ro-ro decks per origin has not been modified since SAFEDOR.

The proportion of fires on ro-ro decks, as found in SAFEDOR, has also been used more recently in a Formal Safety Assessment study on Electric Mobility on RoRo/RoPax vessels submitted to MSC 96 by Germany (IMO, 2016b), which focused on "*fires in the cargo area of ro-pax vessels caused by electrically powered vehicles and refrigeration units connected to the ship's electrical distribution system.*"

It should be noted that the classification method has not been reported in the SAFEDOR study. While determining whether a fire originates from ro-ro spaces could be unambiguous, it is more difficult to classify accidents originating from location different than *engine room* and *accommodation* (e.g. lifejacket store-room), or when no sufficient

information is available. Therefore, for MARINFO and IHS, accidents have been arranged by two categories only: *Vehicle Deck fires* and *Other*.
Statistics on IHS Casualty Database and MARINFO are based on accidents on FIRESAFE compliant ships during the period of study (2002 and 2015). EMCIP statistics has been computed from accident data on an undefined fleet of RoPax from June 2010 to June 2016. As for SAFEDOR, the ships considered are RoPax of 1,000 GRT and above and the period of study is 1994-2004 (no filter on the severity of the accidents).

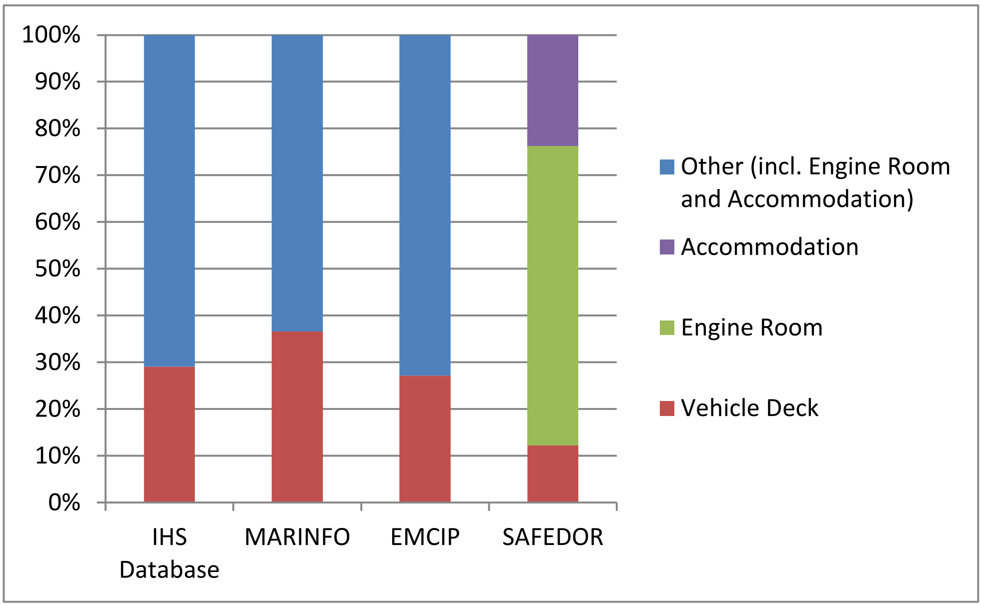

Figure 2.4-3: Relative distribution of fire origin on RoPax ships in different accident data sources.

Due to the different periods and fleets considered, no conclusion should be drawn from Figure 2.4-3 on a potential increase in the proportion of fires on ro-ro decks or potential enhancement of fire safety in engine room and accommodation. However, it is worth noting the good degree of consistency between IHS Casualty Database, MARINFO and EMCIP, all around 30%, and the important difference with SAFEDOR (12%), the origin of this difference has not been ascertained. This proportion in SAFEDOR is close to what had been found in EMC MP08 (11%).
Nonetheless, Figure 2.4-3 shows that, regardless of the database being looked at, fires on ro-ro decks on the FIRESAFE compliant ships represent approximately one third of all fires on ro-ro passenger ships.

2.4.4. Fleet at risk: exposure time

Having described and reported the data collection process, and looked into the contribution of the fires on ro-ro decks on the total risk on RoPax ships, different parameters impacting the calculation of the exposure time (number of shipyears), and therefore the accurate determination of the initial accident frequency (and similar indicators), are investigated in that section.

2.4.4.1. IACS/Non-IACS

One parameter of interest that must be considered is the classification of ship under an IACS society. One of the criteria for selecting the ships under consideration is "ship classed by one of the IACS members" with the rationale that considering only IACS-classed ships would minimize under-reporting. This approach had been followed in several FSA studies.

Under-reporting of accidents occurring on non-IACS ships has been widely reported, and recently well documented on the EMSA III FSA study. Therefore, such analysis will not be reported here, and it is taken as a starting point that ships having never been classed by an IACS society in their lifetime are excluded from the analysis.

By considering this parameter, attention must be given to the "exposure time" considered, (*i.e.* the number of shipyears - fleet at risk - used to calculate the initial accident frequency and historical potential loss of life).

In this study, the choice has been made not to calculate the number of shipyears based on the current IACS-classed fleet[17]. Therefore, two approaches have been considered and are investigated below.

Comparison of accident frequencies and PLLs for two different fleets over the period 2002-2015 has been performed based on the MARINFO database to show the influence of the 'IACS' filtering criterion and is reported in Figure 2.4-4.

The first fleet investigated is the fleet compliant with the FIRESAFE criteria, which considers ships classed or having been classed at least once by an IACS member at some point during their lifetime. This fleet is referred to *All* in Figure 2.4-4. All fires on ro-ro decks (and associated fatalities) having occurred in that fleet are counted, regardless of the class at time of incident (ATOI). They are referred as *All ATOI* in Figure 2.4-4.

As the databases record the change of class over the lifetime of the ships, it is possible to calculate the number of shipyears during which a ship has operated while classed by an IACS society[18]. This is the second fleet[19] investigated and referred as *IACS-class* in Figure 2.4-4. It is also possible to identify accidents which have occurred on a ship classed by an IACS society at the time of incident. This is referred as *IACS ATOI* in Figure 2.4-4.

Therefore, it has been possible to compare the initial accident frequencies and PLLs for both fleets. Only the left-most and right-most frequencies and PLLs are homogeneous (i.e. comparing accidents and exposure time on an identical fleet).

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[17] With this approach, a ship not IACS-classed at the time of the study might not be considered in the fleet whereas she could have had an accident while she was IACS-classed.

[18] The number of ship years was calculated for the time between "Effective Date" of entry into IACS class (as reported in IHS), or the start of the period of study (01/01/2002) and either one of the following:

- the end of the time interval (31/12/2015);
- the death date (Final Date when vessel was confirmed as being lost or scrapped);
- the date of end of IACS class.

[19] The term fleet must not be understood here as a fixed list of ships but rather as a list of ships that might be in or out of the fleet considered over time based on their characteristics.

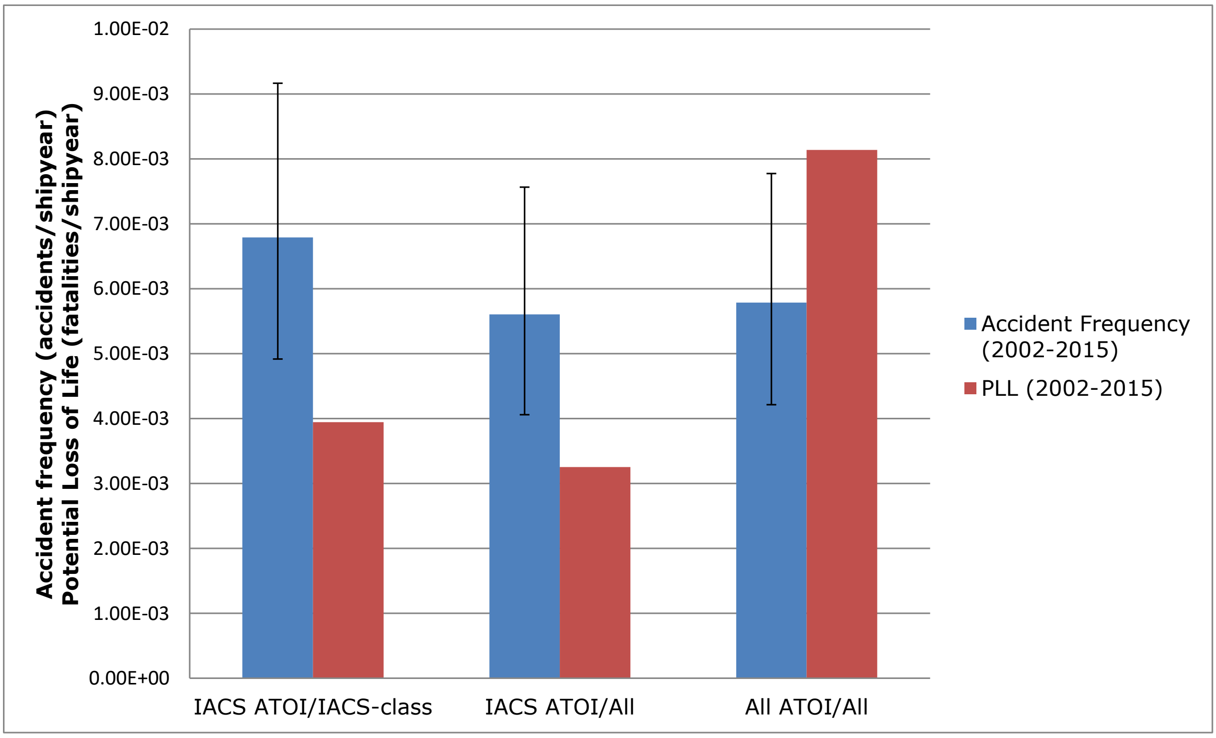

Figure 2.4-4: Impact of the IACS-class filtering criterion on the accident frequency and Potential Loss of Life.

While the consideration of the IACS parameter decreases the number of shipyears by about 20%, there was only one accident having occurred on a FIRESAFE-compliant ship which was not classed by an IACS society at the time of incident. This explains the increase in frequency between the *All* fleet and the *IACS-class* fleet. However, this unique accident was a fatal accident causing 27 fatalities, therefore the PLL of the *All* fleet significantly increases.

The calculation of shipyears for IACS is highly dependent on the quality of the records (which are more likely to be of lower quality than the records of Build date and Death date). Thus, no conclusion can be drawn on a potential under- or over-estimation of the initial frequency of fires on ro-ro decks and historical PLL.
Therefore, choice has been made to consider all accidents, regardless of the class of the ships at the time of incident, and to calculate the number of shipyears based on the whole fleet compliant with FIRESAFE criteria, regardless of their actual class at each time[20]. This ensures consistency between the fleet being looked at and the accident considered. The authors of that study are aware that, with this approach, the initial accident frequency is under-estimated. The Risk Control Options that would be found cost effective, with this approach, would be even more justified, from a cost effectiveness point of view, than with the figures resulting from the IACS-fleet approach.

2.4.4.2. Period of study

Few accidents on FIRESAFE compliant ships have been reported between 1994 and 2002 and there has been at least one accident per year after 2002. In Figure 2.4-5, an

[20] Since the under-reporting of Non-IACS is known and widely documented, the initial selection for the fleet at risk ("have been classed by an IACS society at least once in its lifetime") was justified, and can be considered as a first "filter".

increase in the number of accidents per year can be observed after 2004. This figure should be read while keeping in mind that, due to the selected filtering criteria, the fleet under consideration is growing during the period 1994-2015.

Regardless of the ship type and accident category, this characteristic has already been observed and identified in other FSA studies[21]. This has usually been imputed to "a change in the reporting practice". It should be noted that the difference in the number of accidents between 1990 and 2003, and 2005 and 2016, which are the two periods investigated in the DNV (DNV, 2005) and DNV GL (DNV GL, 2016) technical papers on Fires on Ro-Ro decks, has also been explained, *inter alia*, by better reporting.

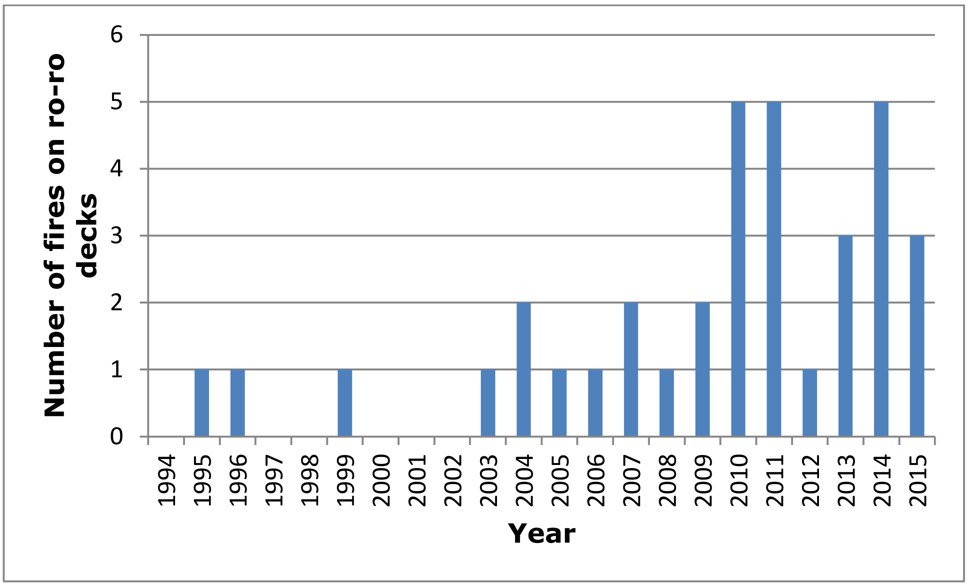

Figure 2.4-5: Number of fires on ro-ro decks per year on FIRESAFE compliant ships (1994-2015).

The IMO Correspondence Group on Casualty Analysis (March 2013) also noted in FSI 21/5 *inter alia* that: "*There have been a number of significant fire incidents on ro-ro passenger vehicle decks since 1994 and there is no sign of these diminishing. Since 2002 there has been a very serious incident every other year, resulting in six constructive total losses.*"

While acknowledging that this gap in 2000-2001 has also been observed in a broader fleet as can be seen in Figure 2.4-6, it has not been possible to determine, for the FIRESAFE fleet at risk, whether data for that period was missing or whether no accidents actually occurred during this period.

The recent figures might be considered closer to the reality than the older data.

Therefore, for the purpose of the study, it seems a conservative approach to consider only accidents from 2002 to 2015 for the calculation of the initial accidents frequency.

[21] EMSA/OP/10/2013 Risk Level and Acceptance Criteria for Passenger Ships. First interim report, part 1: Risk level of current fleet. "*The lack of recordings in earlier years of the reporting period and the increased data after year 2004 may be more attributed to the change of recording practice of the IHS database provider, rather than to genuine risk factors [with regard to Hull/Machinery accidents].*"

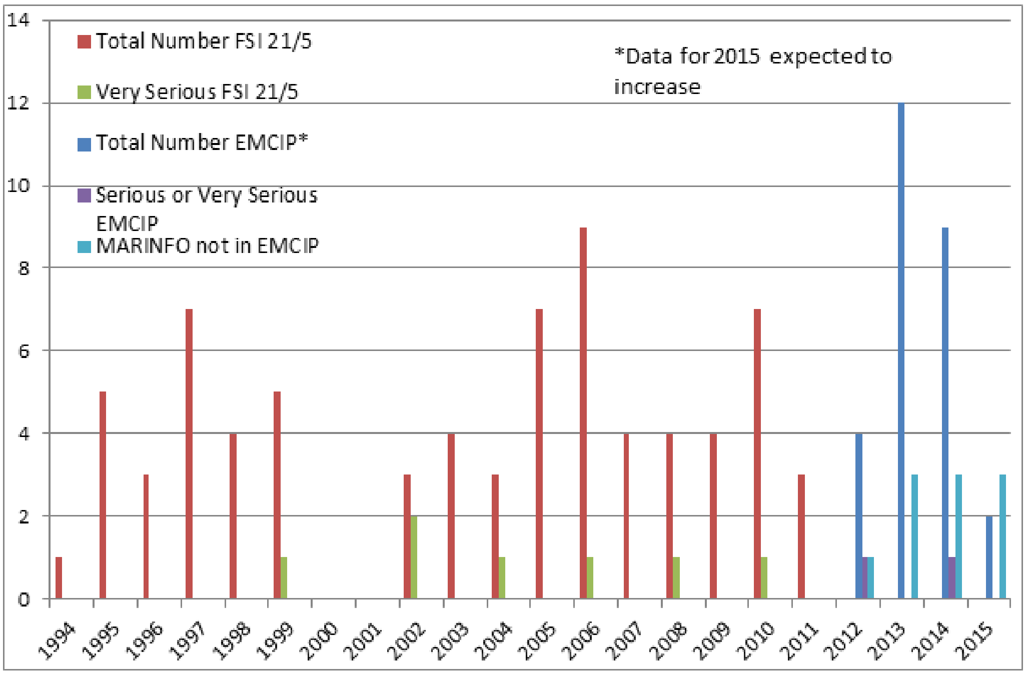

Figure 2.4-6: Fires on ro-ro decks 1994-2015 (from MSC 97/19/3 - Fire safety of ro-ro passenger ships). (IMO, 2016c)

Figure 2.4-7 shows the number of fires on ro-ro decks recorded in the four databases (IHS Casualty database, MARINFO, EMCIP, and FSI 21/5). The high number of records after 2010 comes from the integration of EMCIP into the dataset considered.

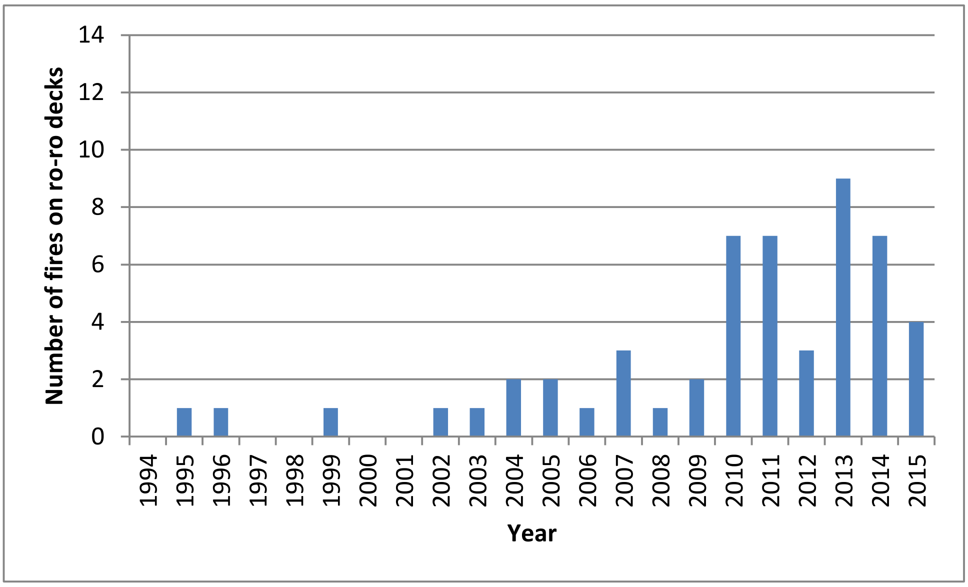

Figure 2.4-7: Number of fires on ro-ro decks per year on FIRESAFE ships, considering all sources of data.

2.4.5. Initial accident frequency, Potential Loss of Life and Potential Loss of Ship

2.4.5.1. Initial accident frequency

32 accidents have been collected for the period of study 2002-2015 on the FIRESAFE fleet at risk, which represents an exposure time of 5530 shipyears for the fleet

considered. The 14-year average accident frequency for FIRESAFE compliant ships is calculated to 5.79E-03 per shipyear ($CI_{90\%}$ [4.21E-03; 7.77E-03]).
The annual accident frequency of fires on ro-ro decks is shown in Figure 2.4-8.

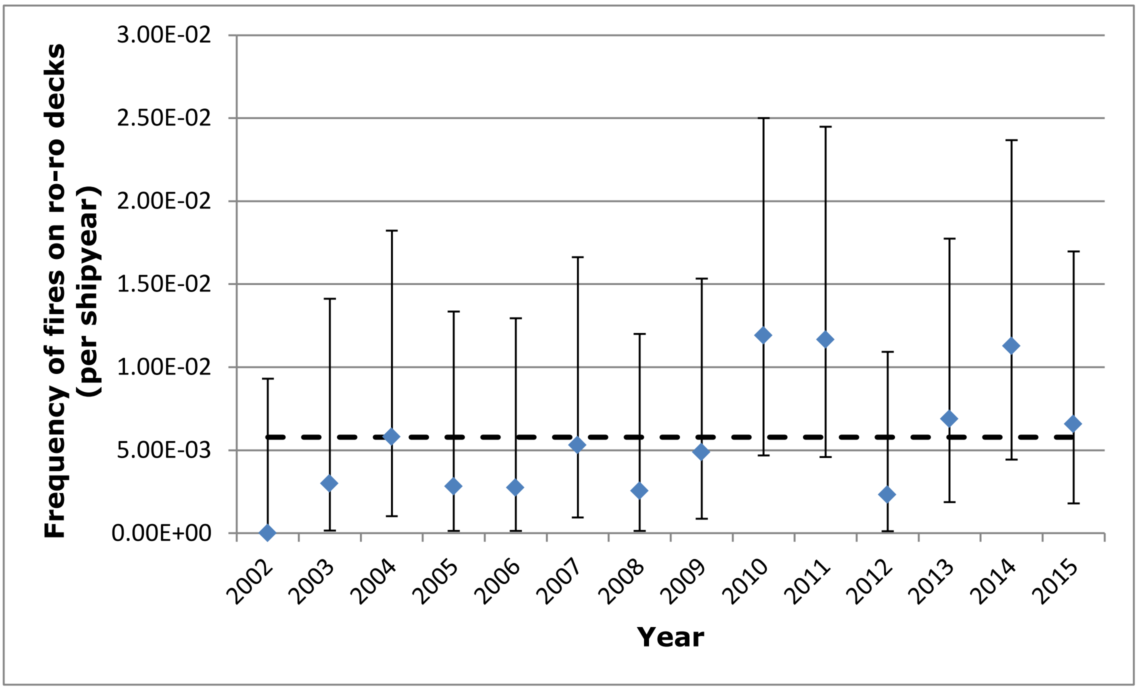

Figure 2.4-8: Annual accident frequency of fires on ro-ro decks with 90 % confidence interval[22] between 2002 and 2015 and the 14-year average.

As indicated in the document FSI 21/5, there is no discernible downward trend in the frequency of accidents and no significant increase in the underlying risk of fire ignition could be ascertained in the recent years.

2.4.5.1.1. Comparison with previous studies

In the technical paper, *Fires on Ro-Ro Decks*, published by DNV in 2005 (DNV, 2005), 7 accidents were identified on the SOLAS ferries fleet, for a total of 12000 shipyears. This led to an accident frequency of 5.83E-04 fires on ro-ro decks per shipyear.
An update of that publication, published by the DNV GL in April 2016 (DNV GL, 2016), which considered only "*vessels complying with the SOLAS convention or domestic ferries assumed to be substantially in compliance with this standard*", identified 18 accidents for an average fleet of 9000 shipyears, leading to an accident frequency of 2.00E-03 fires on ro-ro decks per shipyear. It should be noted that DNV GL also made the distinction between RoPax built before and after the SOLAS 1974 Convention, specifying that only 2 RoPax built prior or on 1980 were involved in an accident.
It is also possible to retrieve the accident frequency from the statistics used in the previous SAFEDOR and EMSA III FSA studies. In SAFEDOR FSA on RoPax, the initial fires frequency was estimated to 8.28E-03 accidents per shipyears, and the proportion of fires initiating on ro-ro decks to about 12.28%. Accident frequency of fires on ro-ro decks is therefore: 1.02E-03 fires on ro-ro decks per shipyear.

[22] Assumption that accidents are Poisson distributed.

	Fires on ro-ro decks Frequency (per shipyear)
DNV Fires on ro-ro decks (1990-2003)	5.83E-04
SAFEDOR - FSA on RoPax	1.02E-03
DNV GL Fires on ro-ro decks (2005-2016)	2.00E-03
FIRESAFE	**5.79E-03**

Table 2.4-2: Comparison of accident frequencies of fires on ro-ro decks found in literature.

2.4.5.2. Total losses

Over the period, 2002-2015, four ships have been reported as Total Losses following fires on ro-ro decks (in 2010, 2011, 2014, and 2015). This led to a potential loss of ship (PLS) of 7.23E-04 total losses per shipyear ($CI_{90\%}$ [1.97E-04; 1.85E-03]).
It should be noted that several total losses due to fires on ro-ro decks have occurred on ships not covered by the FIRESAFE fleet such as the Maria Carmela in 2002, the Al-Salam Boccacio 98 in 2006, or more recently, the Ant 2 in 2013, and the Sun Flower Daisetsu in 2015.

2.4.5.3. Fatalities

There have been two fatal accidents due to fires on ro-ro decks on the FIRESAFE fleet during the period under consideration. The number of fatalities in the first accident (Accident A) is estimated to 18 and the second accident (Accident B) caused 27 fatalities. This leads to a Potential Loss of Life of 8.14E-03 fatalities per shipyear.
Accident investigation report of Accident B indicated the cause of deaths: 14 people died due to drowning and 13 due to the fire.
It was possible to derive the estimated PLL from the SAFEDOR and EMSA III FSA studies, based on their respective risk model for fire/explosion which included a branch focusing on fires on vehicle decks.

	Potential Loss of Life (fatalities per shipyear)
SAFEDOR - FSA on RoPax (estimated)	1.84E-03
EMSA III (estimated)	3.45E-03
FIRESAFE (historical)	**8.14E-03**

Table 2.4-3: Comparison of PLL caused by fires on ro-ro decks estimated in previous FSA studies.

It should be noted that several high-fatalities accidents due to fires on ro-ro decks have occurred on ships not covered by the FIRESAFE fleet. Amongst them are the ships mentioned as total losses in the paragraph above (Maria Carmela: 18 fatalities out of 346 persons on board, Al-Salam Boccacio 98: 1031 lives lost and 387 persons rescued, Sun Flower Daisetsu 1 fatalities out of 94 persons on board).

2.4.5.4. Injuries

Injuries in accidents have been considered such as that 1 minor injury is equivalent to 0.01 fatalities and that 1 serious injury is equivalent to 0.1 fatalities (See table in paragraph 3 of Appendix 4 of Annex of MSC-MEPC.2/Circ.12/Rev.1).

While not directly available in every data sources, the number of injured people can sometimes be retrieved from the detailed narratives of the circumstances of the accidents, accident investigation reports when available, or local press articles.

When it was explicitly mentioned "*serious injuries*", "*taken to the hospital*", or where there was no explicit record of the severity of the injuries in MARINFO, the injuries have been considered as serious. Otherwise, all the injuries have been considered as minor.

Based on that analysis, 71 serious injuries and 282 minor injuries have been counted (on 8 accidents out of the 32 considered), which can be considered as 9.92 equivalent fatalities. This brings the total number of fatalities and equivalent fatalities to 54.92. A potential loss of life (which reflects both fatalities and injuries) can be calculated on that basis and is estimated to 9.93E-03 equivalent fatalities per shipyear over the period 2002-2015 on the FIRESAFE fleet at risk.

2.4.6. Impact of ship age

By normalizing the number of accidents for each age with the exposure time, it has been possible to determine the accident frequency as a function of the ship age. Contrary to the structural failures, where the effect of age of the ship has been shown[23], most of fires on ro-ro decks might be independent from the ship itself (and therefore its age) and be caused solely by the cargo itself.

Note that to maintain readability, abscissa axis on Figure 2.4-9 has been cut short at the age of 27 years old. No accident happened on ships older than 26 years old.

The full data set of accident occurring on FIRESAFE compliant ships has been taken.

Based on Figure 2.4-9, the impact of ship age on the accident frequency cannot be ascertained.

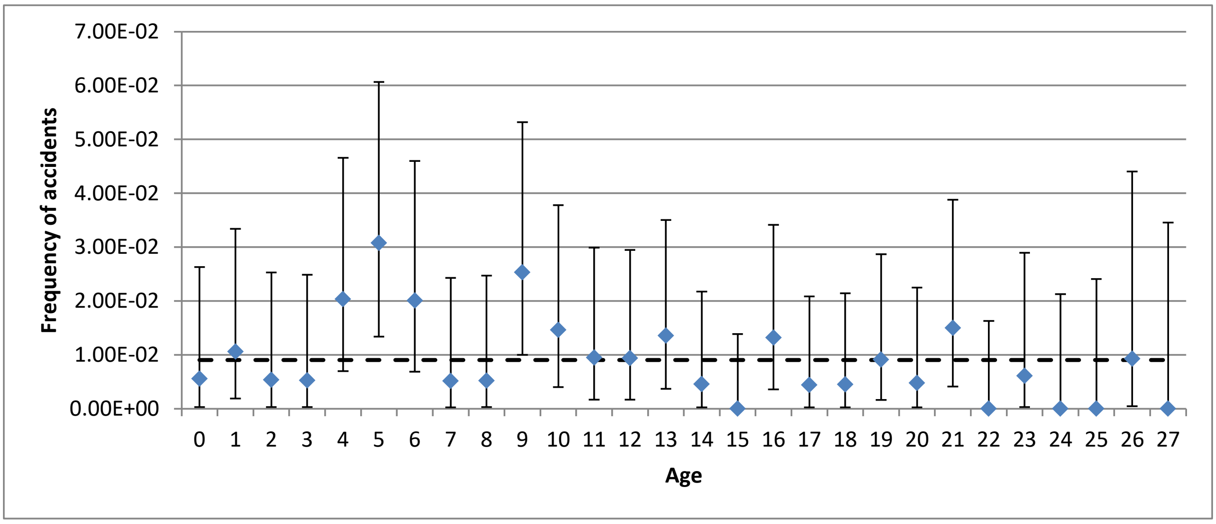

Figure 2.4-9: Accident frequency per age at date of incident and 90 % confidence interval and average for the whole fleet at risk over the period 2002-2015.

[23] FSA study on General Cargo Ships (IMO, 2010)

2.4.7. Impact of ship size and length of ro-ro lanes

The impact of the ship size on the accident frequency on the FIRESAFE fleet between 2002 and 2015 has been investigated. There seems to be an increasing trend for larger ships, as indicated in Figure 2.4-10. However, it must be noted that the number of shipyears for the size category (GT>60328) is very low (about 30 shipyears over the full period) to provide an accurate estimation of the accident frequency for that period, as clearly shown by the large confidence interval.

In the following investigation, the full data set of accidents occurring on FIRESAFE compliant ships has been considered (50 accidents).

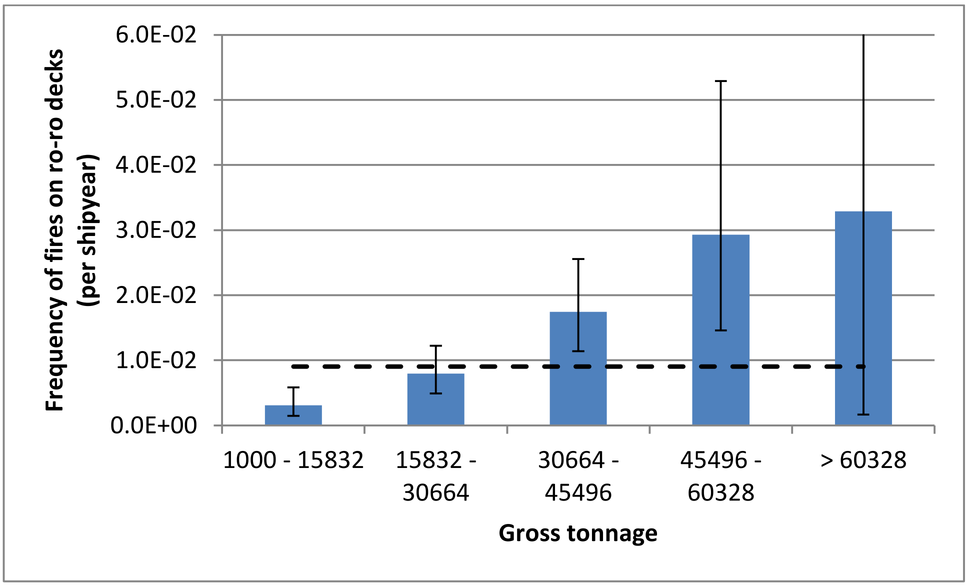

Figure 2.4-10: Frequency of fires on ro-ro decks per size (GT) with 90 % confidence interval between 2002 and 2015 and average for all categories.

The confidence interval for the GT>60328 size segment has been cut short to maintain the readability of the figure, the upper bound being at 1.56E-01 fires on ro-ro decks per shipyear.

As mentioned during the analysis of the impact of ship age on the accident frequency, and based on the review of the accident reports, sources of most of the fires on ro-ro decks were external to the ship itself, *i.e.* mainly due to cargo.

Therefore, the effect of the length of ro-ro lanes on the accident frequency has been looked into.

The number of lane meters (or length of ro-ro lanes) is available in IHS World Fleet database. However, this information was provided only for 368 ships out of the 490 ships of the FIRESAFE fleet. The frequency of fires on ro-ro decks for the fleet for which this information was available is reported in Figure 2.4-11 for different size categories.

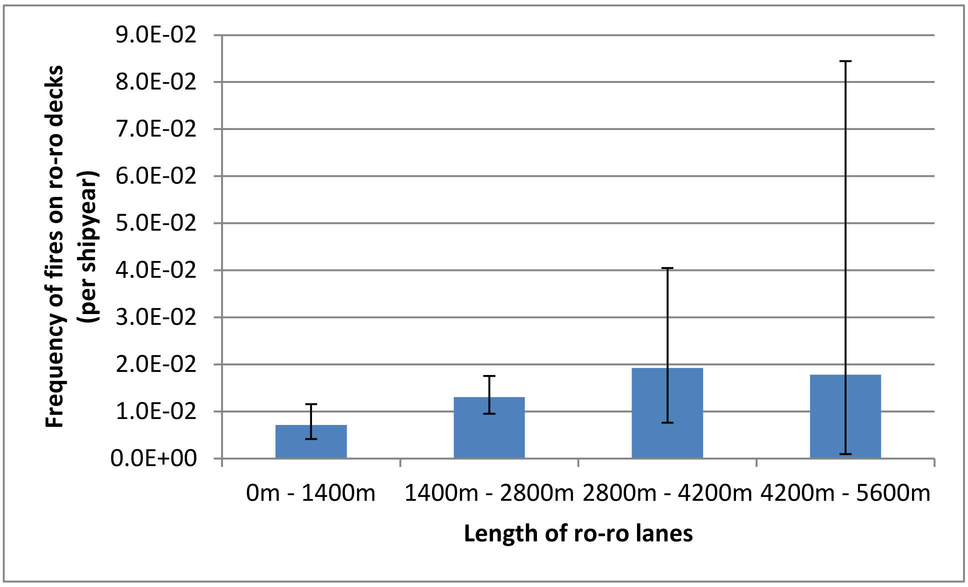

Figure 2.4-11: Frequency of fires on ro-ro decks per length of ro-ro length category between 2002 and 2015 with 90% confidence interval (note that the fleet considered is not the entire FIRESAFE fleet at risk due to lack of data on lane meters).

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As for the gross tonnage, there seems to be an increasing trend for ships with high number of lane meters. However, due to the large confidence intervals, which indicate that this trend could be explained only by stochastic variations, no conclusion will be drawn from that figure.

2.5. Fire hazards/risks

2.5.1. Fire HazId workshop

Prior to the FIRESAFE project a Fire Hazard Identification (Fire HazId) workshop with focus on ro-ro spaces was held at SP Fire Research in Borås. This workshop was a part of an internal fire safety project in the STENA Rederi AB. The focus on that HazId were to investigate all possible risks and hazards regarding fire safety on roro spaces. This HazId was than complemented by comments and views from the project team including BV and EMSA experts.
The results from this HazId have not been made publicly available before and in this report an extract will be used. A Fire HazId is a systematic brainstorming session where ship systems, procedures and designs are thoroughly investigated to identify potential fire hazards, such as fire causes, mitigation measures and affecting conditions. For the workshop, three ro-ro and ro-ro passenger ships, representing different designs, had been selected for further investigation to be used as starting point in the Fire HazId.

Participants at the HazId workshop were four research scientists with expertise in risk management, fire safety engineering, HazId, vehicle fire investigation, maritime regulations, ship fire safety and ship surveying, and nine senior officers and fleet managers (masters, chief engineers and naval architect) selected for their competence and interest in fire safety issues.

Method
A Fire HazId (Fire Hazard Identification) workshop is a systematic brainstorming session where various experts are gathered to identify potential fire hazards from investigations of ship conditions, systems, procedures etc. The focus of this Fire HazId was "ro-ro space fire". For this purpose, three ships with different types of ro-ro spaces had been selected to be used as starting point for discussions and investigations.

A spreadsheet was developed to guide the Fire HazId workshop procedure and for documentation of results. It was based on a model used in risk management referred to as the bow tie model, as further described below. Based on this model, the Fire HazId was divided in two sections: fire prevention and fire recovery. In each section were identified potential hazards which could initiate fire or prevent control as well as potential safety measures to control the hazards. The procedures for the Fire HazId are further described below.

Basic concept of the Fire HazId – the Bow Tie model
The concept used for the current Fire HazId was developed based on a well-known model in risk management called the Bow Tie model. It is a barrier risk model developed to assist the identification and management of hazards. The Bow Tie model is illustrated in Figure 2.5-1.

Figure 2.5-1. Illustration of the Bow Tie model, a barrier risk model for identification and management of hazards.

The Bow Tie model consists of different elements that build up the risk picture. The risk picture revolves around a hazardous top event. The top event is something with potential to cause harm unless it is controlled, in this case a ro-ro space fire. Focus is turned to one side at a time beginning with the threats on the left-hand side. These are potential causes for the top event which are explored through different escalation factors and control measures. Thereafter potential outcomes are investigated together with escalation factors and different recovery measures. The different control measures are barriers populated on either side of the model that are described by Table 2.5-1:

Left hand side of the model shows	***Right hand side of the model shows***
Preventative measures which eliminate the threat entirely or prevent the threat from causing the top event	Measures which reduce the likelihood of the consequences owing to the top event or mitigate the severity of the consequences

Table 2.5-1. Description of what is shown in the Bow Tie model

The escalation factors can be failures, conditions affecting the top event or reasons to why a control is less effective. In the current Fire HazId these were simply referred to as challenges. These were used to identify potential control measures, here referred to as safety measures. The practical procedure for investigating both sides of the Bow Tie model, fire prevention and fire recovery, is described below.

Fire prevention - addressing origins

For the fire prevention part of the Fire HazId, a number of fire origins were identified. These were investigated individually and categorized accordingly (with exemplifying images):

- Reefer unit;

- Conventional vehicle (truck, bus, car);

- Special vehicle (tractor, wheel loader, sky lift, process machinery, forest vehicle/rebuild truck, forklift, military vehicle, recreational vehicle, etc.);

- New energy carriers (vehicles with CNG, methanol, hydrogen fuel-cell, battery, LNG/CNG, etc.);

- Dangerous goods;

- Palletized goods (paper rolls, paper pulp, fibre boards, cardboard boxes, etc.);

- Ship equipment and activity (connection boxes for reefers, transformers for reefers, lighting, hoist able decks/hydraulics, welding/hot works, hoisting operations close to ro-ro space other equipment and activity); and

- Unsolicited activity (campers, stowaways, arson, etc.).

Each of these categories of fire origins were first considered with regards to fire causes (1 in Figure 2.5-2). Fire is generally caused by electrical fault, mechanical overheating, leakage of easily flammable substance or chemical reaction, which were used as leading factors in identifying fire causes. As illustrated in Figure 2.5-2, each fire cause was then connected to potential challenges or failures which could be the reason for the fire cause (2). Thereafter potential safety measures were identified for each challenge, as illustrated in Figure 2.5-2. Then potential failures/challenges and safety measures were identified for the next fire cause. A field was also provided for comments regarding each fire cause.

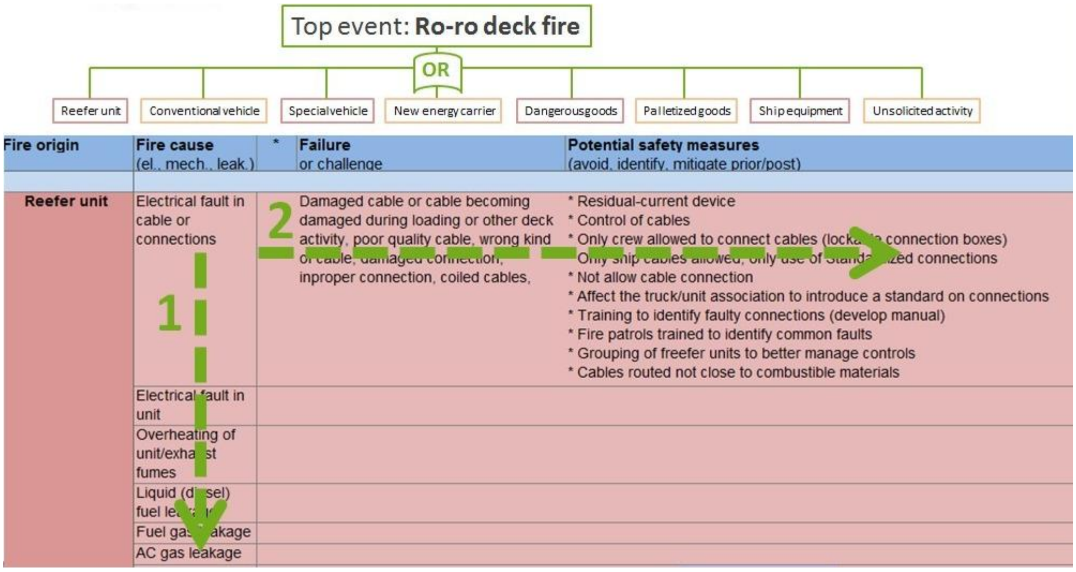

Figure 2.5-2. Illustration of how the fire prevention part of the Fire HazId was carried out.

When fire causes, failures and safety measures had been identified for all fire origins, the Fire HazId moved on to consider fire recovery, i.e. how to manage the top event if it occurs.

Fire recovery - addressing barriers

For the fire recovery part of the Fire HazId, a ro-ro space fire was first investigated with regards to factors affecting an uncontrolled fire development. Thereafter barriers for recovering from a ro-ro space fire were identified as:

- Detection/Alarm;
- First response;
- Suppression;
- Ventilation;
- Fire integrity;
- Manual extinguishment; and
- Evacuation.

Each of these barriers was investigated after agreeing on purpose and desired functions. First the group brainstormed on affecting conditions (1) before forming distinguished challenges to reaching the desired functions (2). These steps are illustrated in Figure 2.5-3. Thereafter was for each challenge discussed potential safety measures (3).

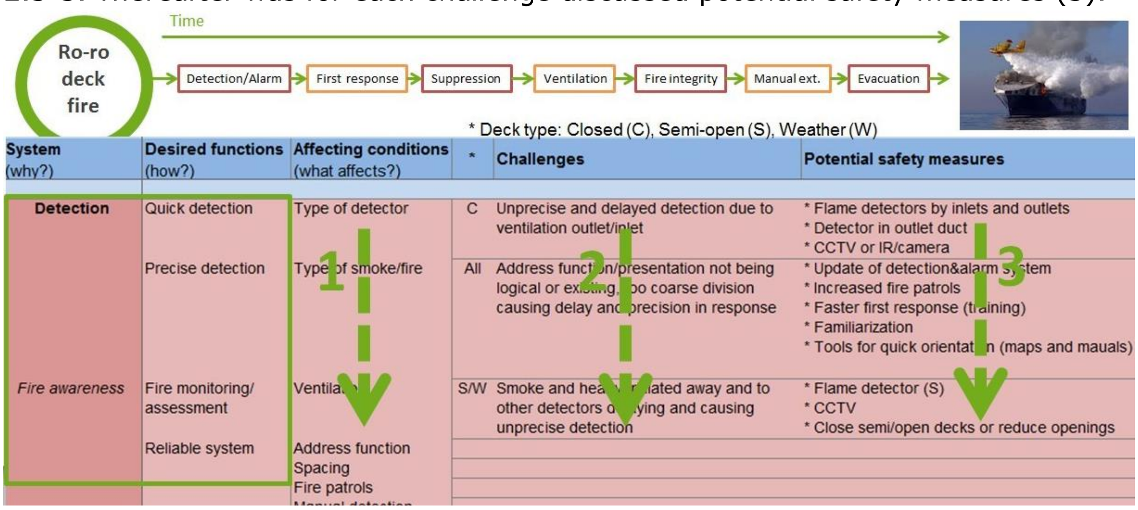

Figure 2.5-3. Illustration of how the fire recovery part of the Fire HazId was carried out.

Each challenge was also provided a comment section where requested investigations and other relevant information could be provided, e.g. on typical cargo, conditions and procedures.

Results

The STENA HazId covered many aspects that are outside the scope of this study and consequently it is mostly the parts dealing with risk of fire starting in electrical equipment and risks of failure of fire suppression that has been used. However, also the other parts have provided good background information and knowledge to this study. The results were summarized in both identified hazards and proposed risk control measures (RCMs). Identified hazards and proposed RCMs from other projects were then added to the lists and the members of the project team were also given the opportunity to make additions.

A fire safety workshop was then organized within the project. In addition to the project team members also technical experts from Bureau Veritas and EMSA participated in the workshop. The objectives were to select RCMs for quantitative evaluation. The selection process was finalized at an additional project meeting.

Meetings	
1-2/12/2015 HAZID workshop	Participants at the HazId workshop were four research scientists with expertise in risk management, fire safety engineering, HazId, vehicle fire investigation, maritime regulations, ship fire safety and ship surveying, and nine senior officers and fleet managers (masters, chief engineers and naval architect) selected for their competence and interest in fire safety issues.
14-15/06/2016 Consortium Meeting	Kick-off Meeting SP, BV, STENA, EMSA Day one: Scope – data – Method of work Day two: Main Risk Model and Sub-Models Method
Several Web conferences and internal meetings	SP, BV, STENA, EMSA: Fleet analysis Casualty analysis BV: Review of HAZID and RCOs
13-14/09/2016 Consortium Meeting	SP, BV, STENA, EMSA Selection of RCOs for further analysis Agreement on the structure of risk models Population of Reference Risk models
11-12/10/16 Consortium Meeting	Risk reduction in qualitative Terms Finalisation of Risk models Cost models for damage and RCO costs
Several Web conferences and internal meetings	SP, BV, STENA: Each partner independent risk reduction evaluation Agreements for final risk reduction values Reporting

2.6. Risk acceptance criteria

2.6.1. Review of risk acceptance criteria

A deep review of the risk acceptance and cost-benefit criteria and their comparison with those of various transport modes and industries has been carried out as part of the recent EMSA 3 FSA project[24] (EMSA, 2015). Given the recentness of that study, such investigation will not be repeated in FIRESAFE.

Two indices used to calculate the cost-effectiveness of risk control options are introduced in the FSA Guidelines (IMO, 2015) and have been widely used in most of the FSA studies submitted to IMO to date. These indices are the Gross Cost of Averting a Fatality (Gross CAF or GCAF) and the Net Cost of Averting a Fatality (Net CAF or NCAF).

Definitions and formulae to calculate these indices have been extracted from the FSA Guidelines (IMO, 2015) and reported below:

- GCAF (Gross Cost of Averting a Fatality): A cost-effectiveness measure in terms of ratio of marginal (additional) cost of the risk control option to the reduction in risk to personnel in terms of the fatalities averted.

$$GCAF = \frac{\Delta \mathrm{Cost}}{\Delta \mathrm{Risk}}$$

- NCAF (Net Cost of Averting a Fatality): A cost-effectiveness measure in terms of ratio of marginal (additional) cost, accounting for the economic benefits of the risk control option to the reduction in risk to personnel in terms of the fatalities averted.

$$NCAF = \frac{\Delta Cost - \Delta EconomicBenefit}{\Delta \mathrm{Risk}}$$

In the definition of the NCAF, it can be seen that this index allows considering the economic benefits of the introduction of a RCO such as the reduced costs for loss of property (e.g. cargo, cars, ship).

2.6.2. Value for Preventing Fatality calculation

As specified in the paragraph 1.3.2 of the Appendix 7 of the FSA Guidelines (IMO, 2015), the specific values for NCAF and GCAF criteria "*used in an FSA study […] should be updated every year according to the average risk free rate of return (approximately 5%) or by use of the formula based on LQI*".

If updated according to the average risk free rate of return of 5%, and taking a VPF of $3m in 1998 as a basis, as provided in the FSA Guidelines, the VPF in 2015 is estimated to $7.22m.

An update based on the Life Quality Index (LQI)[25] has been performed during the GOALDS study (IMO, 2012) and the VPF has been estimated to $7.45m. It should be noted that this value has been used in the formal safety assessment for ro-ro and ro-pax ships regarding the transport of electrically powered vehicles and vehicles with

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[24] Interested readers are invited to consult that report, and in particular Annex C: Review and update of VPF, which provides more insight on the use of Risk Acceptance and Cost-Benefit criteria in the maritime industry.

[25] Formula based on the Gross Domestic Product (GDP) per capita, life expectancy at birth and portion of life spent in economic production, for OECD countries.

refrigeration units carried out in 2016 (IMO, 2016). Therefore, given the very similar focus and the recentness of that study, the $7.45m criterion will be used in this study.

2.6.3. NCAF and GCAF

As discussed in the section risk model, the review of the SOLAS fire safety objectives, in particular those included in Regulations II-2/2.1.1.2 and II-2/2.1.1.3 reveals that the SOLAS Chapter II-2 objectives are not limited to *the risk to life* but also consider *the risk of damage caused by fire to the ship, its cargo and the environment*.

Therefore, in addition to the calculation of GCAF, consideration has been given to the use of the NCAF criterion. This is in accordance with the approach recommended in paragraph 1.3.3 of the Appendix 7 of the FSA Guidelines (IMO, 2015) which stipulates that:

"*In principle, either of the two criteria can be used. However, it is recommended to firstly consider GCAF instead of NCAF. The reason is that NCAF also considers economic benefits from the RCOs under consideration. This may be misused in some cases for pushing certain RCOs, by considering more economic benefits on preferred RCOs than on other RCOs.*

If the cost-effectiveness of an RCO is in the range of criterion, then NCAF may be also considered."

2.6.4. Assumptions

The expected lifetime (*T*) of a RoPax has been set to 33 years[26] (which correspond to the life expectancy at delivery calculated in the section Analysis of the FIRESAFE fleet). As identified in GOALDS (IMO, 2012), "*most owners will use a shorter investment period for a new ship; however, the costs are to be seen from the society's point of view. Therefore, the investment time will be equal to the ship's expected lifetime*." This value has been used to calculate the reduced risk in terms of fatalities averted:

$(\Delta Risk = \Delta PLL * T)$

The average age of the fleet has been estimated to 17 years old, this has been considered in the calculation of the cost effectiveness for existing ships.

The Delta cost and benefits are calculated in Net Present Value (NPV) with a depreciation rate of 5%.

[26] It should be noted that this value differs from the one that has been taken in SAFEDOR, GOALDS, and EMSA 3, which have all set a lifetime of the ships to 30 years.

2.7. Development of fire scenarios

2.7.1. Fire growth rate

In fire safety engineering the fire growth is often simplified and described as a so called "T-squared" fire. This means that the heat release rate increases proportionally to the square of time. By using different proportionality constants, ɑ, various fire growth velocities are described. The heat release rate is expressed as:

$$\dot{Q} = \alpha t^2$$

Where $\dot{Q}$ is the heat release rate, ɑ is the fire growth rate (kW/s^2) and t is the time from ignition in seconds.

The fire growth in car fires has been studied in a number of research projects. Some of these studies were consolidated by Yuguang Li [Li Y,2004] and it was shown that the fire growth in parked cars varies between 0.003 kW/s^2 (denominated "slow" fire growth) and 0.012 kW/s^2 ("medium" fire growth). A number of relevant fire scenarios to support this are presented in Figure 2.7-1.

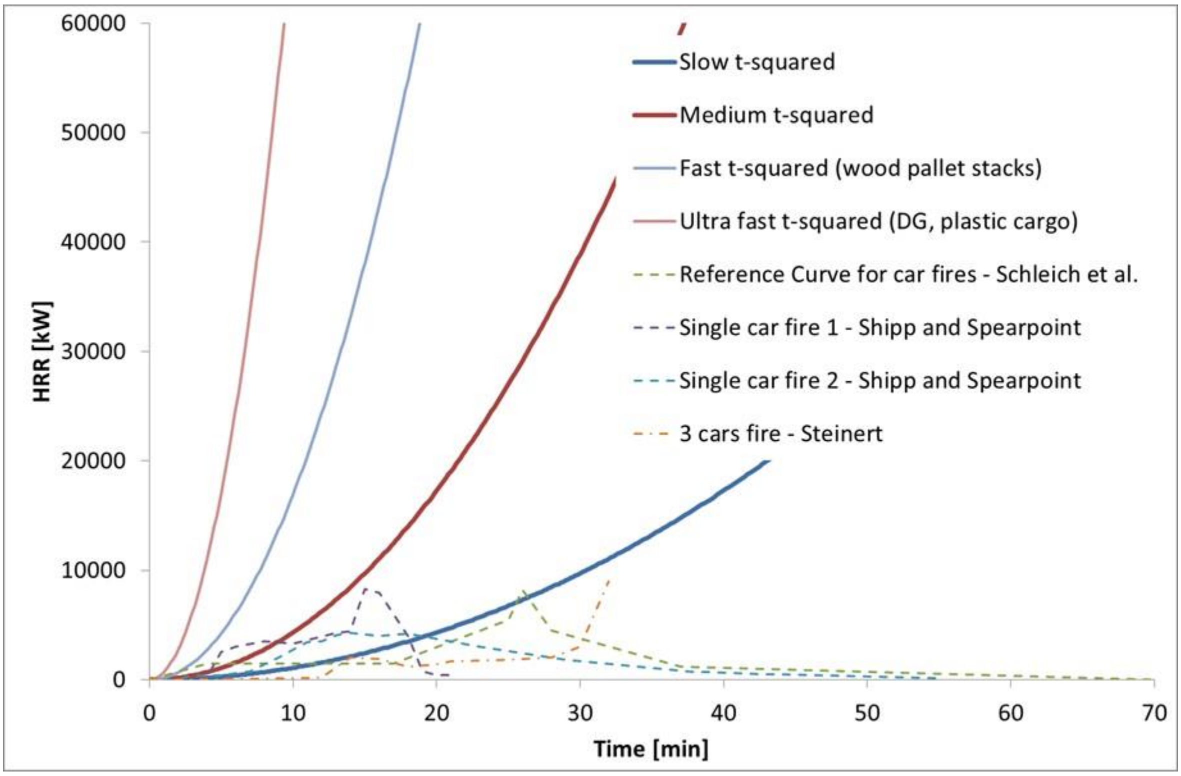

Figure 2.7-1 – Slow, medium, fast and ultrafast t-squared fires compared to a number of actual car fire tests and a reference car fire curve

Based on these experiences from car fires a medium fire growth is considered to be the expected fire growth rate for ro-ro deck fires, in most car fire scenarios this can be considered conservative. However, it should be noted that on a ro-ro space there is potential for fires with a more rapid fire growth e.g. in case of a large fuel spill, dangerous goods or other kinds of combustible cargo.

2.7.2. Ventilation influence on fire development

Open ro-ro spaces are those ro-ro spaces which are either open at both ends or have an opening at one end, and are provided with adequate natural ventilation effective over their 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.

Closed ro-ro decks are defined as ro-ro spaces which are neither open ro-ro spaces nor weather decks. Depending on regulations and cargo conditions the mechanical ventilation on a closed ro-ro deck at sea is either 6 air changes per hour or 10 air changes per hour. For passenger ships 6 air changes per hour is applicable for ships carrying not more than 36 passengers and 10 air changes per hour is applicable for ships carrying more than 36 passengers. The natural ventilation openings are normally kept to a minimum, doors are closed and the compartment is surrounded by A-class divisions.

Under normal operations at sea all doors to the ro-ro spaces are closed and the spaces are ventilated at a rate of at least 6 to 10 air changes per hour. Hence, it can be assumed that a fast growing fire within a closed ro-ro space will be ventilation controlled at a certain point and when the ventilation is closed, according to the firefighting routines, the fire will be reduced in intensity and eventually self-extinguish due to oxygen depletion.

A series of Branzfire simulations were performed to demonstrate how the ventilation conditions affects the potential fire development with regards to heat release rate and upper gas layer temperatures.

In the simulations, an open ro-ro space of the dimensions 140 m x 25 m x 5.8 m (L x W x H) is used. These are the rough dimensions of the open ro-ro space on deck 4 of the reference ship. The obstructed volume of the ro-ro space will have an effect on the amount of oxygen available in the space. The rate of obstructed volume does of course vary with the loading density and varying types of cargo. In these simulations 30% of the volume is assumed to be obstructed, this is realized by reducing the length of the ro-ro space with 30% to 98 meters in the Branzfire model.

For the open ro-ro space the permanent openings are modelled with 10% permanent side openings and large permanent openings in the aft. In the simulations, this is modelled with two 30 m x 3 m (L x H) openings with a sill height (height of the lower edge of the opening) of 1.4 meters, representing side openings and one 19 m x 5.6 m (L x H) opening representing aft openings with no sill.

For the closed ro-ro deck simulations, a space of the dimensions 122 m x 25 m x 5.8 m (L x W x H) is used. These are the rough dimensions that represents the deck area of the closed ro-ro space on deck 3 of the reference ship. Also in these simulations 30% of the volume is assumed to be obstructed, this is realized by reducing the length of the ro-ro space with 30% to 85 meters in the Branzfire model. For the closed ro-ro space case three different setups with mechanical ventilation were analysed:

1. 10 air changes per hour (acph) running continuously.
2. 10 acph where the ventilation is closed after 30 minutes.

3. No ventilation, simulating conditions where the ventilation was already closed or was quickly closed after ignition.

All simulations were performed assuming a medium fire growth rate and the fire was always allowed to grow until ventilation control was reached. The resulting heat release rate data is presented in Figure 2.7-2 .

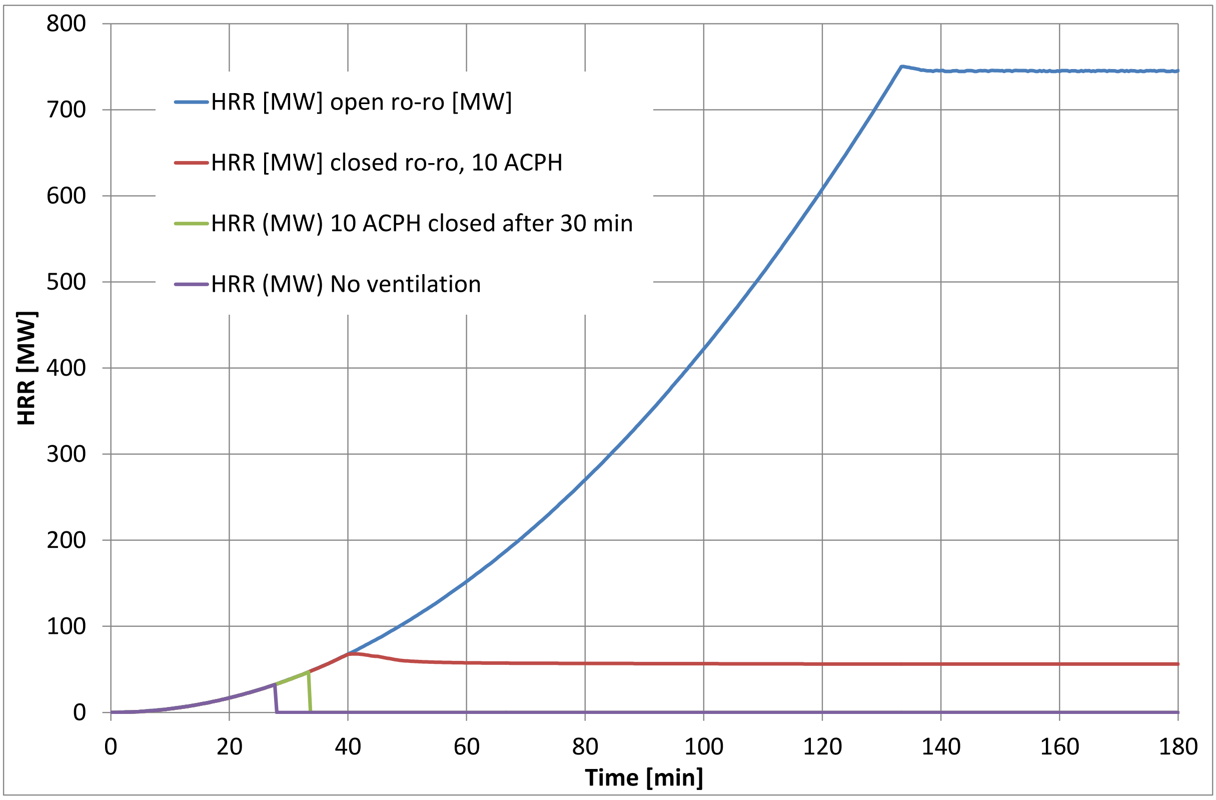

Figure 2.7-2 - Heat release rates as a function of time for varying levels of ventilation

It is not obvious that a ro-ro deck fire will continue to grow until ventilation control is reached. However, Figure 2.7-32 clearly shows that the natural ventilation available on the open ro-ro deck will not be a limiting factor for the fire development before it reaches catastrophic dimensions that seriously threatens the entire ship is reached. A more detailed plot of the first 60 minutes of the same results is shown in Figure 2.7-3.

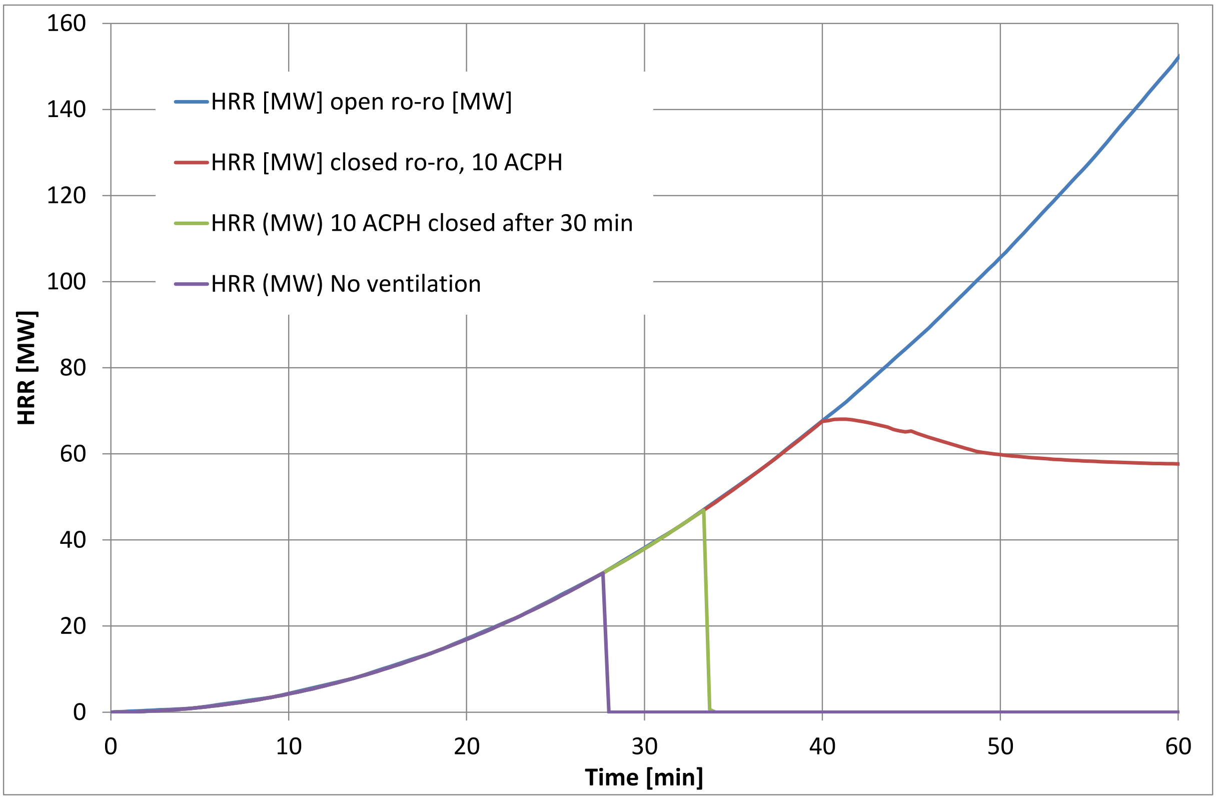

Figure 2.7-3 - Heat release rates as a function of time during the initial 60 minutes for varying levels of ventilation

It can be seen that if the mechanical ventilation, for any reason, is not turned off there will be a continuing ventilation controlled fire at about 60 MW. Further, if the ventilation fans and dampers are closed after 30 minutes the fire will reach about 45 MW before it self-extinguishes due to oxygen starvation just a few minutes after the ventilation is closed. If the ventilation is closed immediately after ignition the fire grows to about 30 – 35 MW before it self-extinguishes.

Not only the total area, but also the geometry, of the permanent openings affects the fire development. The ventilation grade is driven by buoyancy of gases heated by the fire. Hence, a higher sill reduces the peak HRR; a higher but narrower opening increases the peak HRR. The sensitivity to these parameters within normal design geometries is, however, small.

2.7.3. Fire load

If a fire at ventilation control is not extinguished by manual means or by fixed firefighting systems, the fire will continue until the available fuel is consumed. If we consider the same ro-ro decks as above, there are sufficient lanes for about 200 cars. Each car (incl. fuel) has a fire load of about 5-8 GJ/car [Li Y,2004] hence, a total fire load of about 1 300 GJ can be expected if the deck is fully loaded with cars. Based on this, the duration of an uncontrolled car fire can be calculated for the different ventilation scenarios, see Figure 2.7-34.

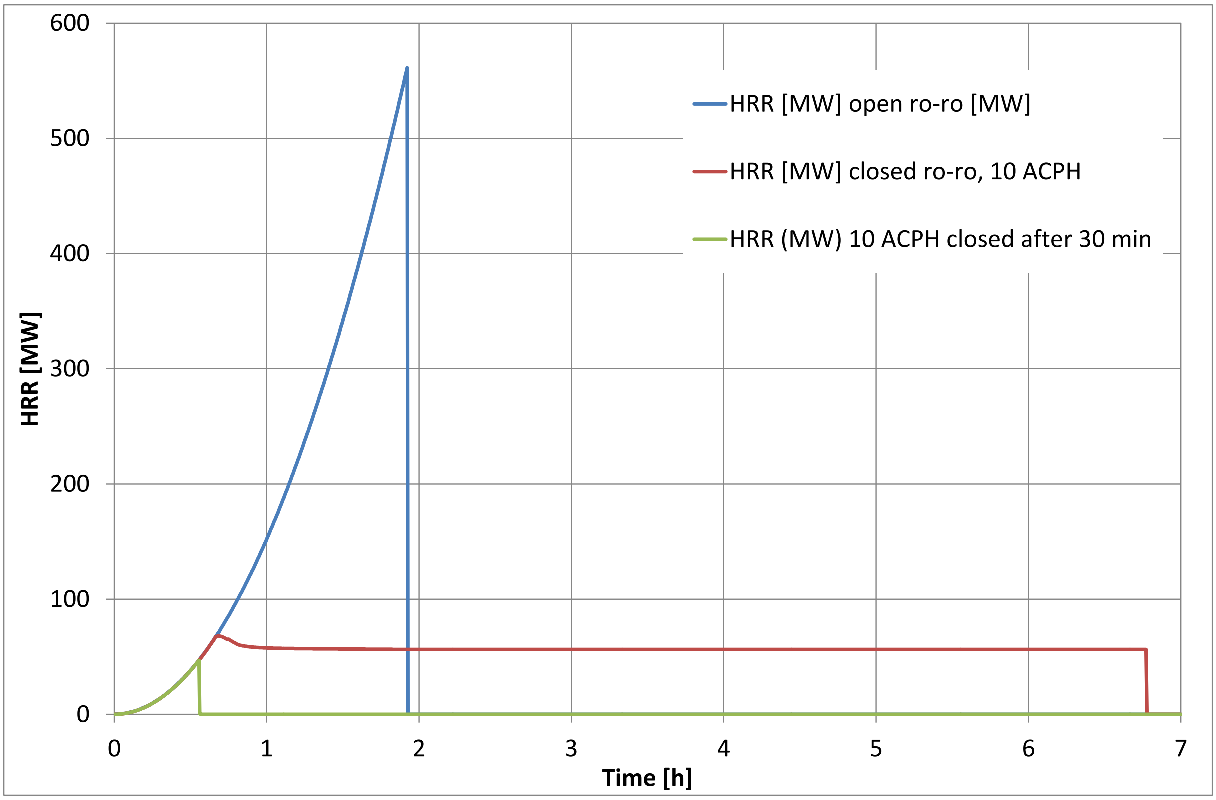

Figure 2.7-4 - Duration of uncontrolled car fire at different ventilation rates (assuming all fires grow until ventilation control).

It can be seen that the scenario where the ventilation is completely closed after 30 minutes the fire self-extinguishes after about quickly thereafter and reaches a maximum heat release rate of about 45 MW. The other two scenarios where the fire is not extinguished with active firefighting means and the ventilation is not closed results in long lasting fires (2 - 7 hours) with a high-energy release rate. Such fires are not likely contained in the space of origin and it is likely that abandonment of the ship is required at such conditions.

2.8. Main risk model

The purpose of this section is to explain the risk model and its quantification.

2.8.1. Definitions

As some of the terms used in the risk model might have a different meaning from previous publications on fires on ro-ro decks, definitions of these terms in the context of this study are provided below.

Although containment was referring to the duration of the fire (*i.e.* fire not exceeding 60 minutes) according to the EMSA Group of Experts (GoE) on fires on ro-ro decks, in this study, containment refers to containing a fire in the space of origin (*i.e. the ro-ro deck*), as specified in SOLAS II-2 Regulation 9. In that sense, a contained fire might have propagated "cold" smoke, but no flame or heat in the adjacent spaces.

Fire suppression is the sharp reduction of the heat release rate of a fire and the prevention of regrowth, as defined in MSC.1/Circ.1430 (IMO, 2012a), and extinction means putting the fire completely out.

2.8.2. Background

In order to consider the two parts investigated in the study (*i.e.* Electrical Fires as ignition risk and Fire Extinguishing Failure) [27], three risk models have been developed and are as follows:

- Fire risk model, later referred to as *Main model*;
- (Sub-) risk model on *Electrical fire as ignition risk*, later referred to as *Fire ignition tree*; and
- (Sub-) risk model for *Fire extinguishing failure*[28].

The Main model makes, *inter alia*, the link between the initial event (*i.e.* the fire ignition) and the fire extinguishing failure. It has been developed in such a way that it can be used in future investigations into specific nodes not within the scope of the FIRESAFE study.

The fire ignition tree has been developed to provide the contribution of each fire origin to the total fire frequency (with a distinction between electrical and non-electrical origin) and is connected to Tier 0 of the Main risk model. This tree is further detailed in the section Risk model for electrical fire as ignition source.

A *fire extinguishing failure* tree has been developed to quantify the contribution of each possible failure and to calculate the total fire extinguishing failure. It is connected to Tier 2 of the Main risk model. Four different trees have been developed for fire extinguishing failure to consider the deck configuration and decision time (both further discussed below). While the structure of the tree remains the same in all cases, the dependent probabilities are adapted. These trees are further detailed in the section Risk model for fire suppression failure.

The Main risk model and associated sub-risk models have been developed in such a way that it is possible to assess, in quantitative values, the consequences of additional preventing and mitigating measures to reduce the risks of electric fires and fire extinguishing failures.

This methodology is in accordance with what is usually performed in FSA studies, as reported in the document III 3/4/5 (IMO, 2016a).

"As explained in MSC-MEPC.2/Circ.12/Rev.1, and shown, for example, in MSC 87/INF.4, the purpose of risk analysis in step 2 of the FSA process is to undertake a detailed investigation of the frequencies and consequences of identified accident scenarios. This is normally achieved by using suitable risk models built by means of standard techniques such as fault trees and event trees. The generic methodology applied during risk analysis consists of linking fault trees with the event trees to represent full accident scenarios."

2.8.3. Explanations of the nodes

Although dynamic fire risk models have been used in some studies, the Main risk model that has been developed in FIRESAFE is static (*i.e.* no time dependency). This allows keeping the study as transparent and upgradeable as possible. It reflects what has been done in most of the FSAs submitted to IMO to date which had a focus on fires, such as FSA on container fire on deck (IMO, 2009), or including a section dealing with fires such as the FSA on RoPax ships (IMO, 2008). This also permits focusing more specifically on the two topics of interest. This structure does not impede the inclusion of time

[27] In this section, fires refer to fires on ro-ro decks, unless explicitly stated otherwise.

[28] It should be noted that while fire extinguishing failure has been used as a title for the second part, fire *suppression* failure is also of interest.

dependency, for specific investigation such as detection, in the future, when the model has been fully developed and validated.
Based on the information that has been provided by EMSA stemming from the work of the GoE regarding the structure of the risk model, as well as the hazard identification (see Section Fire hazards/risks) and the fire scenarios identified (see Section Development of fire scenarios) in the previous step, a suitable risk model has been developed. Figure 2.8-1 provides the chain of event as provided by EMSA, which is composed of 4 tiers and is applicable to any spaces.

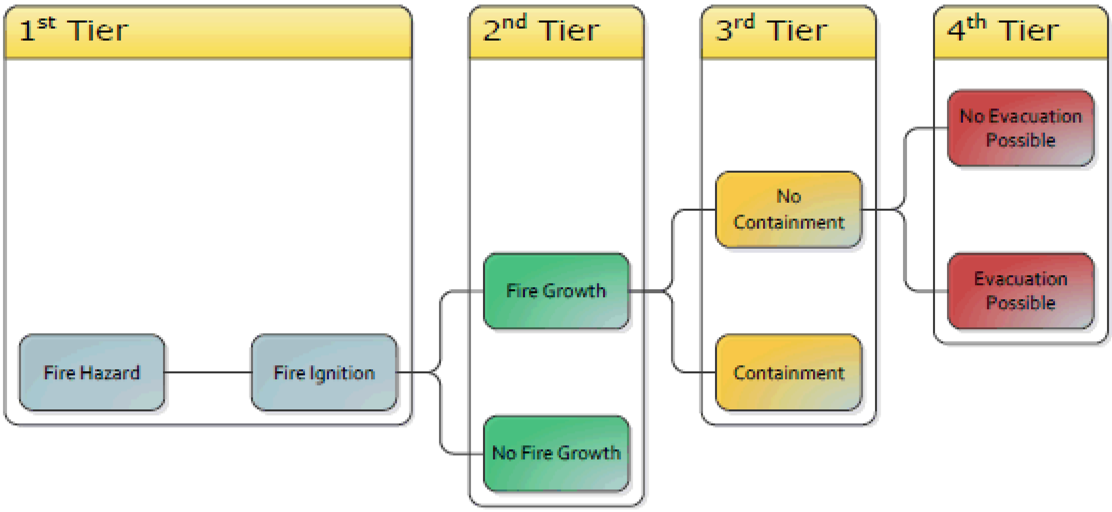

Figure 2.8-1: Fire risk model (extracted from document: 1st Correspondence of the Group of Experts on fire on ro-ro decks, EMSA, 2015).

This chain of event allows the identification of pivotal events which affect the outcome of different fire on ro-ro deck scenarios.
As both creative (see section 2.5.1) and analytical (see section 2.4) methods have been used for the identification of the hazards, as recommended by the FSA Guidelines (IMO, 2015), it has been ensured that the scenarios considered within this tree are not confined to accidents that have materialized in the past.
It should be noted that the fire risk model, as provided by EMSA, does not explicitly mention fire extinguishing. This is included within the 2nd tier along with fire detection.
Therefore, for the purpose of the study, the chain of event has been modified as shown in Figure 2.8-2. The fire growth tier has been expanded into Decision (which include the detection and decision time) and Extinguishing. Both tiers are further explained in the following.

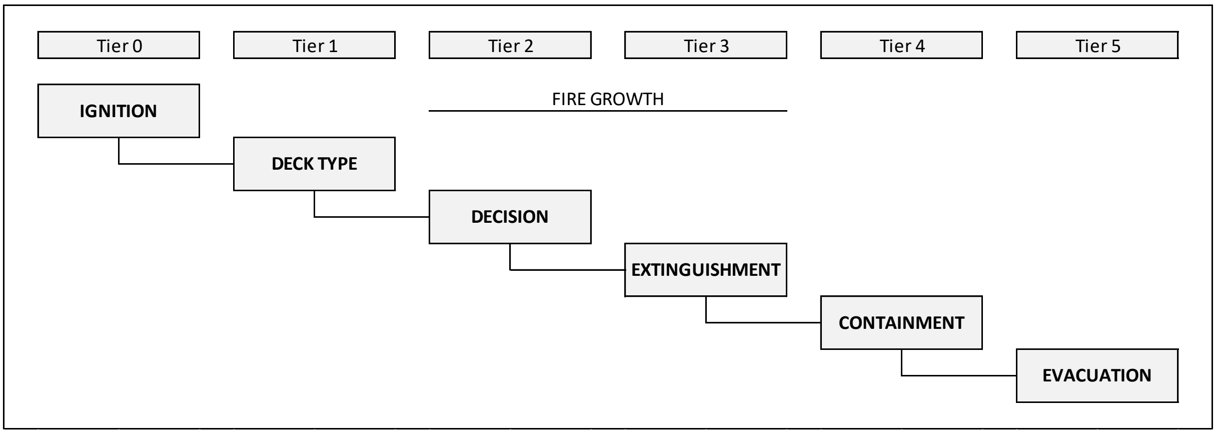

Figure 2.8-2: Fire risk model as modified for the FIRESAFE study.

It can be noted that compared to the fire risk model provided by EMSA, a tier has been added to consider the deck configuration on which the fire started. This tier is further explained in the following.

Tier 0 – Fire ignition
The initial event of the Main risk model is the ignition of the fire on a ro-ro deck. While *Electrical fire as ignition risk* is one of the focus of the study, the risk control options investigated in the *Fire extinguishing failure* part are expected to have an impact also on non-electrical fires. Thus, all fires have been taken into account (*i.e.* electrical and non-electrical fires) and the initial accident frequency is the addition of the frequency electrical fires and the frequency of non-electrical fires ($f = f_{elec} + f_{non\ elec}$).

Tier 1 – Closed, Open, and Weather Decks
The main objective of the *Fire extinguishing failure* part is to identify and assess RCOs considering both *open* and *enclosed* ro-ro spaces. A first tier has been included into the risk model, providing the probability for a fire to occur on a specific deck configuration. The three deck configurations being considered are: Closed deck, Open deck, and Weather deck[29].
Open and closed ro-ro decks have been investigated separately as these types have different accident scenarios. Therefore, they might require different risk mitigation measures. Furthermore, a specific RCO might be more effective on one deck configuration than on the other one.
In particular, the open ro-ro deck configuration is more susceptible to fire spread because of, *inter alia*, unlimited ventilation (see Section Development of fire scenarios). As it could have been observed in the review of historical data and in the recent accidents leading to the total loss of the ships, additional specific issues regarding open decks have been found amongst them, we can note the location of life-saving appliances, the escape ways, and the detection and extinguishing (that might be both impacted by the wind).
Lack of structural fire containment measures has also been highlighted for the weather deck, and to a lower extent for the open deck (smoke and flames able to spread through openings).
Most of these have been considered in the quantification of the following tiers.

[29] Definitions of the different deck configuration are those of SOLAS and are provided in the annex.

Tier 2 – Early/Late Decision

Early detection of the fire and quick activation of the fire extinguishing means is often cited as the key to successful extinguishment. Since the decision process and detection time are not being separately investigated into details in FIRESAFE, choice has been made to gather both detection and decision in the same node. Thus, the first tier focuses on early or late decision regarding fire-fighting actions.

Since the model is not time-dependent, "Early" and "Late" decision should be understood in relation to the fire growth rate. "Early" means that the system has been activated early enough to have a certain chance to extinguish the fire. "Late" means that the fire is already too developed, and that it is too late to have a chance to extinguish it. However, the fire can still be suppressed[30].

Regardless of the cause of the delay in the fire-fighting actions (detection, or decision process), the consequence in terms of the ability of the first response team, fire-fighting group or fixed fire extinguishing system to extinguish the fire remains the same.

With such definitions, the "fire growth" mechanisms such as slow and fast growth are considered in the early/late characteristic.

Tier 3 – Extinguishment

As mentioned in the Commodore Clipper investigation report (MAIB, 2011) and the BRE study (BRE, 2006), it has been acknowledged that a traditional water drenching system "may no longer be able to extinguish the fire as implied by the title of the resolution A.123(V)" ("*Recommendation on fixed fire extinguishing systems for special category spaces*").

With that in mind, fire suppression is considered as a success since "*effective suppression may buy time for fire extinguishing or permit an orderly evacuation in cases where it is acknowledged that fire extinguishment is unlikely*" as explained in the document MSC 97/19/3 (IMO, 2016b).

It should be noted that this node refers to *fire extinguishing failure* and not to the failure of fire extinguishing systems since "*there have been instances of failure to extinguish fires despite the proper operation of extinguishing systems*" (IMO, 2016b). The technical failure of the fixed fire extinguishing system (which includes the removal of water), the design incapacity of the system and the failure of manual extinguishment are all considered. These causes of *fire extinguishing failure* are further explained in the dedicated part and insight into unsuccessful deployment of drencher is investigated in the fault tree related to fire extinguishing failure.

In this context, *unsuccessful* means that there is neither fire suppression nor fire extinguishment.

For an early decision, the system might either suppress or extinguish the fire (*successful*) or have no impact as mentioned above (*unsuccessful*).

According to the definition of late decision, as explained above, there is no chance to extinguish the fire, but the fire extinguishing system is still likely to suppress it (thus mitigating the damages to life, ship and cargo). Therefore, the corresponding branches of the tree have been adapted accordingly and four different fault trees have been developed for Fire extinguishing and suppression failure to take into account the decision time and deck configuration.

[30] Interested readers can refer to (DNV GL, 2015 see reference list) for more insight on the average absolute time values for the detection, confirmation of fire, communication to master, decision taking, and release, in case of fire on ro-ro decks.

Tier 4 – Containment

In case the fire would not be extinguished or suppressed, the fire may spread beyond the ro-ro deck area where it started, with potentially disastrous consequences if spreading to critical areas. As mentioned above, containment would prevent from flames and heat to propagate for a duration of one hour[31] in laboratory standard conditions. Those laboratory conditions consist of a furnace fire test with temperature curve ISO 834 simulating a free-burning ventilated fire in a small compartment.

A failure of the containment (due to temperature loads higher than in standard, or for longer than in standard, or failures of containment, *e.g.* poor insulation status or bad door closing) would propagate hot gas and fire itself throughout the ship, or provide elevated temperatures to the neighbouring structure.

For open ro-ro decks, in the context of this work, the containment of the fire also means no external flaming at the openings because of the threat to other areas of the ship (open or not)

For open decks, in the context of this work, the risk control options that would prevent external flaming will act on the Tier 4.

With an early decision (*i.e.* the fire has a limited size) and when the fire is extinguished or suppressed, the containment was guaranteed by definition (lower temperature than in the test).

Nevertheless, with an early decision but unsuccessful extinguishment or suppression, the containment is not guaranteed.

With a late decision, because the fire has large size, the containment is not guaranteed and is depending on the suppression status.

Tier 5 – Evacuation

Depending on the outcome of the previous events, the evacuation is more or less likely to be successful.

If the fire is contained, there might not be the need for an evacuation and in case the fire is not contained, as discussed above, this may buy time for orderly evacuation, and even more time, depending on the suppression status.

It should be noted that, in addition to the abandonment at sea, disembarkation at port has also been considered. This is to reflect the "*difficulties of disembarking pedestrian passengers when the only means was via a single ramp to a vehicle, special category or ro-ro space*", as highlighted in the document FSI 21/5 (IMO, 2012b). Such issues have been observed during the Commodore Clipper (MAIB, 2011) accident. Although not complying with the FIRESAFE criteria, it can be noted that such issue has also been reported in the Kriti II accident investigation report (HMBCI, 2014).

Although location of openings are regulated in the SOLAS Convention (Regulation II-2/20.3.1.5: "*permanent openings in the side plating, the ends or deckhead of the space shall be so situated that a fire in the cargo space does not endanger stowage areas and embarkation stations for survival craft and accommodation spaces, service spaces and control stations in superstructures and deckhouses above the cargo space*"), damages to LSAs have been reported in different accident investigation reports.[32]

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[31] SOLAS Chap II-2/20.5, except for spaces of category (5), (9) and (10), and fuel tanks below the ro-ro deck

[32] Evacuation is out of the scope of the study. The generic vessel is built according to SOLAS Regulations. Therefore, this parameter (deck type) has not been taken into account in the risk model.

Consequences

The review of the SOLAS fire safety objectives, in particular those included in Regulations II-2/2.1.1.2 and II-2/2.1.1.3 reveals that the SOLAS Chapter II-2 objectives are not limited to the *risk to life* but also consider the *risk of damage caused by fire to the ship, its cargo and the environment*. Therefore, the risk model considers these different types of risk (*i.e.* risks to people, cargo and ship).

While acknowledging that the environmental risk is not zero (fire and smoke gases or oil spill after actual total loss have been identified, *inter alia*, in the FSA on Container fire on deck (IMO, 2009)), environmental damage (*i.e.* environmental pollution) has not been considered in the analysis. Exclusion of environmental damage is consistent with the approach followed in previous FSA studies on RoPax or FSA studies focusing on fires.

2.8.4. Quantification

Quantification of the frequency of fires on ro-ro decks and dependent probabilities of the Main risk model mainly originate from available accident reports and failure data and other sources of information.

As far as possible, results from previous projects have been considered. In accordance with FSA Guidelines, if statistics were insufficient to produce reliable results, or when deemed appropriate, physical models, tests and simulations results have been extracted from existing available studies and relied upon. In case none of the previous option was available, expert judgements have been used. For each node, the data sources selected is indicated.

To maintain consistency with the initial accident frequency estimated in the section Initial accident frequency, most of the statistical values have been computed from the list of 32 accidents introduced in the section Results of data collection. A comparison between the different datasets is provided in section Input data analysis for extinction/suppression failure.

The use of any other databases (such as EMCIP or FSI 21/5) might bring inconsistency as it is expected that non-serious incidents (mainly *Early Decision*/*Successful extinguishment*) are over represented in these databases compared the sample considered in FIRESAFE.

2.8.5. Assumptions

The generic vessel under consideration has a capacity of 880 persons on board (850 passengers and 30 crew members). The same average occupancy rate as EMSA 3 study has been considered. An average occupancy rate of 62.5% was taken (on the passenger capacity) while the number of crew was kept constant[33]. These statistics have been judged very sound and relevant for FIRESAFE (information from project partners, CLIA as well as GOALDS project as indicated in the EMSA 3 study)

Based on the information provided by STENA, a 70% of cargo load has been considered (which is the ratio used for considering that ship is fit for a given route).

Different approaches are followed in FSA studies for the management of "unknown" data as pointed by the document SDC 3/3/4 (IMO, 2015b). For some accidents, the information of interest (*e.g.* early or late decision) was not available. In this case, these

[33] Seasonal pattern had been used in the EMSA 3 study: 100% occupancy for passenger for 12.5% of the year; 75% occupancy for passenger for 25% of the year; and 50% occupancy for passenger for 62.5% of the year.

accidents have not been considered in the calculation of the dependent probabilities. It was assumed that these accidents, for which information of interest was missing, were distributed in the different categories following the distribution of "known" data. The approach which has been followed in this study is consistent with the one of EMSA 3.

Tier 0 – Fire ignition
The frequency of fires on ro-ro decks (*initial accident frequency*) has been estimated to 5.79E-03 accidents per shipyear $CI_{90\%}$ [4.21E-03; 7.77E-03], based on the statistics of the FIRESAFE compliant ships over the period 2002-2015. This estimation has been detailed in the section *Casualty Data analysis*.
More than 60% of the fires on ro-ro decks are electrical fires. More details on the origin and causes of the fires are provided in section Input data analysis for extinction/suppression failure.

Tier 1 – Closed, Open, and Weather Decks
No sufficient data were available for an accurate estimation of the probability of fire ignition per deck type. Therefore, the following reasoning has been followed. The probability of fire ignition on a given deck configuration is considered to be proportional to the size of the deck. This is correlated to the amount of cargo transported on that deck and to the number of equipment[34]. Due to lack of information it was also assumed that the risk of ignition is evenly distributed on the different decks. This may not be the case since on some ships larger numbers of reefers are loaded on the weather deck while on other ships only cars are loaded on the weather deck. The lane meters have been used as a metric to quantify the size of the deck (*i.e.* if normalized by the number of lane meters, no deck is at higher risk than the others). The proportion of each deck configuration (also the proportion of fire on each deck type) is based on the STENA fleet and is as follows:

- Closed deck: 60%
- Open deck: 35%
- Weather deck: 5%

Tier 2 – Early/Late Decision
All incidents with quick manual extinguishment (with description such as: "*Fire detected by smoke detector and extinguished using portable fire extinguisher*")[35], with successful manual and drencher extinguishment ("*deluge released after 10mins; confirmed out/under control within 90 minutes*"), or incidents where accident investigation report concludes that the decision was made early such as the LISCO GLORIA accident, were considered as *Early decision*.
All incidents where the extinguishment system and manual efforts (even though fully functional) were not able to extinguish the fire (everything from suppression to no obvious effect on the fire), or where accident investigation report concludes that the decision was made late was considered as *Late decision*.
Based on 28 accident reports, the probability of early decision was estimated to 67.9%. 4 accidents did not provide the information regarding early or late decision.

[34] See Electrical fire model quantification.
[35] All quotes in italics between parentheses are extracted from the Annex 6 of the document FSI 21/5 and are provided for illustration purpose.

Tier 3 – Extinguishment

Four fault trees have been developed to investigate more in detail the probability of fire extinguishing failure. These trees are as follows:

- Open Deck / Early Decision;
- Open Deck / Late Decision;
- Closed Deck / Early Decision; and
- Closed Deck / Late Decision.

Their quantifications are further detailed in the dedicated part.
However, it can be noted that the probability of fire extinguishing failure is the highest for the Open Deck / Late Decision and the smallest for Closed Deck / Early Decision. For a given deck configuration, the probability of fire extinguishing failure is higher for a late decision than for an early decision.

Tier 4 – Containment

As the *Containment* branches apply to accident with late decision or accidents with *Early decision* with a fire extinguishing and suppression failure, detailed accidents investigation reports of such accidents were available. Therefore, it has been possible to compute some statistics based on those to support the reasoning and the expert judgement for the quantification of the different values.

Closed deck

For the branch *Closed deck / Early Decision / Unsuccessful*, experts agreed on the fact that this branch has the same Tier 5 outcome (in terms of containment or no containment dependent probabilities) that the branch *Closed deck / Late Decision / Unsuccessful* for which more data were available.
Four accidents falling under the scenario *Closed deck / Late Decision / Unsuccessful* were found. The fire was contained in two out of the four accidents.
Therefore, dependent probabilities of 50% were assigned to the nodes *Contained / Not Contained* for the branches *Closed deck / Early Decision / Unsuccessful* and *Closed deck / Late Decision / Unsuccessful.*
On the 32 fires considered, 2 fires on a closed deck subject to a late decision and being successfully suppressed were contained (no fire not contained). Therefore, the assumption 90%/10% was used in favour of containment for the branch *Closed deck / Early Decision / Suppression.*

Open deck

Only one accident could be found for the branch *Open deck / Early Decision / Unsuccessful.* Therefore, the assumption 10%/90% was used in favour of *Not contained* in that branch.
Three accidents have followed the scenario *Open deck / Late Decision / Unsuccessful*, and none of them was contained. In order to differentiate between *Early* and *Late Decision,* the assumption 10%/90% has been changed to 5%/95%. This is to account for the fact that an early decision might buy time for the vessel to head to port or call for external assistance (leading to a higher chance of containment).
No data could be found for the branch *Closed deck / Late Decision / Suppression.* The assumption 90%/10% has been used in favour of *Contained.*

Tier 5 – Evacuation

It is assumed that evacuation from the ship if the fire is uncontained does not differ significantly between a closed and an open ro-ro space and likewise for a contained fire.

The probability of a contained fire on an open ro-ro space does however differ significantly from the probability of a closed. Thus, no differentiation is made in terms of probability of successful evacuation according to the deck type where the fire ignited. Therefore, data for both open and closed decks have been merged and led to the following.

Only one case of successful evacuation could be found for an uncontained fire after an early decision (LISCO GLORIA). Therefore, it is expected to have 90% of successful evacuation in those cases.

For an uncontained fire following fire suppression failure in case of late detection, 5 cases could be found. Among those 5 cases, 3 resulted in successful evacuation and 2 in unsuccessful evacuation. Therefore, a dependent probability of 60% has been assigned to successful evacuation in those cases.

No data were available regarding evacuation for the sequence of events *Late Decision/Suppression/No containment*. Therefore, the values for a successful and unsuccessful evacuation after a fire on ro-ro deck that escalates have been drawn from the FSA on RoPax ships (IMO, 2008) and were supported by the experts involved in these studies. These values are 75% and 25% respectively.

2.8.6. Weather deck quantification of average fatalities, loss of ship, and cargo damage

Since no RCOs (for fire suppression failure) are investigated for the weather deck type (as no fixed fire-fighting system is installed), this branch has not been further developed in the Main risk model.

While the frequency of fire ignition on weather deck can be directly calculated (Fire ignition x Proportion of fires on weather deck), the outcomes in terms of fatalities, cargo damage and ship damage must be estimated. Such estimation is necessary as the RCOs identified for reducing the risk of electrical fires also impact the weather deck (therefore impacting the partial PLL, PLS and PLC for that branch - which calculation requires knowing the average number of fatalities per accident).

It is assumed that the values for the Early/Late decision remain the same as for open and closed decks. Since there is no fixed-fire extinguishing part, only a manual extinction/suppression is possible. Therefore, the values for manual extinction failure (for Early and Late decision) have been extracted from the fault trees and put into these nodes. For the remaining of the nodes (in particular Containment) the same values as for the Open deck are taken. This allowed the calculation of the average fatalities (7.28 fatalities), loss of cargo (11 204 666 €), and ship damage (26 113 898 €), and contribute to 10% of PLL, 10.4% of PLC and 9.4% of PLS.

2.8.7. Consequences

The objective of the risk model is to evaluate the Potential Loss of Life from contribution of each of the Main model branches. While the variety of outcomes has been recognized, an average value for the number of fatalities is sufficient in the context of calculating a PLL.

In terms of consequences, previous FSA studies (SAFEDOR, EMSA 3) used 8% of Persons on Board to calculate the average fatalities following the scenario: fire on vehicle deck / escalation / unsuccessful evacuation.

This 8% was considered relevant for the FIRESAFE study. If compared to the 2 accidents (on the FIRESAFE fleet) that led to fatalities:

- Accident A: 18.4 equivalent fatalities out of 474 persons on board leading to a fatality rate of 3.9%.

- Accident B: 31.61 equivalent fatalities out of 454 persons on board leading to a fatality rate of 7.0%.

When the evacuation is successful, a 1 equivalent fatality fixed value has been assigned to take into account the frequent injuries and possible indirect fatalities following such evacuation.
Consequences for cargo and ship have been discussed in the dedicated Cost of ship and cargo damage .

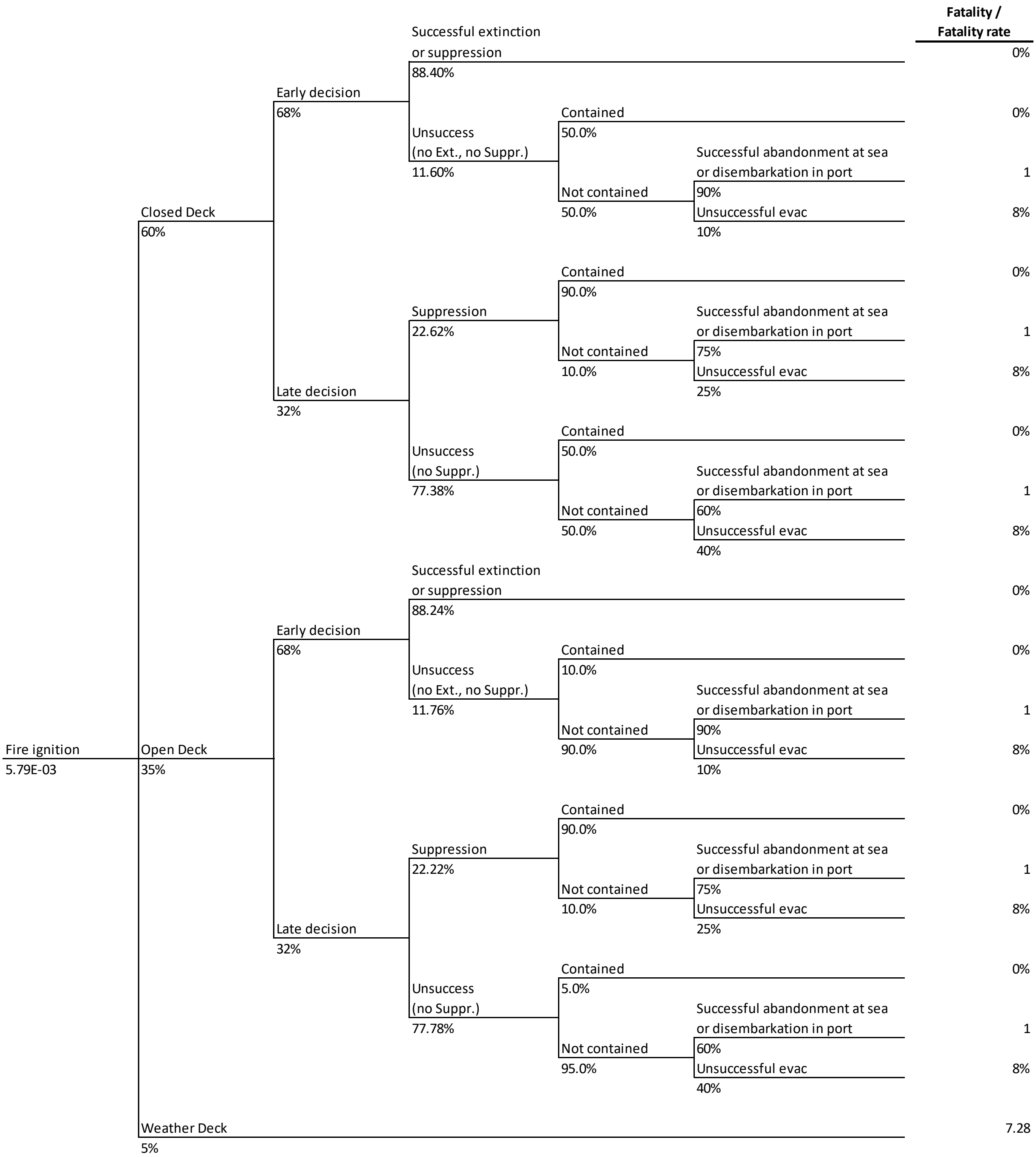


Figure 2.8-3 The Main Risk Model (fatality rate is in some branches in the event tree expressed as fixed number of fatalities)

2.9. Cost of ship and cargo damage

In the Main risk model, there are 21 branches that represent the different accident scenarios. These could be group into 5 different fire scenarios, A to E. Below will these four scenarios and their associated costs be discussed. The details of the cost estimates can be seen in Table 2.9-1.

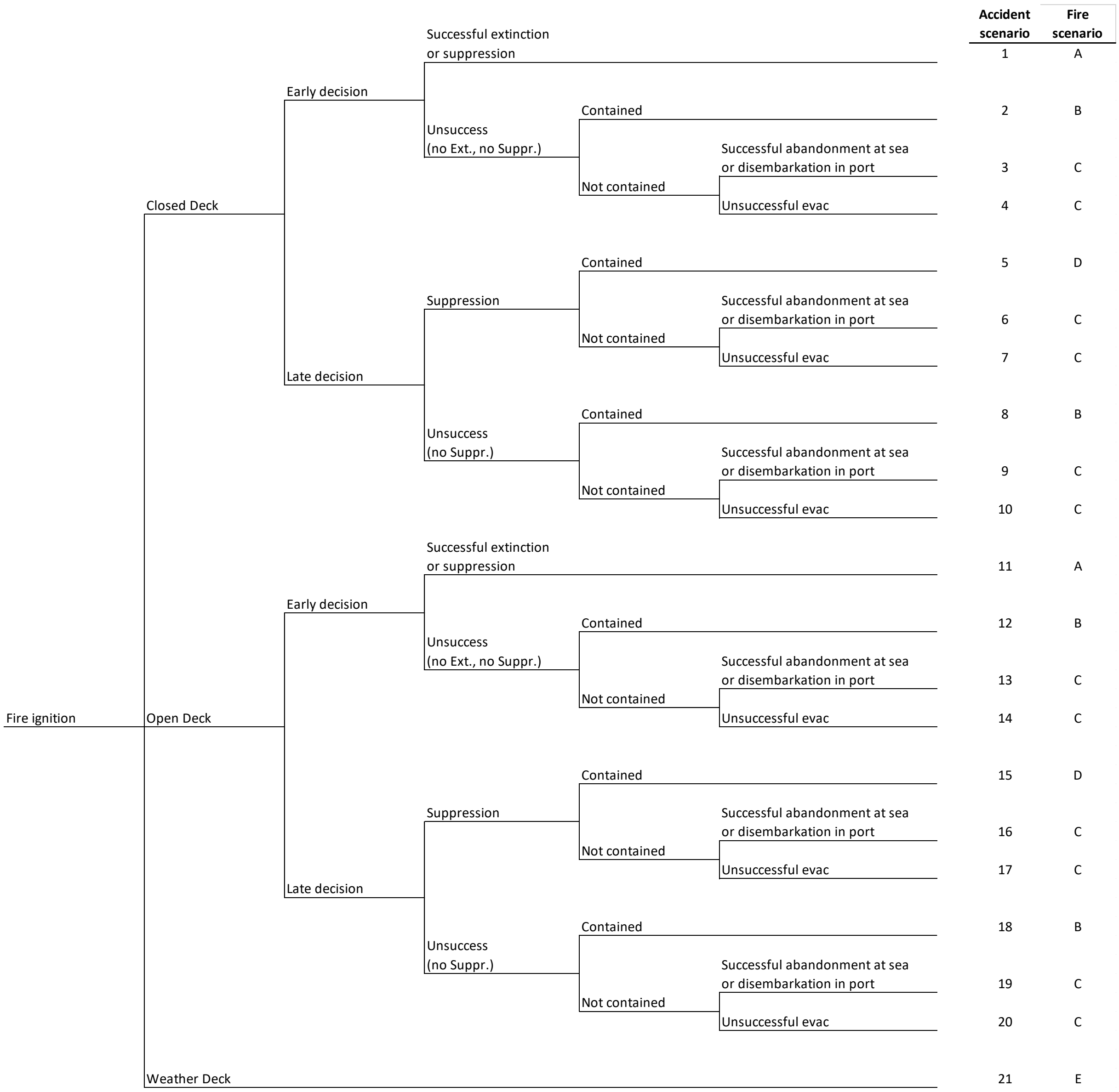


Figure 2.9-1 Accident and fire scenarios

2.9.1. Fire scenario A

Successful extinction or suppression means that the fire is detected and the decision to release the drencher is taken in time for the system to be successful in extinguishing the fire or suppress it to one vehicle. Damages will be restricted to about one vehicle and possibly the structure and equipment above the vehicle. Based on two fires that have occurred on-board two different ships it could be concluded that the costs caused by the

fires differed significantly. In both cases the crew handled the fire very quickly and successfully.
The first fire started in a caravan which was completely destroyed. The fire also damaged four nearby cars to about 50%. However, the damage to the ship was limited to cleaning and sanitation and there were no off-hire. Estimated costs are 70 000 €.
The second fire started in the cabin of a truck. It was also put out quickly by the crew. The truck and its trailer were totally damaged while three nearby trucks suffered 50% damage. The fire also caused some damage to the structure above the truck, including hydraulic pipes and electrical wires. The ship was taken off-hire for repairs during 10 days. Estimated costs are 2.4 M €.
These two fires are considered to represent the smallest and largest consequences in this scenario and the cost that is used in the cost benefit analysis is taken as an average 1.2 M €.

2.9.2. Fire scenario B

Early or late decision, unsuccessful extinction/suppression and fire contained to the ro-ro space in which it started. The fire is assumed to have a medium fire growth rate. It will be contained within the ro-ro-space but since the suppression system is failing to extinguish or suppress it the complete ro-ro-space will be destroyed. In many cases this will be treated as a total loss by ship owners and insurance companies. In some cases, the ship has been repairable but to a large cost. After discussions, it was decided that the costs in this scenario should be set to 80% of a total loss (40.2 M €).

2.9.3. Fire scenario C

The drencher fails and the fire is not contained. This will lead to a total loss. The time available for evacuation will be different for the different accident scenarios. In accident scenarios 6, 7, 16 and 17 the drencher is able to suppress the fire but since it is not contained in the ro-ro space it will spread through the rest of the ship and eventually cause a total loss. The cost for a total loss of the generic ship is estimated to 57.7 M € including cargo.

2.9.4. Fire scenario D

The decision to activate the drencher is late and the system is thus only able to suppress the fire to 1-3 trucks. To estimate the damages caused by a suppressed contained fire an area equivalent to 1-3 trucks will be exposed to flames and heat while the remainder of the space only will be exposed to smoke and soot and low temperatures. The cost has been estimated to about 2.4 M €.

2.9.5. Fire scenario E

This scenario is a fire on the weather deck. Since no RCOs (for fire suppression failure) are investigated for the weather deck type (as no fixed fire-fighting system is installed) only an estimation of the costs has been done. In section 2.8.6 a discussion about this could be found.

Small Fire	Fire in Caravan Damage to Caravan 100% + 4 cars; 50% No damage to vessel but sanitation needed No off-hire	Estimated cost of damage: Cargo damage: 70 000 € * / *** Ship damage : 1 000 €** **Total cost: 71 000 €**
Medium fire	Fire in Truck Damage to 1 Truck +Filled trailer 100% 3 Trucks + Filled trailers 50% Damage to ship Off-hire 10 days	Estimated cost of damage: Cargo damage: 420 000 € * / *** Ship damage: 2 000 000 €** **Total cost: 2 420 000 €**
Fire to one closed deck	Assumes 80% loss of ship value. Assume 70% filling grade on cargo deck Assume 44 Truck+ trailer units, damage 100% Assume 50% damage on cargo deck above. Meaning 50% damage to 80 cars.	Estimated cost of damage: Cargo damage: 8 192 000 € Ship damage: 32 000 000 € **Total cost: 40 192 000 €**
Total loss	Assumes 100% loss of ship value. Ship age 17,5 years Assume 70% filling grade on cargo deck Assume 100% loss of cargo (Truck+trailers 90pcs / Cars 130pcs)	Estimated cost of damage: Cargo damage: 17 720 000 € Ship damage: 40 000 000 € **Total cost: 57 720 000 €**
New building cost	Approximate newbuilding cost of reference vessel	**Total cost: 80 000 000 €**

* Cost estimation based on data in the EMSA 3 study (Impact Assessment)
Car: 20 000 €
Filled Trailer: 58 000 €
** Cost based on real accidents 2013 - 2016
*** Cost based on estimation
Caravan: 30 000 €
Truck: 110 000 €

Table 2.9-1 Cost estimates for fire scenarios A to D

3. Electrical fire as ignition risk (first part)

3.1. Risk model for electrical fire as ignition source

In order to be able to investigate the impact of RCOs aimed at decreasing the risk of ignition from electrical failures it is necessary to develop a model describing the risk of fire ignition in roro spaces. Since the total risk from fires needs to be estimated all ignition sources are included even though the model focuses on ignition form electrical failures.

3.1.1. Development of risk model for electrical ignition sources

With regards to data on fires on ro-ro decks it should be noted that there is no consistency in the typology of categories of hazards and ignition sources amongst the several publications on fires on RoPax ships, and more specifically on fires on ro-ro decks. The titles of the main categories in some publications are presented in table 3.1-1

EMSA GoE *Group of Experts (1st and 2nd correspondences)*	**DNV-GL (2016)** *Fires on ro-ro decks (2005-2016)*	**FSI 21/5 (2012)** *Analysis of available data on ro-ro ferry vehicle deck fires*
Electrical fire	Buses, trucks (not their cargo)	Fire in vehicle cab
Ship's equipment and cabling fire	Cars (other than new)	Electrical fire on vehicle
Electrical vehicle fire (BEV, HEV, FC, RU)	New cars	Fire on reefer (elect.)
Fire on cabling/sockets on ships to vehicle connection	Other vehicles (type not identified)	Fire on reefer (other cause)
Electrical fire on cargo units	Cargo on trucks (incl. transported vehicles)	Vehicle engine fire (general)
Vehicle engine fire	Reefer unit	Fire on other cargo unit
Cargo fire, non electric	Un-authorized charging of electric car	Fire in ship’s equip.
Vehicle engine fire	Shifting of cargo due to adverse weather	Other cause
Fire by friction (e.g. ship's equipment)	Unknown	
Fire on other cargo unit (e.g. trailers, semi-trailers)		
Auto ignition by gas leakage		
Vehicle cab fire (e.g. stowed material)		
Arson		

Table 3.1-1: Categories used to characterize sources of fire on ro-ro deck in literature

For the FIRESAFE study, a tiered approach was used. It was decided to use categories of ro-ro deck fires similar to the ones documented in FSI 21/5 (IMO, 2012) as basis for the tiers in the development of a risk model for probability estimations. The model was developed similar to a fault tree, with potential causes leading to a top event (in this case *Ro-ro deck fire*) are derived and structured. The fires documented FSI 21/5 (see table 1 of Annex 6 of that document) were reported in the eight categories presented in table 3.1-1 above. The first seven categories of fire origins were divided in two main categories: *Ship equipment* and *Ship cargo*, leaving the category *Other cause* as a third main category (tier 1). The latter includes for example fire due to cargo shift and arson. The category *Ship equipment* includes both fixed and portable equipment, i.e. both equipment fixed to the ship as well as equipment which is portable and potentially plugged in to the ship's electrical system. As illustrated in Figure 3.1-1, the *Ship cargo* category was first divided in *Vehicle* and *Cargo unit* (tier 2), to distinguish between fires originated in vehicles used to carry cargo onboard and fires originated in cargo units, such as reefer units, trailers, trucked vehicles, etc. Fires on vehicles were divided in the categories *Cab*, *Powertrain*, and *Other* (tier 3). In the cab are included temporary and permanent electrical installations which could cause fire in the cab, such as electrical seats, lights, heaters, flammable liquids, kettles, mobile units and other items which could occur in a cab. The powertrain can be defined as the components of a vehicle that generate power to the road surface and include engine, transmission, drive shafts, differentials, and wheels. Elements such as breaks, tanks, batteries and electrical systems are also seen as elements of the powertrain, except from the electrical systems inside the cab. Furthermore, the electrical system of carried cargo unit/trailer is not included in this category but in the *Cargo unit* category. This was further sub-categorized in the two categories *Reefer* and *Not reefer* (tier 3), to separate refrigerated units from other cargo.

Each distinguished category of fire origin was further divided in *Electrical* and *Other* (tier 4), referring to whether the fires were caused by electrical fault or not. Electrical fires in vehicle powertrains and reefer cargo units were further divided in *Connected* and *Unconnected* (tier 5), to distinguish fires in vehicles and cargo units connected to the ship power supply. The fire risk model with the five tiers is illustrated in Figure 3.1-1.

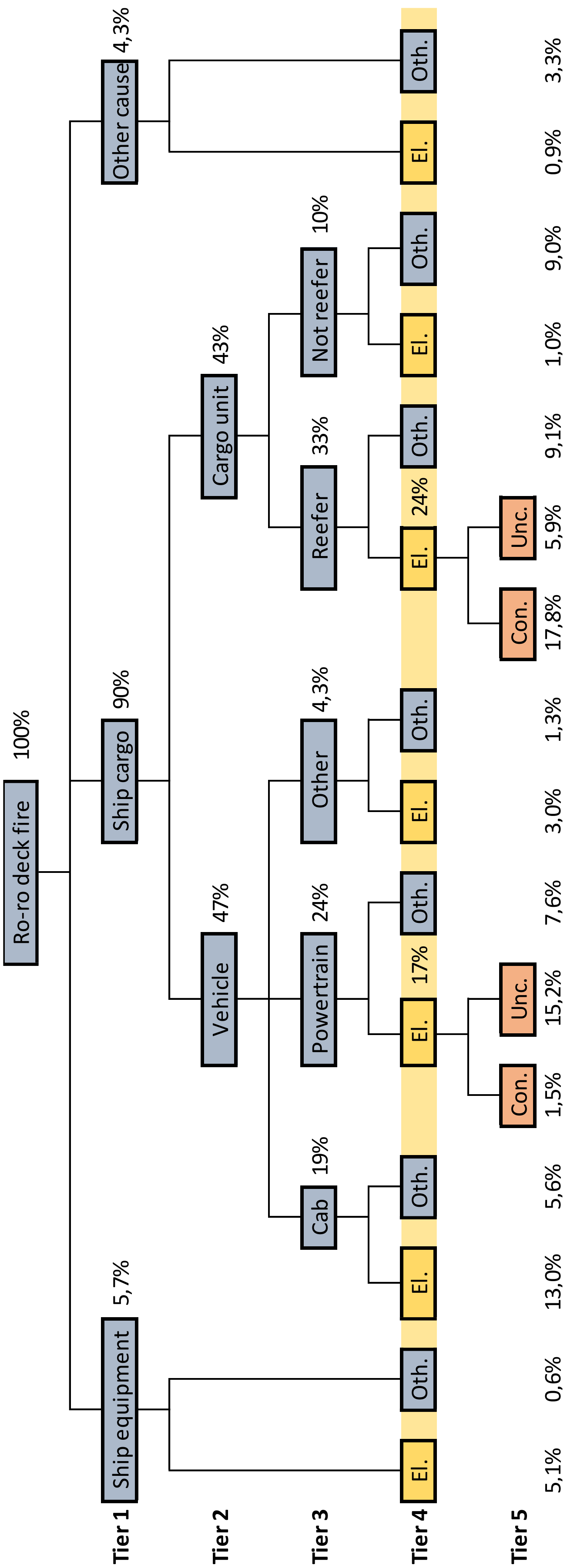


Figure 3.1-1. Fault tree risk model for electrical fire as ignition source on ro-ro deck.

3.1.2. Input data analysis for electrical ignition source model

The risk model is simply a way to structure the statistical data available in order to better assess effects of risk control measures. To populate the model, categorizations were made of incidents reported in three different datasets:

- **'FSI 21/5'**: 70 accidents - data from FSI 21/5 only, including FIRESAFE and Non-FIRESAFE compliant ships from 1994 to 2011;
- **'FIRESAFE'**: 50 accidents - data from MARINFO, EMCIP, and IHS between 2002 and 2015, all compliant with FIRESAFE criteria, as well as non-anonymized FIRESAFE compliant FSI 21/5 data; and
- **'All data'**: 140 accidents - data from all available sources, including FIRESAFE and Non-FIRESAFE compliant ships from 1994 to 2016 (also including accidents in above datasets)[36].

For the data available in FSI 21/5, the incidents were carefully scrutinized and categorized. During this work personnel from SP working with fire cause investigations of vehicle fires (trucks, buses, forest, tractors, wheel loaders, forest vehicles, etc.) where consulted. The categorizations of the incidents in the three different datasets were compared, as presented in Figure 3.1-2, Figure 3.1-3, Figure 3.1-4, and Figure 3.1-5, below.

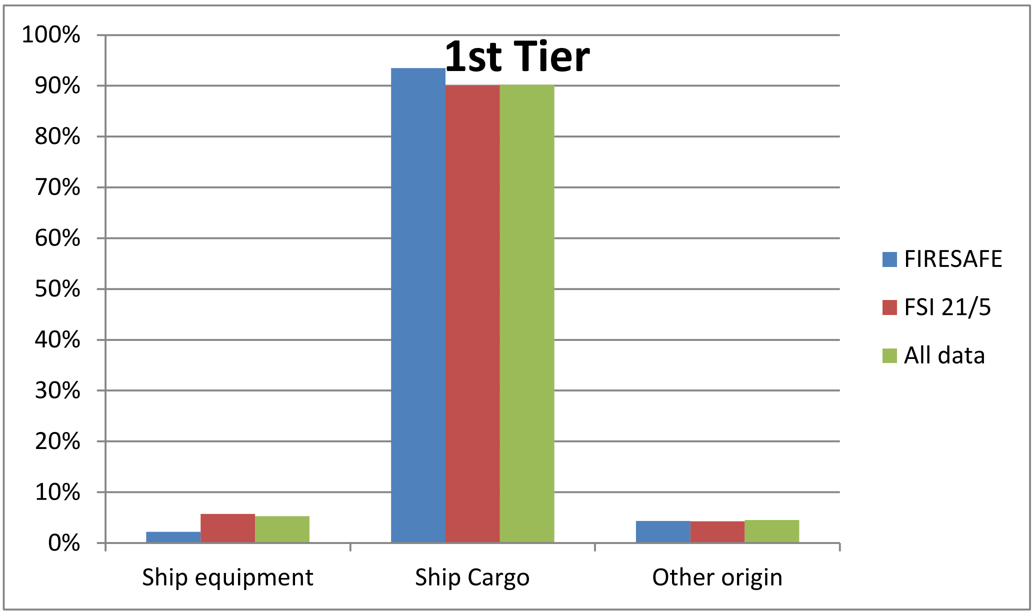


Figure 3.1-2. Distribution of accident reports over the first tier three categories (Ship Equipment, Ship Cargo, Other origin) for different datasets.

[36] These databases have been further described in the section on Casualty Analysis.

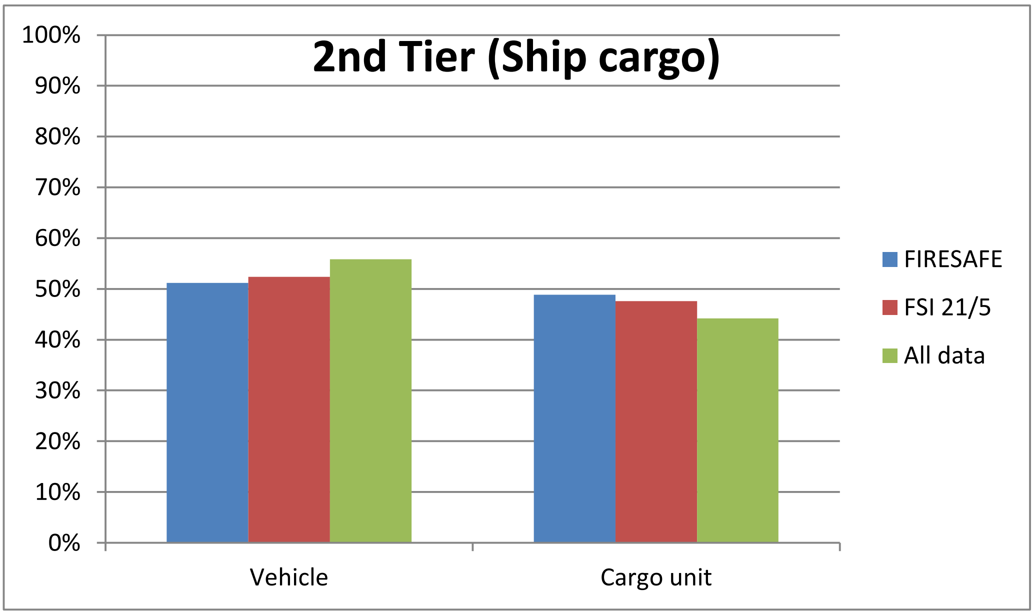


Figure 3.1-3. Distribution of accident reports over the second tier two categories (*Vehicle*, *Cargo Unit*) for *Ship Cargo* for different datasets.

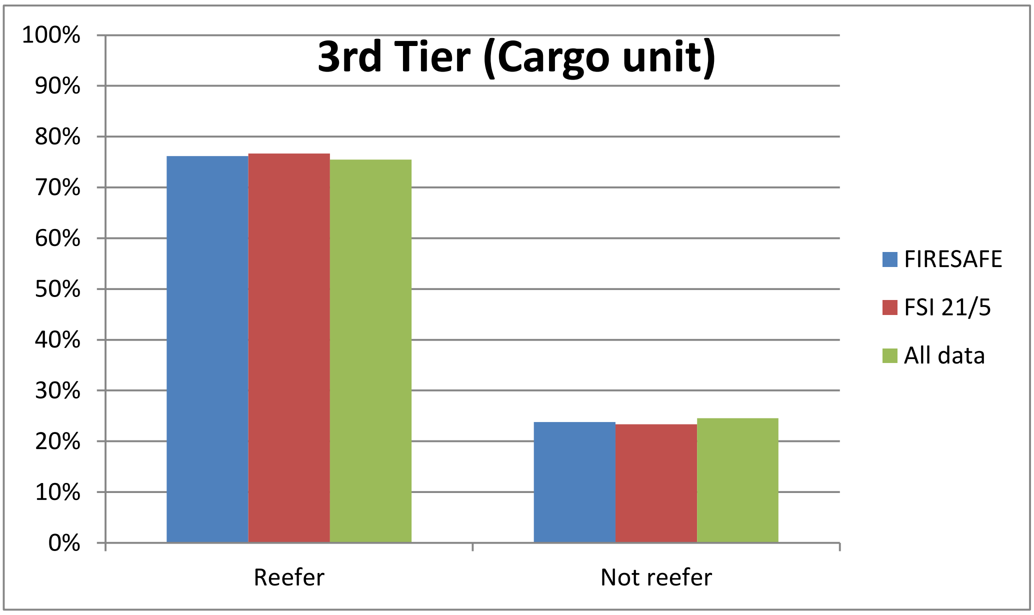


Figure 3.1-4. Distribution of accident reports over the third tier two categories (*Reefer*, *Not reefer*) for *Cargo Unit* for different datasets.

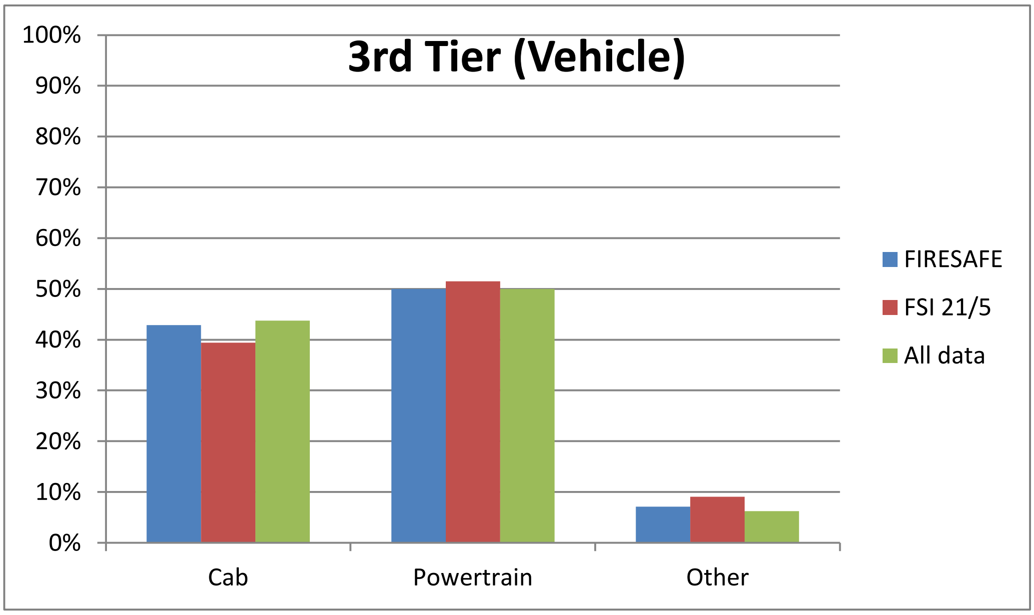


Figure 3.1-5. Distribution of accident reports over the third tier three categories (*Cab*, *Powertrain*, *Other*) for *Vehicle* for different datasets.

It should firstly be noted that the different data sources show very similar results when organized in the categories selected for this study[37]. It is hence likely that the variability between the different data sources is smaller than the uncertainty of each data source. This argues that any of the datasets could be used to populate the risk model for electrical fire as ignition source on ro-ro deck.

In addition to the above comparisons, the data can be compared with information in the Commodore Clipper accident investigation report (MAIB, 2011), showing consistency also with this data:

> "*A total of 38 cases involving fires on vehicle decks of ro-ro ferries have been reported to the MAIB from 1995 to 2010. Analysis of these cases determined that the most frequent causes of fires were:*
>
> - *Eleven electrical fires specifically recorded as having occurred on refrigeration trailers* [29 % (11/38) compared to 24% in the FSI 21/5 data]
> - *Eleven electrical fires on other vehicles* [29% (11/38) compared to 33% in the FSI 21/5 data]
> - *Seven fires in vehicle cabs.* [18% (7/38) compared to 19% in the FSI 21/5 data]"

FSI 21/5 is the single dataset with the largest number of reported incidents. It has also been quality assured through review by experts. It includes both FIRESAFE compliant and non-compliant ships but it has been judged that the probability of ignition per origin is independent from the reporting process and therefore not related to the database (which seems to be confirmed given the high consistency of the results throughout the databases). Furthermore, to cope with the data accessibility issue often highlighted in FSA Expert Group reports, the FSI 21/5 dataset has been selected since it is publicly available, which allows scrutiny and reorganization of categorization if desired, hence

[37] It should be noted that part of the consistency might come from the overlapping of the databases.

improving the transparency and repeatability of the study. It was therefore decided to use FSI 21/5 as input to the electrical ignition source fault tree, as further described below.

3.1.3. Input to risk model for electrical fire as ignition source

As discussed above, the data in FSI 21/5 was used to populate the fault tree for electrical fire as ignition source. However, in this data, fires initiated in cables connecting reefers to ship outlets were categorized as "Fire in ship's equipment", as indicated in paragraphs 14.4 and 14.6 of the Annex of FSI 21/5. This implies that cables belonging to the ship are used. However, in many cases drivers use their own cables to connect their reefer units. In this study, cables connecting reefers to the ship power grid were considered as ship cargo, more specifically under *Connected-Electrical-Reefer* fires. There were two defined such incidents, namely the cases defined as:

- 1777/1997 (MAIB), 1997; and
- Commodore Clipper (GISIS CR), 2010.

Furthermore, as discussed in Section Data sources exploitation, three cases were removed from the data in FSI 21/5 since they were identified as cargo vessels, which were not included in this study, namely:

- Und Adriyatik (Ro-ro cargo ship), 2008;
- Schieborg (Ro-ro cargo ship), 2005; and
- Silver Ray (Pure car carrier), 2002.

A total of 70 incidents were thus left in the FSI 21/5 dataset, categorized as presented in table 3.1-2.

				Tier 4		**Tier 5**
		Defined Electrical	Defined Non-el.	Assumed electrical	Assumed Non-el. rel. tot	Connected
Tier 1						
Ship equip.	4	4	0	5.14%	0.57%	
Ship cargo	63	31	18	57.39%	32.61%	
Other origin	3	0	2	0.94%	3.34%	
Total	**70**	**35**	**20**	**64.81%**		
Tier 2						
Vehicle	33	18	8	32.66%	14.48%	
Cargo unit	30	13	10	24.73%	18.13%	
Total	**63**	**31**	**18**	**58.73%**		
Tier 3						
Cab	13	7	3	13.00%	5.57%	
Powertrain	17	11	5	16.70%	7.59%	1.52%
Other	3	0	0	2.97%	1.32%	
Total	**33**	**18**	**8**	**32.66%**		
Reefer	23	13	5	23.73%	9.13%	17.80%

Not reefer	7	0	5	1.00%	9.00%
Total	**30**	**13**	**11**	**24.73%**	

Table 3.1-2: Electrical ro-ro deck fire risk model categorization based on FSI 21/5

As noted above, many of the fires were undefined in the FSI 21/5 data, in particular with regards to whether they were caused by electrical fault or not. For categories with both defined *Electrical* and *Other* (non-electrical) fires, the general assumption was made that this relation was applicable also to the undefined fires of that category. However, for the category *Other-Vehicle* fires (fires in vehicles other than in the cab or powertrain) and the main category *Other cause* there were no defined fires with regards to electrical cause. These categories were therefore assumed to have electrical fires in relation to the other fires in the respective tiers. Hence, electrical fires in the category *Other cause* were assumed to be in relation with electrical fires in the *Ship cargo* and *Ship equipment* categories. Similarly, electrical fires in the category *Other-Vehicle* fires were assumed to be in relation with electrical fires in the *Cab* and *Powertrain* categories. For ship equipment, all the fires were categorized to be of electrical cause. This was not considered representative to reality, since there are many fires that can be initiated by other than electrical cause, e.g. hydraulics. To manage this considered lack of data, a 90-10 assumption was made which implies that 10% of the fires in this branch were assumed non-electrical, in this case 0.57%.

The data in table 3.1-2 was used to populate the electrical ro-ro deck fire fault tree. It only includes OR gates, implying that single errors are sufficient to reach the top event and that probabilities can simply be added to summarize contributions. Each figure relates to the top event, ro-ro deck fire, and represents a fraction of the frequency of such fires, in this case 5.79E-03 fires/shipyears. For a conventional design the provided data indicates that electrical fires represent approximately 60 % of all ro-ro deck fires.

3.2. Develop RCMs and RCOs

A large number of risk control measures have been discussed within the project, including those proposed in other studies (see Annex 1). Individual risk control measures could be combined into risk control options (RCO). This means that the RCO that are analysed quantitatively consists of some different proposed RCM. After a selection process as described in chapter 2, six RCO were chosen to be analysed in the risk model. These six RCO are described in 3.2.1 to 3.2.6. Some more RCOs are described in 3.2.7 and 3.2.8.

In the selection process the probable benefits, probable risk reduction, estimated costs and the practicability of the proposal were assessed qualitatively. The proposals that were not chosen are listed in Annex 2. It should be noted that the annex contains valuable proposals and could be further evaluated even though they were not chosen to be included in the quantified study. It is of course possible to use the developed risk model and analyse these in the future.

3.2.1. Connection boxes RCO El 1

With regards to socket outlets (connection boxes) on ro-ro-spaces there are some requirements in different classification societies rules that could be applicable. The requirements are furthermore not exactly the same for different societies, which means that the protection on different ships will vary. During the identification of RCMs, a large number of proposals where put forward with regard to protection of the connection boxes. During the workshop the project summarized the most important of these into one RCO. This RCO is called Robust Connection Boxes. Some or all of the proposals in this RCO may already be in place on a specific ship depending on flag, class and age. The impact of upgrading, installing and maintaining the connection boxes in line with the requirements below could become a uniform IMO standard. The features for the robust connection boxes are:

- Earth fault breakers to be installed (see separate discussion below)
- Increased maintenance of the connection boxes
- IP-class (e.g. IP56)
- Individual circuit breakers
- Individual and interlocked switches
- Secured cables

Examples of requirements in the regulations and in the rules of some classification societies are given here.

Circuit breakers

In SOLAS chapter II-1/45.6.1 it is required that each separate circuit shall be protected against short circuit and overload. A separate circuit may consist of several sub-circuits and a definition of final sub-circuit can be found in LR and DNV GL rules.

> LR p6 ch2 sec1 1.6.8. A `final sub-circuit' is that portion of a wiring system extending beyond the final overcurrent device of a board.
>
> *LR p6 ch2 sec 13 13.6 Socket outlets and plugs*
> *13.6.1. The temperature rise on the live parts of socket outlet and plugs is not to exceed 30°C. Socket outlets and plugs are to be so constructed that they cannot be readily short-circuited whether the plug is in or out, and so that a pin of the plug cannot be made to earth either pole of the socket outlet.*
>
> *13.6.2. All socket outlets of current rating in excess of 16 A are to be provided with a switch, and be interlocked such that the plug cannot be inserted or withdrawn when the switch is in the 'on' position.*
>
> *13.6.3. Where it is necessary to earth the non-current carrying parts of portable or transportable equipment, an effective means of earthing is to be provided at the socket outlet.*
>
> *DNVGL p4 ch8 s10 2.1.1 f) All equipment of smaller type (luminaires, socket outlets etc.) shall be protected against mechanical damage either by safe location or by additional protection, if not of a rugged metallic construction.*
> *2.2.1 Cargo holds IP55 + reg II-2/20.3.2*

P4 ch8 s8 1.1 Socket outlets and plugs
1.1.1 General
a) Socket outlets and plugs with a rated current not exceeding 63 A in AC installations and 16 A in DC installations, shall be constructed for making and breaking the rated current by insertion and withdrawal of the plug, unless they are provided with an interlock as described in b).
b) Socket outlets with a rated current above 63 A AC or 16 A DC shall be provided with interlocks so that the plug can only be inserted and withdrawn when the switch is in the "off" position.

Earth fault breakers (Residual current device)

When discussing safety of electrical systems one of the most important concerns is the protection from earth faults. An earth fault could be described as a fault where the current flows from the live part to earth instead of back through the neutral part in a one phase system. In a three-phase system, it is leakage from one of the phases to earth. A small leakage is not uncommon (especially for refrigerated units on trucks) and if it is small enough it could be harmless. When reaching to about 30 mA it will become hazardous to humans and could even cause a risk to life depending on the duration (IEC Report 479-1 'Effects of current passing through the human body'). This is of course an important concern that also needs to be addressed. Protection could be achieved with an earth fault breaker (also called Residual Current Device RCD).

With regards to fire safety the leakage needs to be larger in order to cause a fire. According to Kidd 1985 a RCD which cuts of at 100 mA and after 200 ms will give a good protection against start of a fire. The following example is also given: "If an overcurrent protective device rated at 5 A were the only means available to protect against such a situation well over 1 kW would need to be dissipated in the developing fault path before the condition could be detected". This could be compared to electrical barbeque igniters that uses 500-800 W.

In IACS rec. no 137 the problems with earth faults and road freight units are discussed. They recommend that RCD protection is installed for all outgoing distribution circuits to road freight units. The rec. does not give any advice on the sensitivity of the RCD.

It should be noted that the electrical system on ships could be of different types with regards to the neutral, earth and the phases. In some cases, the equipment is locally earthed. It is important that the technical details of the system are taken into account when installing RCDs. For supplying power to reefer, it would be preferable to use an insulation transformer, in order to isolate reefer circuits from ship's distribution. The connection of systems like reefers which are not always in good condition and not well maintained is a frequent source of insulation failures. This transformer is also a means to change the distribution system from IT to TN-S or TT, which could be easier to manage.

Here are some examples of SOLAS and class requirements for earth fault protection:

> *SOLAS II-1/45.4.2. When a distribution system, whether primary or secondary, for power, heating or lighting, with no connection to earth is*

used, a device capable of continuously monitoring the insulation level to earth and of giving an audible or visual indication of abnormally low insulation values shall be provided.

BV Pt C ch 2 sec 3:
3.11 Refrigerated containers.
3.11.1 Where the ship is intended to carry a large number of refrigerated containers, provision of suitable means for preventing earth faults on containers from affecting the main distribution system is to be made (galvanic isolation, tripping of the faulty circuit).

LR Part 6 ch 2 sec 6
6.4 Protection against earth faults
6.4.1. Every distribution system that has an intentional connection to earth, by way of an impedance, is to be provided with a means to continuously monitor and indicate the current flowing in the earth connection.

6.4.2. If the current in the earth connection exceeds 5 A there is to be an alarm and the fault current is to be automatically interrupted or limited to a safe value.

6.4.3. The rated short-circuit capacity of any device used for interrupting earth fault currents is to be not less than the prospective earth fault current at its point of installation.

6.4.4. Insulated neutral systems with harmonic distortion of the voltage waveform, which may result in earth fault currents exceeding the level given in 6.4.2 because of capacitive effects, are to be provided with arrangements to isolate the faulty circuit(s).

DNVGL part 4 ch 8 sec 2
7.1.2 Insulation fault
d) On systems with low-resistance earthed neutral automatic disconnection of circuits having insulation faults shall be arranged. This earth fault protection shall be selective against the feeding network. For low resistance earthed neutral systems the disconnection shall operate at less than 20% of minimum earth fault current.
f) For direct-earthed systems (i.e. TN-S, TN-C-S and TT) the single or three phase effective overcurrent and short circuit protection is acceptable as earth fault protection.

3.2.2. Only allow ship cables and ship adapters RCO El 2

The cargo on ro-ro-passenger ships mainly consists of trucks, buses and cars. Some of these will request the possibility to get connected to the ships electrical system. The purpose could be to run reefer units on trucks or charging of electrical vehicles. On some ships this connection is done with cables and adapters brought by the drivers. It could also be possible for drivers to connect without the knowledge of the crew, (e.g. if they use an extension cord with multiple outlets). This means that unknown cables could be connected to the ship with possible increased risk of short circuit in cables and adapters, higher risk of overheated cables due to wrong size and higher risk of sparks from possible damaged cables.

Routines for maintenance and exchange of cables shall be further developed (cables shall be treated as consumables).

Ships cables (and especially fixed installed cables) are subject to a large number of requirements in the classification rules.

> *BV pC ch2 s9 1.1.1 Cables and insulated wiring are generally to be constructed in accordance with IEC Publications of the series 60092-3.., as well with the provisions of this Chapter.*
>
> *DNVGL p4ch8s9 8.1.1 Flexible electrical cables shall be constructed and tested in accordance with the technical requirements given through DNVGL-CP-0417 Flexible electrical cables.*

3.2.3. IR camera RCO El 3

Many of the fires caused by an electrical problem starts with overheating. It has thus been proposed that potential fires could be detected and avoided if overheated equipment could be found. Portable Thermographic cameras have during recent years become increasingly smaller, more inexpensive and easier to use. This RCO proposes that portable thermographic cameras shall be used for screening during fire rounds or upon suspicion to detect hot areas and overheated electrical equipment.

IR cameras could also be used during firefighting and rescue operations. Furthermore, they could be useful to detect mechanically overheated equipment which also could start a fire. IR-cameras are frequently used in engine rooms to find hot spots. These benefits are supplementary and not considered in this study. Our study assumed the camera to be dedicated to the Ro-Ro space personnel (no sharing).

3.2.4. Training for awareness RCO El 4

Partly due to that the electrical system on ro-ro-spaces are mostly consisting of fixed cabling, lighting and some socket outlets, the majority of fires caused by electrical equipment will start in the cargo. The cargo (i.e. trucks, buses and cars) could be anything from brand new and well maintained to very old and unreliable. In the HAZID performed it was pointed out that for all vehicles the main fire hazards were in many cases associated with non-manufactured installations, e.g. home-made electrical installations (e.g. lights, heaters, etc. in trucks) or home-made, rebuilt or vintage vehicles. Furthermore, the quality of spares and repairs could be of a low standard also on newer vehicles.

This RCO is more of a soft option since it deals with knowledge and training. All crew involved in cargo operations should be made aware of the hazards of substandard installations and other possible electrical fire hazards of the cargo. This should be part of a training program that should be included in familiarization and ongoing training processes. It should lead to increased crew awareness of smell, damaged vehicles, heat radiation, "smart installations", open windows, late and overheated buses and other signs of possible fire risks. It could be beneficial that also include other fire risks than those caused by electrical installations.

Routines for reviewing units and performance of directed inspections should be included as well as routines about how to handle the risk e.g. send those units back ashore or special locations on the ship or increased surveillance and monitoring by the fire patrol. Help booklets and warning posters could be developed to assist with maintaining crew awareness of "smart" installations.

SOLAS II-2/16 Operations, does contain the requirement that the crew shall be given necessary information and instructions for the safe operation of the ship and its cargo. However, in most cases these operation booklets does not contain information at the level of detail about fire risks caused by vehicles that is proposed in this RCO.

> *SOLAS II-2/16.2 Fire safety operation booklets*
> *2.1. The required fire safety operational booklet shall contain the necessary information and instructions for the safe operation of the ship and cargo handling operations in relation to fire safety. The booklet shall include information concerning the crew's responsibilities for the general fire safety of the ship while loading and discharging cargo and while underway. Necessary fire safety precautions for handling general cargoes shall be explained.*

3.2.5. Only crew connections RCO El 5

One of the identified risks is caused by electrically connected cargo such as reefers and charging of electric cars. The equipment used for the connection are frequently used and handled under time pressure or by the drivers. This results in wear and tear of connection boxes, cables, cable connections and adapters. One proposal that also has been put forward in other projects is to only allow trained crew to connect and disconnect cables. A training program should be developed which should include training and routines for control of, care for and maintenance of cables (as well included in this RCO).

The crew shall be trained to identify faulty and risky connections and how to managing connections. Issues that should be covered include avoiding long cables and cable routing. Electricians and dedicated crew to do maintenance and keep equipment ship shape.

SOLAS II-2/16 Operations, does contain the requirement that the crew shall be given necessary information and instructions for the safe operation of the ship and its cargo. However, in most cases these operation booklets do not contain information at the level of detail about fire risks caused by electrical connections of vehicles that is proposed in this RCO.

> *SOLAS II-2/16.2 Fire safety operation booklets*
> *2.1. The required fire safety operational booklet shall contain the necessary information and instructions for the safe operation of the ship and cargo handling operations in relation to fire safety. The booklet shall include information concerning the crew's responsibilities for the general fire safety of the ship while loading and discharging cargo and while underway.*

Necessary fire safety precautions for handling general cargoes shall be explained.

3.2.6. Use of cable reeling drums RCO El 6

One method for protecting cables and to facilitate the handling of cables that has been developed is to install cable reeling drums. These are placed in appropriate locations in the ceiling of the ro-ro-space. The cable is rolled out when needed and (automatically) rolled in when disconnected. The main advantages are that the cables are protected when not used and that handling becomes easier. Drawbacks are costs, the requirement to pull all the line, the required installation space and the connection inside the drums are more difficult to inspect.

3.2.7. Plan for reefers RCO El 7

One fire hazard that is identified in many investigations is trucks and trailers with refrigeration units (reefers). It would be beneficial if the crew is aware of the exact location of the reefers that are carried onboard. First it could be possible to increase the possibility to detect a fire before it starts by increasing the frequency of the fire patrol where reefers are located. In case of a fire alarm with large amount of smoke the knowledge where reefers are positioned may help locate the fire. Furthermore the electric supply may be cut off to reefers close to a fire alarm.

This RCO proposes that reefers should be included in the Dangerous Goods plan or in a similar plan for those ships without dangerous goods. It could also be possible to include other identified high fire risk vehicles in the same manner.

3.2.8. Charging of electric cars RCO El 8

The number of electricity driven cars in the cargo is increasing rapidly and as a consequence also the request for charging the car on board the ships during passage. This problem has been highlighted in previous studies partly due to accidents. When looking into the statistics of fires started in electric cars it is clear that the risk is almost only present during charging of the car. Furthermore, there is a large difference in risk between factory built electric cars and "homebuilt" converted cars. The risk of a fire starting in a factory built car that not is being charged is even smaller than the risk of a fire starting in a conventional car.

At the moment some ships have been equipped with approved charging stations. There are two different types of charging that could be done. Most cars could be charged from a normal consumer socket but some could also be connected to special quick charging stations. One RCO that is proposed is to only allow charging of electric cars in sockets designated and approved for this purpose, and that only factory built cars should be allowed to connect to these.

It was decided to not analyse this RCO quantitatively since most ships do not allow charging of electric cars on board. A further reason is that the latest version of SOLAS chapter II-2 would only allow this on weather decks, as explained in the next section.

Electrical connections on Ro-ro spaces

The risk from explosive vapours on ro-ro-spaces has been considered by the SOLAS convention for many years. In the work with the comprehensive review of chapter II-2 that lead to SOLAS 2000 amendments the requirements on electrical equipment on ro-ro-spaces were increased. For ships built before 1 July 2002 the requirements on the electric equipment were only applicable if explosive vapours might be expected in a space. This was also in the proposed text of the 2000 amendments II-2/20.2.2 sent to FP44:

> *"2.2 Electrical equipment and wiring*
>
> *.1 On any deck or platform, if fitted, in vehicle spaces on which explosive vapours might be expected to accumulate, except platforms with openings of sufficient size permitting penetration of petrol gases downwards, equipment and wiring, if fitted, shall be of a type suitable for use in explosive petrol and air mixtures. (Part of Reg.37.2.2.1, Part of Reg.37.3.2.1, Part of Reg.38.4.1, Reg.53.2.4.1 & Reg.53.3)*
>
> *.2 In case of other than special category spaces below the bulkhead deck, notwithstanding the provisions in paragraph 2.2.1, in the closed vehicle spaces a height of 450mm from the deck and from each platform, electrical equipment of a type so enclosed and protected as to prevent the escape of spark shall be permitted as an alternative on condition that the ventilation system is so designed and operated as to provide continuous ventilation of the cargo spaces at the rate of at least ten air changes per hour whenever vehicles are on board. (Part of Reg.37.2.2.1, 53.2.4.2 & Reg.53.3)"*

However, at FP44 the text of the new II-2/20.3.2 was changed to the following which is also the present text:

> *"3.2 Electrical equipment and wiring*
>
> *3.2.1 Except as provided in paragraph 3.2.2, electrical equipment and wiring shall be of a type suitable for use in an explosive petrol and air mixture*.*
>
> *3.2.2 In case of other than special category spaces below the bulkhead deck, notwithstanding the provisions in paragraph 3.2.1, above a height of 450 mm from the deck and from each platform for vehicles, if fitted, except platforms with openings of sufficient size permitting penetration of petrol gases downwards, electrical equipment of a type so enclosed and protected as to prevent the escape of sparks shall be permitted as an alternative on condition that the ventilation system is so designed and operated as to provide continuous ventilation of the cargo spaces at the rate of at least ten air changes per hour whenever vehicles are on board."*

The requirements in regulation "37 special category spaces on passenger ships" in the version of SOLAS that is still applicable to ships built before 1 July 2002, and this together with the interpretation that diesel fuel will not produce explosive vapours allows for connecting any cargo to the ships electrical system in enclosed spaces if no petrol fuelled vehicles are carried in the same space.

Furthermore, if petrol vehicles or any other vehicle that may cause the accumulation of explosive vapours are carried, all electrical equipment (including cars, trucks or reefers) shall be of a suitable type. According to most class and flag interpretations suitable type are equipment certified for Zone 1 below 450mm and for Zone 2 above 450mm with >10 air changes/h (IP 55 could be accepted).

For ships built after 2002 the requirements in 20.3.2 is applicable to all ro-ro-spaces without considering if there is any risk of explosive vapours. This means that any electrical equipment on closed ro-ro spaces shall comply with zone 1 below 450mm and zone 2 above 450mm, i.e. all reefers (or electric cars charging) must be above 450 mm and be classified as IP55 unless approved for ex-class Zone 1.

3.3. Costs of RCOs electrical fire risk

A very important factor when deciding whether to recommend a RCO or not is the cost of introducing it, since this is part of the evaluation of the cost effectiveness of the RCO. The costs that have been considered here are e.g. installation costs, maintenance costs, operational costs and increased manning. In the table below are the estimated costs of the RCOs are specified. All costs considered are additional (marginal) costs.

FIRESAFE RCMs for electrical fires		**Retrofit Cost €**	**NB Cost €**	**Service cost/y**
Robust connection boxes	**Retrofit Cost** – Earth fault indication, lockable socket, installation ; 80 sockets Total Cost: 28 000 € (Offer) **NB Cost** – 80% of Retrofit cost 0.8 x 28 000 = 22 400 € (Estimate) **Service Cost –** 500 € / year (Estimate)	**28 000**	**22 400**	**500**
Only ship cables	**Retrofit Cost** – Material ; Cables : 80pcs ; Cost per Cable : 200 € Initial cost 80 x 200 € = 16 000 € (Offer) **NB Cost** – Same as Retrofit Cost 16 000 € (Offer) **Service Cost** - Renewal every 5 years 16 000 / 5 = 3 200 € (Estimate)	**16 000**	**16 000**	**3 200**
IR camera	**Retrofit and NB Cost** – Unit price 1 000 € ; 2 pcs ; Life time approximately 2 years Total: 2 x 1 000 = 2 000 € (Estimate) **Service Cost –** 2 000/2 = 1 000 € (Estimate)	**2 000**	**2 000**	**1 000**
Training for awareness	**Retrofit and NB Cost** – Cost for developing training package 80 000 € Divided on 20 vessels ; 80 000/20= 4 000 € (Offer)	**4 000**	**4 000**	**0**
Only crew connections	**Retrofit and NB Cost** – Cost for developing training package 40 000 € Divided on 20 vessels ; 40 000/20= 2 000 € (Estimate)	**2 000**	**2 000**	**0**

Use of cable reeling drums	**Retrofit and NB Cost** – Assuming there is room for the drums the approximate cost for one drum is 3 000 € each with installation Total cost 80 x 3 000 = 240 000 € (Estimate) **Service Cost** – 200 € / drum and year = 16 000 € (Estimate)	**240 000**	**240 000**	**16 000**

Table 3.3-1 Cost estimates for RCO electrical failures

3.4. Quantification of RCO effects on ro-ro deck fire ignition

A number of the RCMs addressing electrical ignition sources and described above were selected for quantification, namely:

- Robust connection boxes
- Only ship cables
- IR camera
- Training for awareness
- Only crew connections
- Cable reeling drums

The quantification process was initiated by forming a common understanding of each RCO and where (what nodes) each RCO affects the risk model. This was done at a meeting, where more detailed discussions of factors affecting each RCO were also carried out. For example, limitations of the RCO to affect the node, reliability of the RCO, procedures of the RCO, and other important factors which affect the effectiveness of each RCO on each node. Thereafter, estimations of the effects of each RCO on the agreed nodes were estimated individually. The estimations were mainly done by expert judgment, where each partner consulted the internal experts considered necessary to provide their appraisal of how much the contribution by each node could be reduced by each RCO. This resulted in a list of estimations, which was then distributed to all partners. This list was then discussed, with focus on large (relative) and noteworthy differences in appraisals. A few estimations were changed due to different ideas about details of the RCOs.

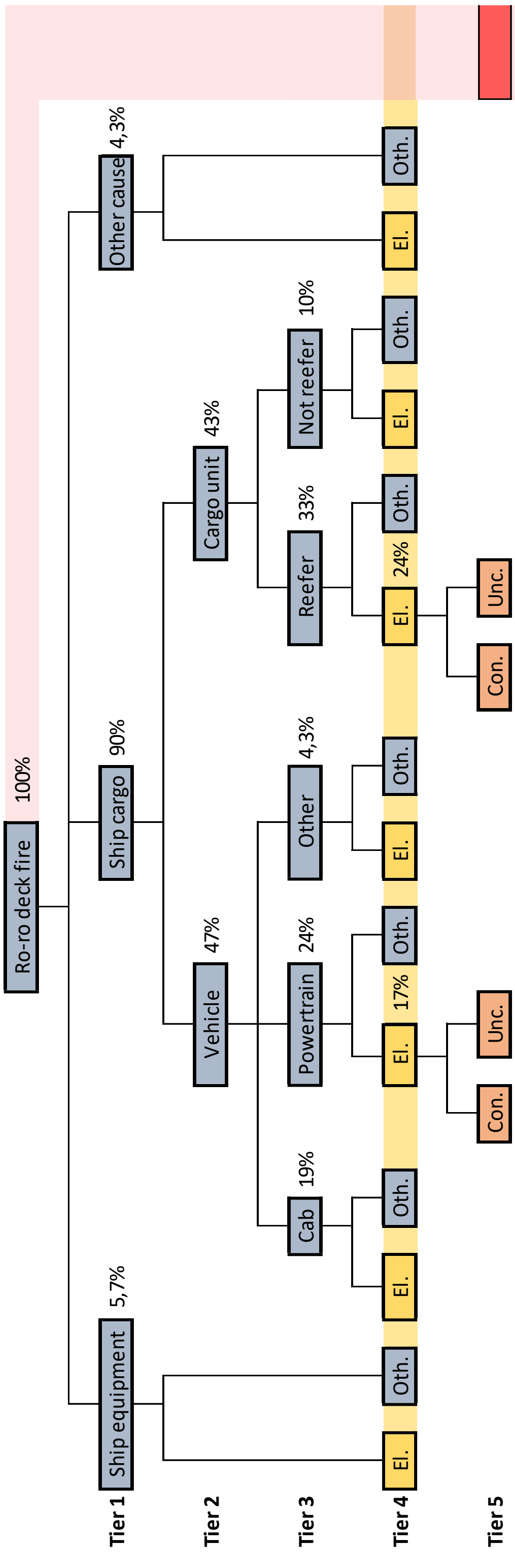
The list with the RCOs, affected nodes, important factors to consider, and the average values of the estimations are presented in Figure 3.4-1. The averaged estimated effects of the RCOs were linked to the risk model for electrical ignition sources on ro-ro deck, as illustrated in Figure 3.4-2. The concluding effects on the probability and frequency of fire and fire with electrical ignition source are presented, respectively, in Table 3.4-1.

	RCMs for quantitat	Description	Affected nodes	Affecting factors (add initials:)	Avg
El 1	**Robust connection boxes**	Earth fault breakers to be installed in combination with increased maintenance of the connection boxes (and if necessary upgrading old) to ensure robustness: IP-class (e.g. IP56/67), individual circuit breakers, individual switches, interlocked switches, and secured cables.	Electrical-Ship equipment	Maintenance is crucial for this RCM to have significant effect. Not covered: faults in other fixed electrical equipment than the connection boxes, electrical motors for hydraulic systems (e.g. earth in windings), faults before connection box/circuit breaker (e.g. electrical fault in switchboard, circuit boards in the control panel, transformer overheating, etc.) (only faults which would give fault on ro-ro deck should be considered in the above). Required by some classification societies but not	50,00%
			Connected-Electrical-Powertrain-Vehicle-Ship cargo	This is mainly about charging batteries on vehicles, faults in cargo could be detected by earth faults monitoring or circuit breakers	40,00%
			Connected-Electrical-Reefer-Cargo unit-Ship cargo		53,33%
El 2	**Only ship cables**	Only allow ship cables and ship adapters.	Connected-Electrical-Powertrain-Vehicle-Ship cargo	decrease the risk of short circuit in cables and adapters, lower risk of overheated cables due to wrong size, lower risk of sparks from damaged cables; the intrinsic fires in loaded obeject remains except at conneciton AND missing one	12,33%
			Connected-Electrical-Reefer-Cargo unit-Ship cargo	decrease the risk of short circuit in cables and adapters, lower risk of overheated cables due to wrong size, lower risk of sparks from damaged	14,00%
El 3	**IR camera**	Portable Thermographic camera, screening during fire rounds, to be used upon suspicion.	Electrical-Ship equipment	Possible to detect hot areas and overheted electrical equipment, Global estimate of effects; can be concealed. Electrical = slow/lasting	4,00%
			Other-Ship equipment	Generally visible for this and all below. Mechanical	3,33%
			Electrical-Cab-Vehicle-Ship cargo		7,67%
			Other-Cab-Vehicle-Ship cargo		7,67%
			Connected-Electrical-Powertrain-Vehicle-Ship cargo	electrical part is covered/shielded	9,33%
			Unonnected-Electrical-Powertrain-Vehicle-Ship cargo	Suspicion is difficult as this vehicle is not easy to re	4,00%
			Other-Powertrain-Vehicle-Ship cargo		4,33%
			Electrical-Other-Vehicle-Ship cargo		5,00%
			Other-Other-Vehicle-Ship cargo		4,33%
			Connected-Electrical-Reefer-Cargo unit-Ship cargo	reefer connection bloc covered/shielded	9,67%
			Unconnected-Electrical-Reefer-Cargo unit-Ship cargo		9,33%
			Other-Reefer-Cargo unit-Ship cargo		6,67%
			Electrical-Not reefer-Cargo unit-Ship cargo	not reefer = less suspicion	5,67%
			Other-Not reefer-Cargo unit-Ship cargo	thermal camera will help to detect overheating car	5,33%
			Electrical-Other cause		2,50%
			Other-Other cause		2,67%
El 4	**Training for awaren**	Training for increased crew awareness (agai	Electrical-Cab-Vehicle-Ship cargo	Increased possibility to detect fires due to awareness, high risk cargo could be avoided, facilitates the crews work with spotting and surveying high risk cargo, better communication	19,00%
			Other-Cab-Vehicle-Ship cargo	more accidental : less possible to prevent	6,00%
			Connected-Electrical-Powertrain-Vehicle-Ship cargo	very specific and easy to check. Also motivating	30,00%
			Unonnected-Electrical-Powertrain-Vehicle-Ship cargo		6,00%
			Other-Powertrain-Vehicle-Ship cargo		3,67%
			Electrical-Other-Vehicle-Ship cargo		6,00%
			Other-Other-Vehicle-Ship cargo		3,67%
			Connected-Electrical-Reefer-Cargo unit-Ship cargo	very specific and easy to check. Also motivating	25,67%
			Unconnected-Electrical-Reefer-Cargo unit-Ship cargo	less suspicion/possible action	9,33%
			Other-Reefer-Cargo unit-Ship cargo	less suspicion/possible action	7,00%
			Electrical-Not reefer-Cargo unit-Ship cargo		7,00%
			Other-Not reefer-Cargo unit-Ship cargo		4,33%
El 5	**Only crew connecti**	Only allow trained crew to connect and disc	Electrical-Ship equipment	Faulty connections avoided, additional screening of cargo, cables handled more carefully, better cable routing, multiple connections on one cable avoided, no disconnection under load, less risk of	20,00%
			Connected-Electrical-Powertrain-Vehicle-Ship cargo		23,33%
			Connected-Electrical-Reefer-Cargo unit-Ship cargo		25,00%
El 6	**Use of cable reeling**	Mandatory installation/use of cable reeling drums (at regular intervals) for power supply of reefers.	Connected-Electrical-Reefer-Cargo unit-Ship cargo	Cables protected when not in use, could be difficult as upgrade, expensive?, surveying of connections inside reel difficult. The benefits of this RCM depends on how often conventional eletric cables are otherwised changed; once every 5 years is likely. Cables deteriorate a lot if cars/trucks drive over them; 1 every 5 years	13,00%

Figure 3.4-1. Quantification of RCOs affecting electrical fire as ignition source on ro-ro deck.

		TOTAL - ALL FIRES			ELECTRICAL FIRES		
	Conventional Design	100,0%	0,0%	5,79E-03	63,5%	0,0%	3,67E-03
	RCOs	Rel. freq.	Rel. freq. red.	Freq. [/s-y]	Rel. freq.	Rel. freq. red.	Freq. [/s-y]
El 1	**Robust connection boxes**	87,3%	12,7%	5,05E-03	50,8%	20,0%	2,94E-03
El 2	**Only ship cables**	97,3%	2,7%	5,63E-03	60,8%	4,2%	3,52E-03
El 3	**IR camera**	93,5%	6,5%	5,41E-03	59,0%	7,0%	3,42E-03
El 4	**Training for awareness**	89,1%	10,9%	5,16E-03	54,3%	14,5%	3,14E-03
El 5	**Only crew connections**	94,2%	5,8%	5,45E-03	57,6%	9,2%	3,34E-03
El 6	**Cable reeling drums**	97,7%	2,3%	5,65E-03	61,2%	3,6%	3,54E-03

Table 3.4-1. Concluding effects of quantified RCOs on the probability and frequency of fires in general and fires with electrical ignition source.



RCMs	El.		Oth.		El.		Oth.		Con.		Unc.		Oth.		El.		Oth.		Con.		Unc.		Oth.		El.		Oth.		El.		Oth.		Rel. freq.
Conventional Design	5,1%		0,6%		13,0%		5,6%		1,5%		15,2%		7,6%		3,0%		1,3%		17,8%		5,9%		9,1%		1,0%		9,0%		0,9%		3,3%		100,0%
The relative REDUCTION is shown in the WHITE fields on the RIGHT of the affected probabilities below																																	
El 1 **Robust connection boxes**	2,6%	50%	0,6%	0%	13,0%	0%	5,6%	0%	0,9%	40%	15,2%	0%	7,6%	0%	3,0%	0%	1,3%	0%	8,3%	53%	5,9%	0%	9,1%	0%	1,0%	0%	9,0%	0%	0,9%	0%	3,3%	0%	87,3%
El 2 **Only ship cables**	5,1%	0%	0,6%	0%	13,0%	0%	5,6%	0%	1,3%	12%	15,2%	0%	7,6%	0%	3,0%	0%	1,3%	0%	15,3%	14%	5,9%	0%	9,1%	0%	1,0%	0%	9,0%	0%	0,9%	0%	3,3%	0%	97,3%
El 3 **IR camera**	4,9%	4%	0,6%	3%	12,0%	8%	5,1%	8%	1,4%	9%	14,6%	4%	7,3%	4%	2,8%	5%	1,3%	4%	16,1%	10%	5,4%	9%	8,5%	7%	0,9%	6%	8,5%	5%	0,9%	3%	3,3%	3%	93,5%
El 4 **Training for awareness**	5,1%	0%	0,6%	0%	10,5%	19%	5,2%	6%	1,1%	30%	14,3%	6%	7,3%	4%	2,8%	6%	1,3%	4%	13,2%	26%	5,4%	9%	8,5%	7%	0,9%	7%	8,6%	4%	0,9%	0%	3,3%	0%	89,1%
El 5 **Only crew connections**	4,1%	20%	0,6%	0%	13,0%	0%	5,6%	0%	1,2%	23%	15,2%	0%	7,6%	0%	3,0%	0%	1,3%	0%	13,3%	25%	5,9%	0%	9,1%	0%	1,0%	0%	9,0%	0%	0,9%	0%	3,3%	0%	94,2%
El 6 **Cable reeling drums**	5,1%	0%	0,6%	0%	13,0%	0%	5,6%	0%	1,5%	0%	15,2%	0%	7,6%	0%	3,0%	0%	1,3%	0%	15,5%	13%	5,9%	0%	9,1%	0%	1,0%	0%	9,0%	0%	0,9%	0%	3,3%	0%	97,7%

Figure 3.4-2. Fault tree risk model for electrical fire as ignition source with estimated effects of RCOs.

	RCO	El 1	El 2	El 3	El 4	El 5	El 6
Robust connection boxes	El 1		Strong	Weak	Weak	Strong	Strong
Only ship cables	El 2	Strong		Weak	Weak	Strong	Strong
IR camera	El 3	Weak	Weak		Strong	No	Weak
Training for awareness	El 4	Weak	Weak	Strong		Weak	Weak
Only crew connections	El 5	Weak	Weak	Strong	Strong		Weak
Use of cable reeling drums	El 6	Strong	Strong	Weak	No	Weak	

Table 3.4-2. Interdependencies or RCMs effecting the electrical risk model

The effects of RCOs were estimated individually i.e. with the assumption that none of the other RCOs were implemented. In some cases there could be synergy effects of the RCOs and in some cases addition of a second RCO directing similar hazards will not be as effective. Therefore it is important to consider interdependencies between the RCOs if two or more RCOs are considered. A estimation of the interdependencies can be seen in table 3.4-2.

3.5. Cost Benefit Assessment Electrical fire as ignition risk

3.5.1. Net Present Value

Net present values have been calculated based on the assumptions presented in the section Cost benefit assessment. Results of these calculations are shown in Table 3.5-1.

		New building			Existing ship		
RCO #	Description	Initial cost	Periodic costs	NPV	Initial	Periodic costs	NPV
El 1	Robust connection boxes	22 400 €	500 €	30 401 €	28 000 €	500 €	33 419 €
El 2	Only ship cables	16 000 €	3 200 €	67 208 €	16 000 €	3 200 €	50 681 €
El 3	IR camera	2 000 €	1 000 €	18 003 €	2 000 €	1 000 €	12 838 €
El 4	Training for awareness	4 000 €	- €	4 000 €	4 000 €	- €	4 000 €
El 5	Only crew connections	2 000 €	- €	2 000 €	2 000 €	- €	2 000 €
El 6	Cable reeling drums	240 000 €	16 000 €	496 041 €	240 000 €	16 000 €	413 404 €

Table 3.5-1: Lifetime implementation costs for the *electrical* RCO in Net Present Value (NPV) in Euros

Periodic costs for IR camera consider the replacement of 1 camera every year (lifetime of the camera: 2 years).
Details of the cost have been provided in section Costs of RCOs electrical fire risk.
All the costs provided in that section are marginal costs of the risk control options.

3.5.2. Effectiveness of Risk Control Options

Figure 3.5-1, Figure 3.5-2 and Figure 3.5-3 provide the PLL, PLC, and PLS, respectively, for the reference ship without RCOs and after the implementation of the individual RCOs.

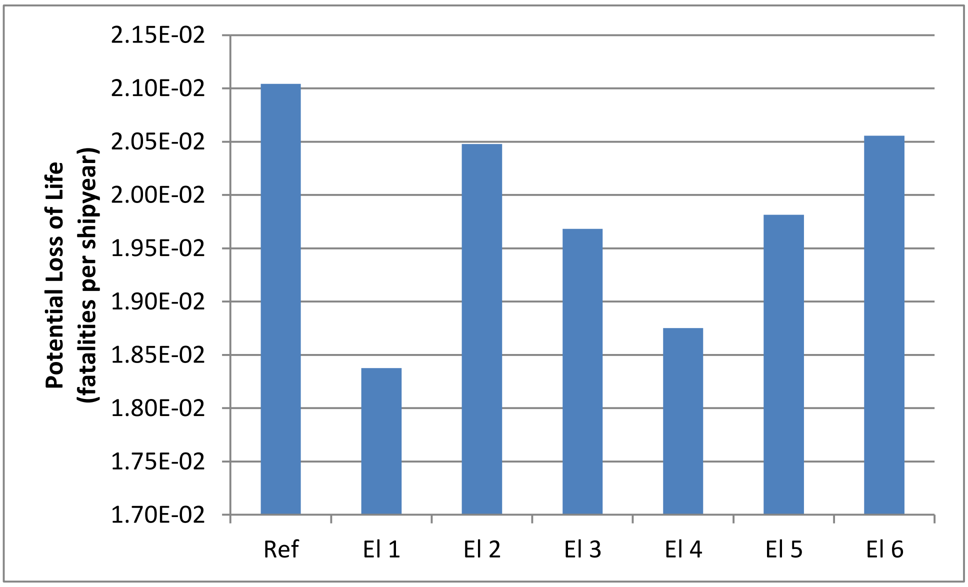


Figure 3.5-1: Potential loss of life for the generic vessel and after (individual) implementation of the RCOs (Electrical fires)

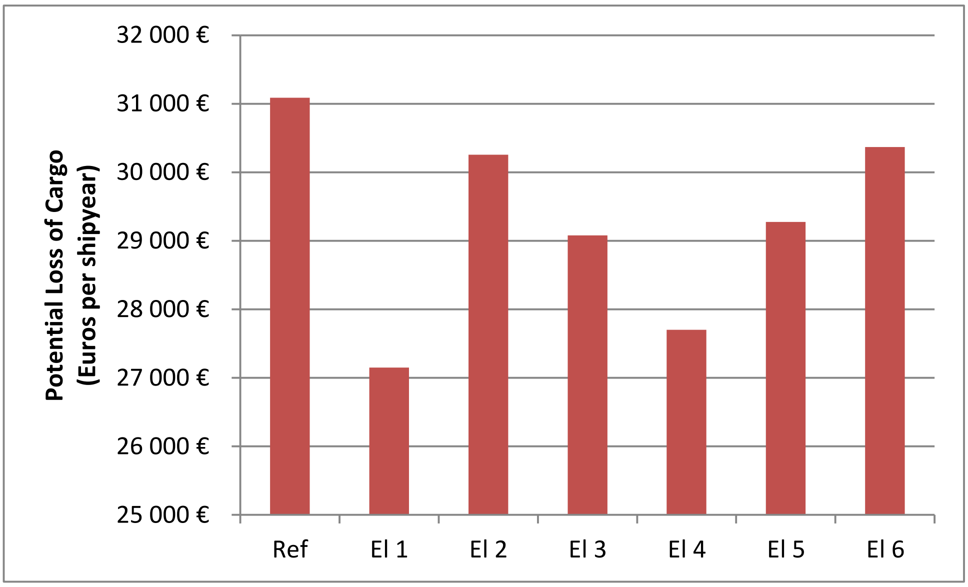


Figure 3.5-2: Potential loss of cargo for the generic vessel and after (individual) implementation of the RCOs (Electrical fires)

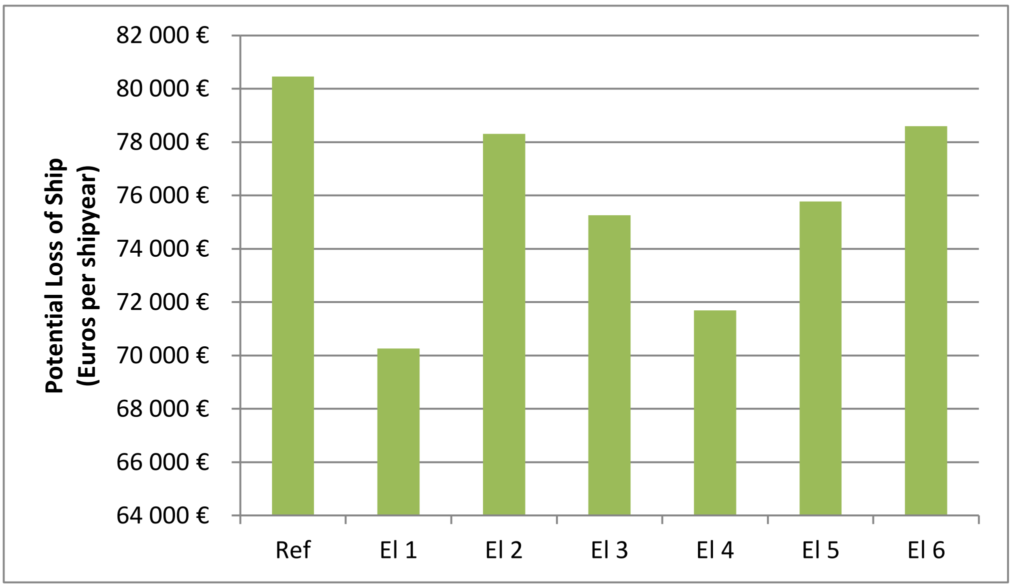


Figure 3.5-3: Potential loss of ship for the generic vessel and after implementation of the (individual) RCOs (Electrical fires)

Summary of the risk reduction efficiency is provided in Figure 3.5-4 to allow easier comparison of the efficiency of the RCOs about loss of life, loss of cargo and loss of ship. The percentage of risk reduction is the same for PLL, PLC and PLS, since the RCOs have been applied before the initiating event. Therefore, only the initial accident frequency in the event tree has been impacted (hence impacting the outcome with the same percentage everywhere).

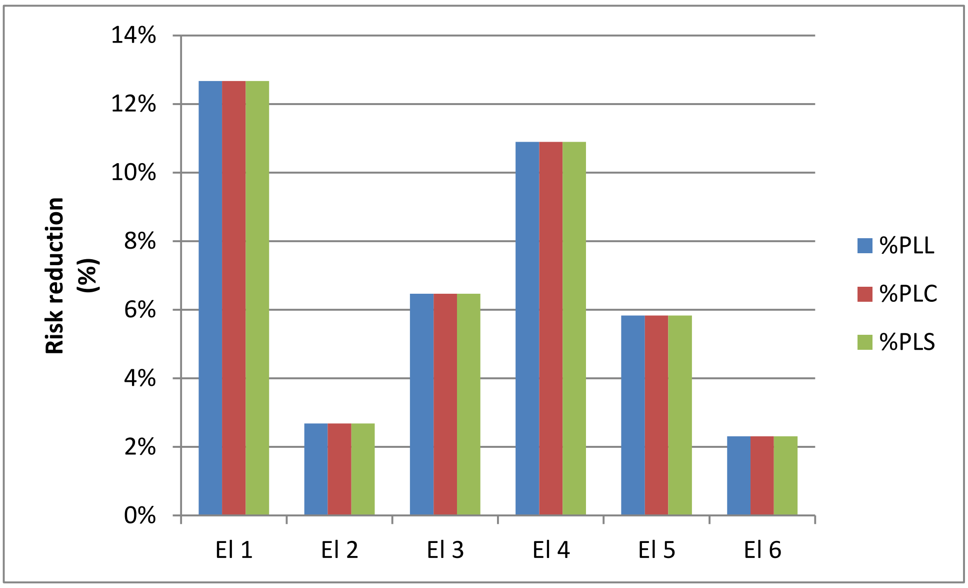


Figure 3.5-4: Risk reduction (Life, Cargo, Ship) in percentage after the (individual) implementation of the RCOs (Electrical fires)

The highest risk reduction is achieved by the RCO *El1: Robust connection boxes*. This can be explained by the high efficiency of that risk control options (frequency reduction: 53%) on the connected reefer fires, which is the biggest contribution (17.8%) to the total fire ignition risk.

The second highest is the training for awareness (*El4*). This is due to the high-risk reduction (26%) on the connected reefer fires as well as over all the other ship cargo fires.
The RCOs *El2* and *El6* have the smallest impact in terms of risk reduction. Although they also focus on connected reefer fires, the efficiency of these RCOs have been estimated to around 15%.

3.5.3. GCAF

Having discussed the efficiency of the individual RCOs, their cost efficiency is assessed in Table 3.5-2 and Table 3.5-3.
Table 3.5-2 and Table 3.5-3 summarize the inputs value for the calculation of the GCAF (as defined in the section Review of risk acceptance criteria), which are the Delta Risk (difference of the PLL after and before the implementation of the a RCO times the expected lifetime of the vessel) and the Delta Cost in Net Present values as listed in Table 3.5-1. These tables also present the result of the cost benefit analysis and assessment by providing the GCAF.
The GCAF Factor is the ratio between the GCAF as calculated and the CAF criterion of $7.45M (6 913 600 €[38]) that has been selected in the review of the Risk Acceptance Criteria (see section Value for Preventing Fatality calculation) and indicates a cost efficiency with values less or equal to 1.00.
This table also provides a ranking of the RCOs as required in the FSA Guidelines (IMO, 2015).
Note that the effect of cumulative RCOs has not been assessed quantitatively and should not be performed by addition of contribution of individual RCO (see interdependency matrixes in Section Quantification of RCO effects on ro-ro deck fire ignition).

New buildings		Delta risk	Delta Cost	GCAF			
RCO #	Description	(Averted) fat.	(NPV)	GCAF	GCAF Factor	Cost effective	Rank
El 1	Robust connection boxes	8.80E-02	30 401 €	345 526 €	0.05	Yes	3
El 2	Only ship cables	1.86E-02	67 208 €	3 612 917 €	0.52	Yes	5
El 3	IR camera	4.49E-02	18 003 €	401 087 €	0.06	Yes	4
El 4	Training for awareness	7.57E-02	4 000 €	52 868 €	0.01	Yes	2
El 5	Only crew connections	4.05E-02	2 000 €	49 384 €	0.01	Yes	1
El 6	Cable reeling drums	1.61E-02	496 041 €	30 874 473 €	4.47	No	6

Table 3.5-2: GCAF for *Electrical Fire* RCOs for new buildings

For new buildings, the RCO ranked first is the *El5: Only crew connections which has the same GCAF factor as El4: Training for awareness*, with a GCAF factor close to 0 €.
The third is *El1*, with a GCAF of 345 526€. *El1* is the RCO with the highest number of averted fatalities (8.80E-02 averted fatalities) over the lifetime of the ship.
Amongst the RCO investigated, only one RCO has not been found cost efficient: *EL6: Cable reeling drums*.

[38] 1$ = 0.928€ (Exchange rate in November 2016)

Existing ships		Delta risk	Delta Cost	GCAF			
RCO #	Description	(Averted) fat.	(NPV)	GCAF	GCAF Factor	Cost effective	Rank
El 1	Robust connection boxes	4.27E-02	33 419 €	783 384 €	0.11	Yes	4
El 2	Only ship cables	9.02E-03	50 681 €	5 619 192 €	0.81	Yes	5
El 3	IR camera	2.18E-02	12 838 €	589 913 €	0.09	Yes	3
El 4	Training for awareness	3.67E-02	4 000 €	109 041 €	0.02	Yes	2
El 5	Only crew connections	1.96E-02	2 000 €	101 855 €	0.01	Yes	1
El 6	Cable reeling drums	7.79E-03	413 404 €	53 070 249 €	7.68	No	6

Table 3.5-3: GCAF for *Electrical Fire* RCOs for existing ships

Although most of the GCAF Factors of the RCOs for existing ships are higher than for the newbuildings, 4 of them still remain very low.
Conclusion regarding the cost efficiency of the El*6: Cable reeling drums* remains the same for existing ships.

3.5.4. NCAF

Table 3.5-4 and Table 3.5-5 present the NCAF related to Electrical fires RCOs for newbuildings and existing ships.
Consideration of the economic benefits does not change the conclusion regarding the cost efficiency status of the RCOs (El 6 remains above the cost effectiveness acceptance criterion).
However, it should be noted that for both Newbuildings and existing ships negative NCAF have been calculated for 4 of the investigated RCOs. As indicated in the FSA Guidelines, this means that the benefits in monetary units are higher than the costs associated with the RCO.
The Guidelines further recommend always considering high negative NCAFs in connection with the associated risk reduction capability since this may be due to either:

- benefits much higher than the costs associated with the RCO;
- RCO with a low risk reduction potential.

New buildings		Delta risk	Delta Cost	Delta Benefits (Ship & cargo)	NCAF		
RCO #	Description	(Averted) fat.	(NPV)	(NPV)	NCAF	NCAF ratio	Cost effective
El 1	Robust connection boxes	8.80E-02	30 401 €	226 143 €	- 2 224 702 €	-0.32	Yes
El 2	Only ship cables	1.86E-02	67 208 €	47 812 €	1 042 688 €	0.15	Yes
El 3	IR camera	4.49E-02	18 003 €	115 363 €	- 2 169 141 €	-0.31	Yes
El 4	Training for awareness	7.57E-02	4 000 €	194 463 €	- 2 517 360 €	-0.36	Yes
El 5	Only crew connections	4.05E-02	2 000 €	104 091 €	- 2 520 844 €	-0.36	Yes
El 6	Cable reeling drums	1.61E-02	496 041 €	41 294 €	28 304 245 €	4.09	No

Table 3.5-4: NCAF for Electrical Fire RCOs for newbuildings

Existing ships		Delta risk	Delta Cost	Delta Benefits (Ship & cargo)	NCAF		
RCO #	Description	(Averted) fat.	(NPV)	(NPV)	NCAF	NCAF ratio	Cost effective
El 1	Robust connection boxes	4.27E-02	33 419 €	153 156 €	- 2 806 797 €	-0.41	Yes
El 2	Only ship cables	9.02E-03	50 681 €	32 381 €	2 029 011 €	0.29	Yes
El 3	IR camera	2.18E-02	12 838 €	78 130 €	- 3 000 269 €	-0.43	Yes
El 4	Training for awareness	3.67E-02	4 000 €	131 701 €	- 3 481 141 €	-0.50	Yes
El 5	Only crew connections	1.96E-02	2 000 €	70 496 €	- 3 488 326 €	-0.50	Yes
El 6	Cable reeling drums	7.79E-03	413 404 €	27 967 €	49 480 068 €	7.16	No

Table 3.5-5: NCAF for Electrical Fire RCOs for existing ships

4. Fire suppression failure (second part)

4.1. Risk model for fire suppression failure

4.1.1. Development of extinction/suppression failure model

A fault tree was developed to model fire suppression failure, illustrated in Figure 4.1-1. A drencher system was used as starting point for the model since it was requested by EMSA to focus on this type of extinguishing system. Other extinguishing systems may be analysed in a similar way but the current risk model must be adapted to such system. It was conceptually divided in the three main parts which can fail, following the way of the water: *Supply fail*, *Distribution failure*, and *Failure in removal of water*. These parts were together categorized as *Technical failure*[39], which implies that there is no discharge from the system, or at least significantly lower discharge than designed. It can also be the case that the system discharges water as designed but that this discharge is insufficient, due to the system being undersized or due to the fire being larger than the design fire. A large pool fire of flammable liquid fuel could for example give rise to such a fire. This fault was referred to as *Design incapacity*, which together with *Technical failure* can cause *Fixed system fail*. Extinguishment or suppression is also possible by manual means, both in a potential *First response* by a runner or adjacent crew member and in an organized ingress by the *Firefighting group*. Manual firefighting was divided in these branches by an AND gate in the risk model, to illustrate that both activities need to fail for manual extinguishment to fail. For *Extinguishment/suppression failure* to occur, both *Manual extinguishment fail* and *Fixed system fail* were considered necessary.

[39]Although the terminology *Technical Failure* is used, it should be noted that human errors have been taken into account.

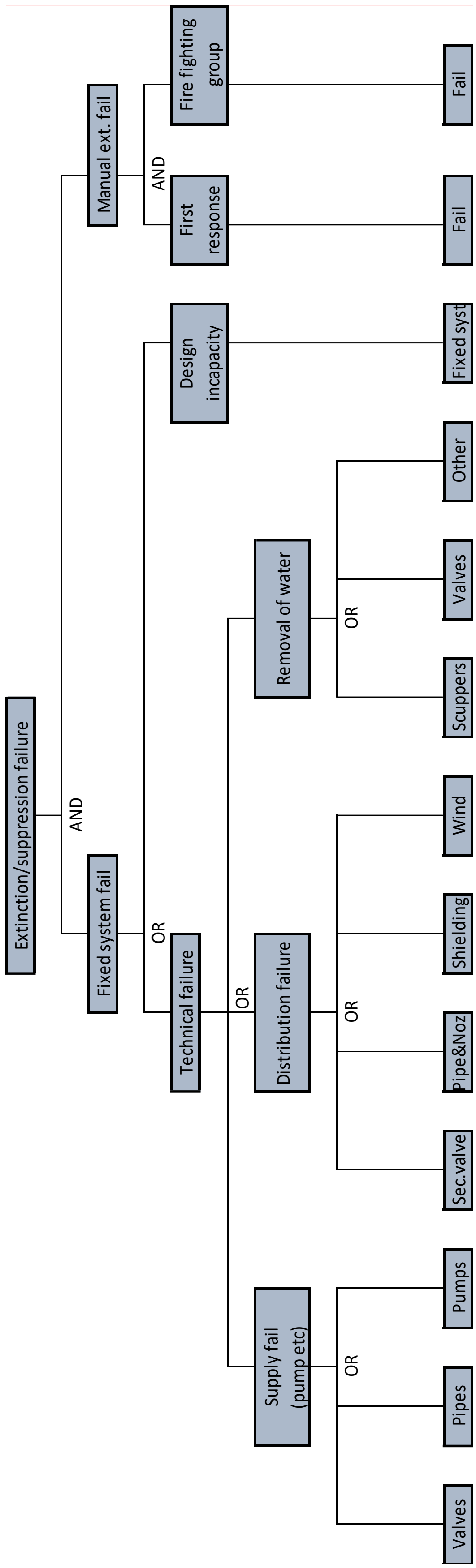


Figure 4.1-1 Fault tree risk model for extinction/suppression of fire on ro-ro deck.

Each of the nodes *Supply fail*, *Distribution failure*, and *Failure in removal of water* was further divided in sub-categories. On the supply side the system was divided in *Valves* (referring to main inlet valves), *Pipes* (including filters), and *Pumps* (including power supply, mechanical parts, redundancy, and human operation). The distribution part was divided in *Sectioning valves* (mechanical parts and human operation), *Pipes & Nozzles* (including clogging), *Shielding* (e.g. obstruction of water spray by truck roof situated right below nozzle), and *Wind*. Removal of water was divided in *Scuppers* (clogging by debris), *Valves* (referring to outlet valves), and *Other* (including potential pumps necessary under waterline as well as effects of heel and list).

In accordance with the Main model, division was made between open and closed ro-ro deck, as well as for early and late decision to initiate means for extinction/suppression. Wind effects are for example not relevant for closed ro-ro deck and design incapacity is significantly less likely in case of early decision making.

4.1.2. Input to risk model for extinction/suppression failure

To populate the extinction/suppression fault tree, estimates were initially made for the bottom events based on available failure frequency statistics and expert judgements. These estimations were then synchronized with statistical data, as described further below. The initial estimations which are shown below were made with assumption of an open ro-ro deck, and early decision making. The estimates and further descriptions of the failures and considered factors are provided below:

Bottom inlet valve for water supply: 1%

Valve is closed when it should be open or it cannot be opened, at least not until it is too late.

- Oreda handbook states $26*10^{-6}$ h for valve general.
- This valve is usually open unless undergoing repair or maintenance. It could also be closed by mistake.
- Damage will likely not cause the valve to close.
- Should be inspected with regular intervals.
- Operator in drencher room has access to pressure gauge on incoming water, which should make it possible to identify faulty valve setting (or pump failure).

Pipes in water supply: 0.1%

Failure in pipes from sea water inlet, through filter to pump and from pump to drencher station.

- Clogging in pipes, filters etc.
- Breakage of pipes/flanges due to corrosion, damaged pipe
- Oreda handbook states $2.93*10^{-6}$ h for pipe and $3.90*10^{-6}$ h for strainer.
- Sprinkler sections required to be tested 1 time in 5 years but inlet pipes are often tested more often.
- No known problem in analysed fire events.

Pump: 5%

Failure of pump, e.g. in power supply, mechanical failure or operational failure (human error).

- Two cases in the statistics, one where the pump was in manual mode instead of automatic and did not start when start button was pressed, and one case where

the pump stopped due to power supply failure due to smoke in air inlet of main engine.
- Emergency generator does not feed the drencher pump, since fire on car deck has traditionally been assumed to not affect the power supply located in the engine room.
- Oreda handbook states 56/10E6 h for sea water centrifugal pumps.
- Redundancy by connecting the fire main to the drencher system is required.
- Air in pump could cause failure, or at least delay in start.
- Operator in drencher room has access to pressure gauge on incoming water, which should make it possible to identify faulty valve setting (or pump failure).

Section Valves in drencher station: 5%

Section valves at drencher station malfunction or are not operated correctly (wrong valve opened, too many opened…). It is assumed that correct information has been given to operator, but it can both be wrongly interpreted and wrongly executed (except that the valve fails).

- Valves are normally closed
- In one severe event amongst the analysed the wrong valve was opened.
- Retrofitted/redesigned ships could have complex systems with non-logic numbering etc.
- Oreda handbook states (17/10E6 h for Solenoid valve and) 26/10E6 h for valves in general.

Pipes & nozzles in drencher system: 5%

Piping failure in piping from drencher station to nozzles, e.g. clogging.

- Oreda handbook states 2.93/10E6 h for pipe.
- Mechanical damage.
- Piping taken apart and reassembled correctly.
- Corrosion, causing clogging or weakening of pipes.
- Clogging of nozzles (or pipes) due to e.g. mud in water.
- Nozzles damaged from vehicle collisions (missing, damaged).
- Not unusual that nozzles are found clogged during inspections.

Shielding of water distribution: 1%

Insufficient distribution of water.

- Shielding by cargo (high trucks), tests have shown reduced sprinkler efficiency.
- It is difficult to verify if this has played a substantial role in drencher failure in real fires.
- Nozzles shielded due to paint work, covered due to functionality test.

Wind effects (open deck): 0.4%

Insufficient distribution of water due to shielding by wind. The effect on the fire growth rate by the wind is considered in the design incapacity node. It should further be noted that the effect of the wind to the detection system is in this model only considered when determining early or late decision since detection is included in the decision node.

- Effects by wind.
- Historical events.

Scuppers for removal of water: 2%

Scuppers failing to remove water.

- Clogging from debris.
- Clogging from ice.
- Fire debris and tarp could still block scuppers with strainers.
- Insufficient design capacity of scuppers not likely due to new regulations.
- Oreda handbook states 3.90/10E6 for strainer.

Scupper valves for removal of drencher water: 0.5%
Scupper valves closed or clogged.
- Scupper valves should have a positive means of closure (difficult to open if pressure from outside larger than pressure from inside).
- Water could in some cases be drained to tanks before it is pumped off the ship.
- Should be opened at sea and opening/closing should be recorded in the logbook.
- Could be closed when docked or during rough sea.
- Often identified faulty at inspections.

Other failure in removal of water: 0.2%
Failure in removal of water, other than in scuppers and valves.
- Design failure.
- Heel and trim.

Insufficient fire extinguishing system capacity: 9%
Fully functional drencher system not capable of suppressing the fire, e.g. too large fire, low flashpoint (or other fuel) fuel impossibility to extinguish.
- Dangerous goods and vehicle fuels on car deck could cause fires that grow faster and larger than the design fire in the fire tests.
- IMPRO tests showed that increased capacity (compared to Res. A123(V)) is generally necessary for effective extinguishment, most drenchers are design according to Res. A123(V).
- A123(V) has been replaced and increased water amount is required for drenchers. However, for alternative systems improved drencher capacity is not required.

4.1.3. Input data analysis for extinction/suppression failure

The estimations made above were compared with statistical data for FIRESAFE compliant ships available from MARINFO and IHS between 2002 and 2015, which is the sample of 32 ro-ro deck ship fire incidents that was selected for the estimation of the initial accident frequency. This dataset was used as input for the extinction/suppression failure model since the same dataset was used to calculate the frequency of a ro-ro deck fire, which is important to maintain consistency and therefore make a correct estimation of the failure probability of extinction and suppression[40].

Of the 32 fires in the sample, 28 were possible to organize under the categories early decision (19 incidents) and late decision (9 incidents), as presented in table 4.1-1[41]. One fire categorized under *Early decision* was unclear with regards to whether extinguishment and suppression had been successful and was therefore excluded from the further

[40] The use of any other databases might bring inconsistency as it is expected that non-serious incidents (mainly Early Decision/Successful extinguishment) are over represented in these databases compared to the FIRESAFE sample.
[41] Further details on the methodology for the categorization of Early/Late Decision is provided in the section for Main risk model explanations.

probability estimations. Out of the 18 remaining incidents with early decision, one fire was successful in providing extinction/suppression, but it is unknown by what means. Manual means were used to successfully extinguish or suppress 8 fires. In the remaining fires, manual means were thus considered failed. In these 8 cases, the fixed extinguishing system was activated and successful to extinguish or suppress the fire in 6 cases and in 2 cases this failed. In case of late decision, manual extinguishment was considered impossible. The fixed extinguishing system was successful in 2 out of 9 such incidents.

	# Early decision	*% Early decision*	*# Late decision*	*% Late decision*
Manual ff success	8	51%	-	-
(Man ff fail)	(8)	49%	-	-
Fixed system success	6	76%	2	22%
Fixed system fail	2	24%	7	78%
Unknown success	1	incl. above	0	-
Total incidents	**17**		**9**	
Extinction/suppression failure	2	11.8%	2	22.2%
Extinction/suppression success	15	88.2%	7	77.8%

Table 4.1-1. Summary of FIRESAFE sample data

For the "Late decision" scenarios the probability estimations are quite straight forward, resulting in a failure probability of 78 %. However, in order to attain correct probability values for the "Early decision" scenarios it is necessary to also consider the successful extinction or suppression by unknown means. Without this scenario (for 16 incidents) the probability of successful manual firefighting would have been 50 % and in case manual extinguishment fails, the probability of fixed system success would have been 75 %. This proportion (2:3) first needs to be added to the unknown success scenario to calculate the probability of manual firefighting failure based on the 17 incidents (49 %). The remaining probability and the proportion 2:3 must then be considered when calculating the probability of fixed system failure. The results of this exercise are presented in Table 4.1.1.

Out of the seven incidents in which the fixed system failed in case of late decision, four were quite well defined. These could be sorted as:

- 1 supply fail (power failure to pump)
- 1 distribution fail (sectioning valve)
- 0.5 removal fail (0.5 scuppers clogged by debris AND 0.5 design incapacity of system); and
- 1.5 design incapacity.

Hence, the failure causes are distributed over all the different main branches, but the statistical dataset is too small to make sufficient estimations at a more detailed level (than failure of the system). The previously presented estimations of failure probabilities of the different bottom events in case of early decision and open deck were therefore kept as input to the extinction/suppression failure model. However, the figures were adjusted by a factor to synchronize with the derived probabilities of extinction/suppression failure. In case of early decision, for which the initial estimates were made, the probability of extinction/suppression failure was derived to 11.8 % (2 out of 17). The previously estimated figures were therefore adjusted by a factor of 1.13 to attain this failure probability, after inserting a probability for *Manual extinguishment failure* of 49 % (as derived above). This probability was equally divided in *First response* and *Firefighting group*, simply to illustrate that both activities need to fail. Manual extinguishment was nevertheless not included in the scope of the project and was therefore not further investigated. For late decision, the probability of manual extinguishment was set to zero and failure of suppression was derived to 78 % (7 out of 9). The simple assumption was applied that all failure probabilities can be increased proportionally to attain this probability. This was reached when adjusting the previous bottom event estimations by a factor of 4.48. The relation between technical system failure and design incapacity then became 63 % to 40 %, instead of the 63 % to 37.5 % indicated by the detailed four (of seven) cases listed above. The probability of design incapacity in case of early decision was set to 10 % of this value (i.e. 4%) since it is still possible in case of early decision to have a system with insufficient capacity or a very fast fire growth rate, making the system insufficient.

The resulting probabilities for the early and late decision, divided on open and closed deck respectively, are presented in Figure 4.1-2 and Figure 4.1-3.

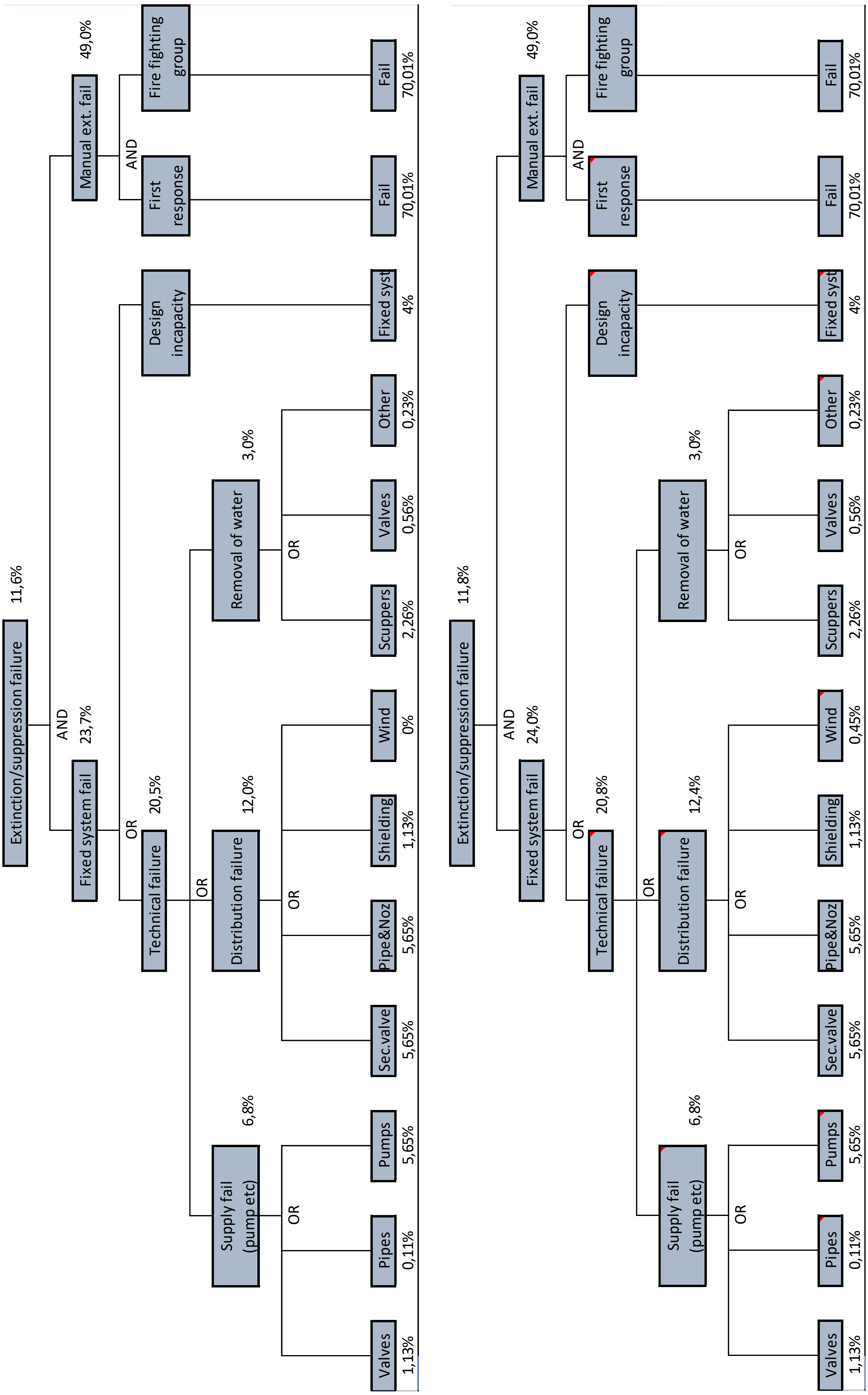


Figure 4.1-2. Fault trees for extinction/suppression failure in case of early decision of extinguishment.

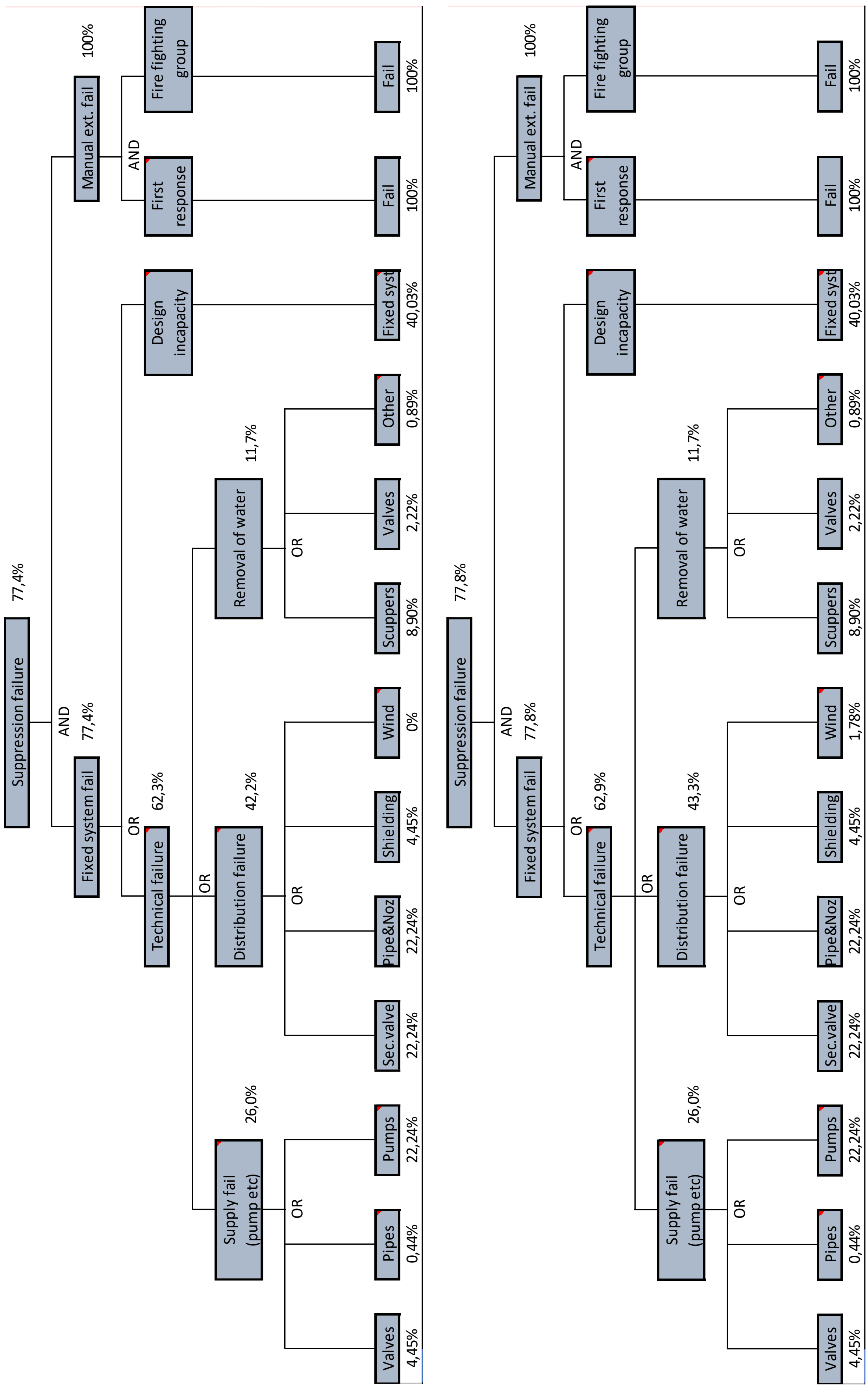


Figure 4.1-3. Fault trees for suppression failure in case of late decision of extinguishment.

The estimations of extinction/suppression failure made above were compared with incidents reported in four different datasets:

- **'FSI 21/5'**: 70 accidents - data from FSI 21/5 only, including FIRESAFE and Non-FIRESAFE compliant ships from 1994 to 2011, in order to enhance transparency and allow repeatability of the categorisation;
- **'FIRESAFE'**: 50 accidents - data from MARINFO, EMCIP, and IHS between 2002 and 2015, all compliant with FIRESAFE criteria, as well as non-anonymized FIRESAFE compliant FSI 21/5 data, in order to provide a view on the picture of the situation based on all available statistics on the FIRESAFE fleet; and
- **'All data'**: 140 accidents - data from all available sources, including FIRESAFE and Non-FIRESAFE compliant ships from 1994 to 2016 (also including accidents in above datasets), in order to show the picture of all available data.
- **'FIRESAFE (sample)'**: 32 accidents - data from MARINFO and IHS between 2002 and 2015[42], which is the sample that has been used as a basis in the justification of the Main risk model and above.

The comparison is presented in the figures below. Difference in favour of Early Decision, Successful suppression or extinguishment, and containment in the FSI 21/5, All data, and FIRESAFE datasets come from the fact that these datasets include much more Marine incidents and Less Serious Accidents than in the FIRESAFE sample. Nonetheless, some trends can be detected.

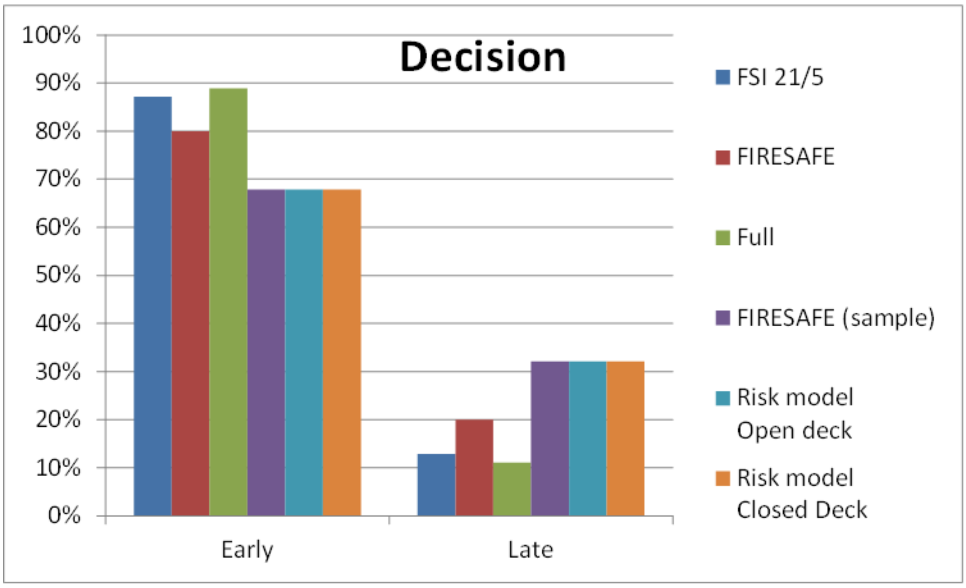


Figure 4.1-4 Comparison of datasets

[42] Rationale for the selection of this sample is provided in the SectionCasualty data analysis.

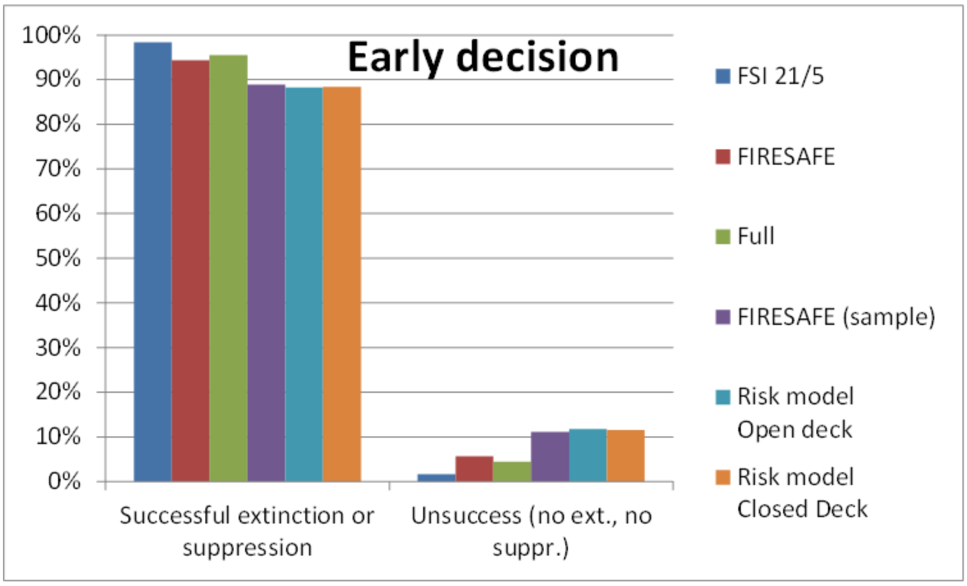


Figure 4.1-5 Comparison of datasets

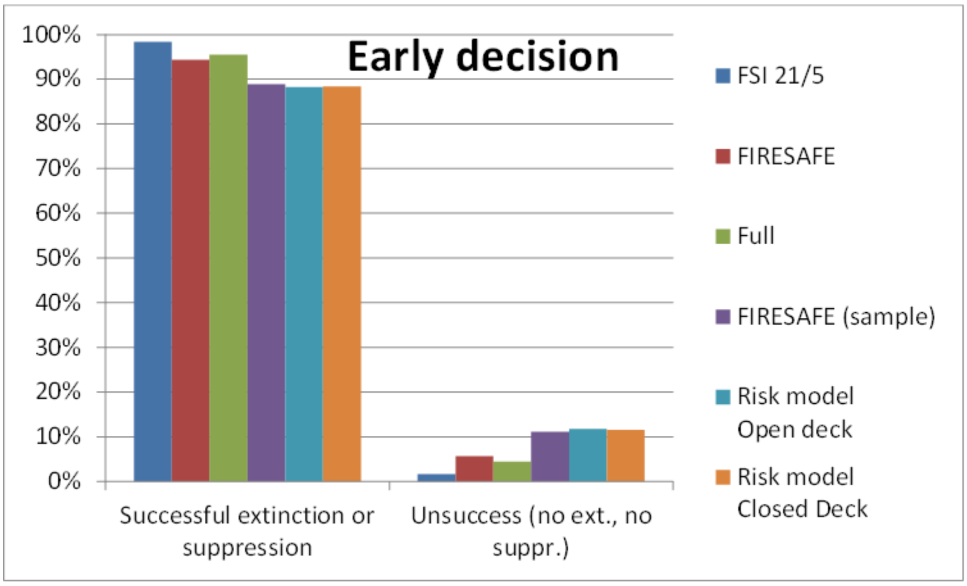


Figure 4.1-6 Comparison of datasets

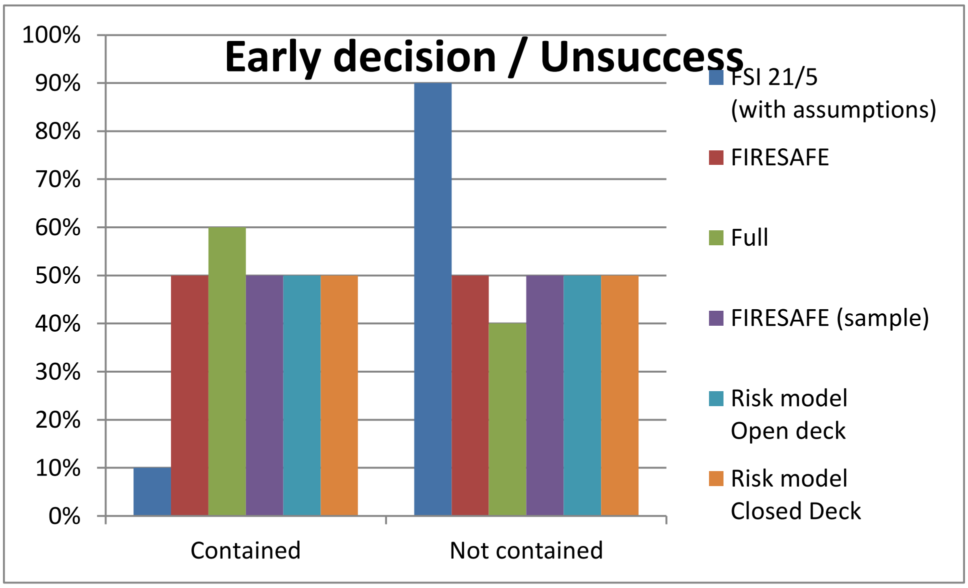


Figure 4.1-7 Comparison of datasets

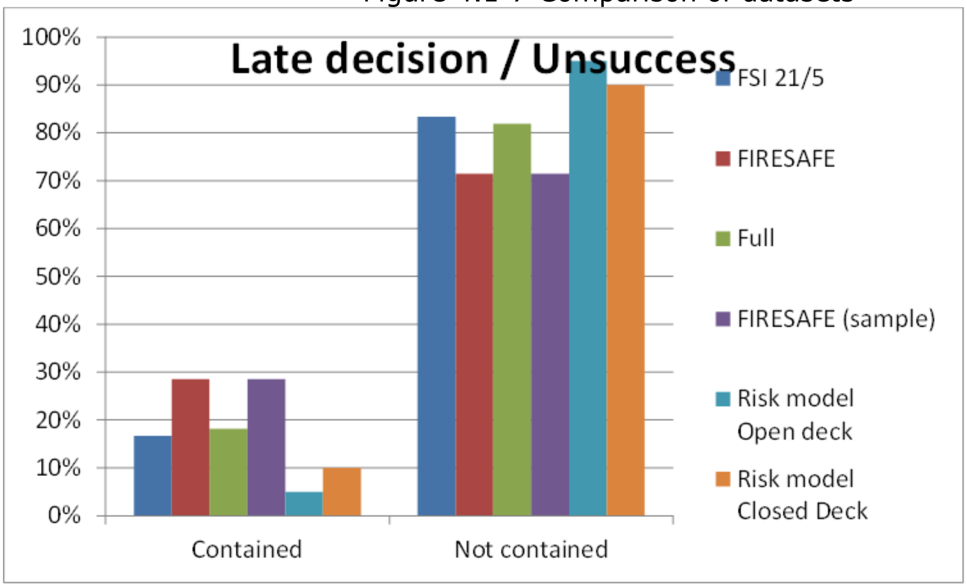


Figure 4.1-8 Comparison of datasets

4.2. Develop RCMs and RCOs

A large number of risk control measures have been discussed within the project. Individual risk control measures could be combined into risk control options RCO. This means that the RCO that are analysed quantitatively consists of some different proposed RCM. After a selection process as described in chapter 2, six RCO were chosen to be analysed in the risk model. These six RCO are described in 4.2.1 to 4.2.6.

In the selection process the probable benefits, probable risk reduction, estimated costs and the practicability of the proposal were assessed qualitatively. The proposals that were not chosen are listed in Annex 2. It should be noted that the annex contains proposals that are good and could be further evaluated even though they were not chosen to be included in the detailed study. It is of course possible to use the developed risk model and analyse these in the future. Some of the RCOs that were not selected for quantitative analysis but still are very interesting to be further analysed are described in 4.2.7 to 4.2.12.

4.2.1. Remote control RCO Su 1

One of the most important factors to get successful fire suppression is quick activation of the drencher system. Quick activation is also dependent on that the correct drencher section is activated. A system that could be released directly by a designated person could facilitate this. The system should be remote controlled from the bridge or the ECR or the safety centre depending on the organization aboard the specific ship. In the case that the officer in charge gets a quick confirmation about the location of a fire he/she could activate the correct drencher section "immediately".

Remote control will also take away the risk of communication failure between the officer in charge and the crew at the drencher station. Another advantage is the possibility to release the drencher if the drencher station becomes inaccessible. It will also be quicker to switch between different sections to do a more tactical firefighting operation.

Drawbacks are that it becomes a more complex system which means increased risk of technical malfunction. During discussions in the project team and based on present procedures onboard ships it was decided to assume that a runner is sent to the drencher station upon fire alarm even if remote control is installed. This is an important assumption and reflected in the evaluation of the RCO.

Risk control option 2 Su 2

Risk control option 2 (Su 2) was removed during the analyses. In order to avoid problem with the numbering and the results of the other RCOs they have not been renumbered.

4.2.2. Rolling shutters RCO Su 3

On ro-ro-ships there are three types of ro-ro-spaces: closed, open and weather decks. The open ro-ro-spaces were developed to adapt to the demand of different cargos. The idea is to have a larger amount of deck space available for cargo requiring large ventilation such as dangerous goods and live animals.

However, the ventilation openings in these spaces will cause problems in a fire, as discussed in section 1.2. If the openings in an open ro-ro-space are closed with e.g. rolling shutters in the case of a fire, the fire will not be able to grow as much. The fire will instead develop similarly as a fire in a closed space. Factors that are affected are supply of air and the negative effect of the wind on the fire growth. The wind could also affect the drencher systems ability to put out a fire. Restricting wind and air supply will increase the probability of a successful extinction or suppression.

It is not only the openings in the side of the ship that need to be closed, also the large opening in the aft (and/or front) must be closed. This may have a negative impact on the cargo carrying capacity of the ship. The fire integrity of the shutters has been discussed in the project. Since the main focus is the efficiency of the drencher system it is not necessary to have full A-60 integrity. Instead two options have been look into, either A-0 rated heavy shutters or flexible smoke and fire curtains. There are several alternatives of fire curtains on the market for use in buildings which fulfil 60 or 120 minutes fire rating (which differ from IMO ones, but could be sensible here). It is also assumed that the shutters are remotely controlled.

Closing of the openings in an open ro-ro-space will have other positive effects, such as restricting the possible spread of smoke and fire. This will affect the containment part of the Main model since the deck should no longer be considered as open but as closed (see figure 2.8-3). The probability of treating the open deck as a closed deck was estimated by SP, BV and Stena based on the reliability and effectiveness of such as system in case of a fire. This likelihood was estimated to 70%. Detection will not be affected since the openings will not be closed until after a fire alarm.

4.2.3. Efficient activation routines RCO Su 4

When looking at the expected fire scenarios in ro-ro-spaces it is clear that the most important factor is to start fighting the fire as quickly as possible. If it is done quickly enough the fire will not be larger than what could be put out manually by a first response person or team. If the fire continues to grow the drencher system needs to be activated, and the possibility of that system to extinguish or suppress the fire is also very dependent on a quick activation.

This RCO is about improved and more efficient routines for activation of the drencher system. The idea is that a quick activation is possible (with the presently installed systems) if the crew is well educated, well trained and has a thorough understanding and knowledge about the drencher system. The understanding of possible fire development on ro-ro-spaces shall be increased.

This could be achieved with realistic training on the use of the fixed fire extinguishing system in order to achieve company defined goals for release times (e.g. 3 minutes from alarm to water on deck). Drills should be performed frequently in a realistic manner, preferably simulating failure of key components.

Simple and clear communication procedures shall be developed to e.g. decrease the risk of opening wrong drencher section. Improved crew familiarization and training will increase the probability that the crew discovers possible faults even before a real fire starts. The possibility to handle and quickly solve unexpected problems during a fire will also increase.

These requirements are in a general manner included in regulation 14, 15 and 16 of SOLAS chapter II-2, for example:

> *SOLAS II-2/15*
> *2.2.1. Crew members shall be trained to be familiar with the arrangements of the ship as well as the location and operation of any fire-fighting systems and appliances that they may be called upon to use.*
>
> *2.2.3. Performance of crew members assigned fire-fighting duties shall be periodically evaluated by conducting on-board training and drills to identify areas in need of improvement, to ensure competency in fire-fighting skills is*

maintained, and to ensure the operational readiness of the fire-fighting organization.

The intention of this RCO is that the detailed knowledge about the drencher system and the understanding of the importance of a very short time to activation of the system shall be significantly increased.

4.2.4. Fresh water activation/flushing RCO Su 5

A conventional deluge system consists of pipes with open nozzles. This design in combination with the use of salt water creates a risk of corrosion that could cause blockage of the pipes or the nozzles. This problem is well known and many different proposals have been put forward to solve this.

During the discussions within the project team it was decided to propose a RCO consisting of use of fresh water (or possibly distilled water) during testing and an increase of deluge system flushing frequency (from one to two times in a five-year period). The amount of available fresh water needs to be sufficient to allow activation of the drencher system with full working pressure. It is believed that the increased flushing frequency needs to be combined with fresh water free from mud in order to achieve less clogging. It is also assumed that in a real fire sea water will be used.

4.2.5. CCTV RCO Su 6

Failure of the drencher system could be caused by late activation or activation of wrong drencher section. A CCTV system may make it possible for the crew to see where the fire is located and to get confirmation that it is not a false fire alarm. Of course, the use of a CCTV camera is restricted by the visibility in the space. The camera could be shielded by smoke or by high cargo (e.g. trucks).

It should be noted that the best use of a camera is to confirm that a fire has started when a fire alarm is received, i.e. it is used in the detection phase. In the firefighting phase, it may be used for confirmation that the drencher has been activated, although it could probably be very difficult to see through the smoke.

The cameras should be placed in a pattern to cover the most of a space and preferably high enough to see over the trucks. The camera covering the detector that gives fire alarm should be automatically displayed on the screen with information on which drencher section. That means at least one camera per section, just below the main stiffeners alternatively on the longitudinal bulkhead and side of the ship.

4.2.6. CCTV & Remote release RCO Su 7

If the drencher system is equipped with remote control it would in many cases still be necessary to send a crew member to the location of the fire alarm to confirm the fire. However, if remote control is combined with CCTV it could be possible for the officer in charge to quickly confirm that there is a fire and release the drencher very quickly. For advantages and disadvantages see RCO 1 and RCO 5. As mentioned for RCO 1, the normal procedure to send a runner to the site must be maintained.

4.2.7. Plan for reefers RCO Su 8

One fire hazard that is identified in many investigations is trucks and trailers with refrigeration units (reefers). It would be beneficial if the crew is aware of the exact location of the reefers that are carried onboard. First it could be possible to increase the possibility to detect a fire before it starts by increasing the frequency of the fire patrol where reefers are located. With regards to the drencher system and in case of a fire alarm with large amount of smoke the knowledge where reefers are positioned may help locate the fire and decrease the time to activation of the drencher. Furthermore, the electric supply may be cut off to reefers close to drencher deployment.

This RCO proposes that reefers should be included in the Dangerous Goods plan or in a similar plan for those ships without dangerous goods. It could also be possible to include other identified high fire risk vehicles in the same manner.

4.2.8. Water wall RCO Su 9

Water Curtain is achieved by an independent remote controlled water spray system providing active barriers to smoke, convective heat and radiation. The principle is to provide for a continuity of the vertical separations inside the Ro-Ro space volume. The system would be installed below main vertical bulkheads. For full efficiency, it would require not to have obstacles on a straight area below the spray ramp. It can be assumed that obstacles such as cars are acceptable. The system is judged expensive. To a lower extent, the system could apply to specific areas as proposed in MSC 96/INF. 3, RCO 4.4.

4.2.9. High expansion foam RCO Su 10

The use of high expansion foam as an alternative to normal drencher has been proposed. The main concerns are how to get a good distribution of the foam on a fully loaded ro-ro-space and also the possibility to cool the deck.

4.2.10. Post-activation flushing RCO Su 11

In order to decrease the risk of corrosion one proposed RCO is to flush the drencher system with fresh water at after each time it has been activated. The intention is not to run the system at full pressure and with the full amount of water but rather to only clean the system from salt water. In the regulations today it is required that a fresh water connection to the system is installed. However, it is not regulated how often the system shall be flushed.

4.2.11. Permanent closure of openings RCO Su 12

Open ro-ro decks have in a fire safety point of view some large disadvantages compared to closed decks, as described in RCO 2 above. It has been proposed to permanently close the openings on existing ships and forbid open ro-ro decks for new ships. On existing ships one concern is that increased ventilation capacity is required. This could lead to a rather extensive installation. The fuel consumption for the ship would increase since additional power supply is needed.

4.2.12. Automatic release RCO Su 13

Drencher systems with automatic release could provide quicker and safer release of water to a fire. The activation of the system requires detection from two separate fire detectors. The system does not have bulbs. All pumps and valves are remote controlled. It is the opinion of the project group that manual remote control is needed in order to be able to use the system in a more proactive way, e.g. cooling of sections of a deck.

The main concern with this system comes from the automatic release of large quantities of water which could cause stability problems. Another concern is with regards to releasing water on the cargo if there is a false alarm.

4.3. Costs of RCMs Fire Suppression

A very important factor when deciding whether to recommend a RCO or not is the cost of introducing it. The costs that have been considered here are e.g. installation costs, maintenance costs, operational costs and increased manning. In the table below are the estimated costs of the RCOs specified.

FIRESAFE RCMs for fire suppression		Retrofit Cost €	NB Cost	Service cost/y
Remote control	System cost and installation on retrofit 100 000 € Cost estimate based on two retrofit installations in 2015- 2016 NB Cost assume 80% of retrofit Service cost / y assume 1000 €	100 000	80 000	1 000
Rolling shutters	Newbuilding cost for system and installation. Total cost per opening in average € 60 000. Total 14*€60 000=€ 840 000 Cost from offer on newbuilding 2016. Service cost 1000 €/ year and shutter = 14 000€ Retrofit cost 150% of newbuilding cost	1 260 000	840 000	14 000
Efficient activation routines	Material 200 € Total cost 200 €	200	200	0
Fresh water activation/flushing	Connection of heeling tank (existing tank) to drencher pump Material (valves, pipes, welding rods, paint): 6 000 € Working cost (cleaning tank, welding etc) : 160 man hours x 50 Euro = 8 000 € Total : 14 000 € Newbuilding cost 50% of retrofit = 7 000€ Service cost : 0€	14 000	7 000	0
CCTV	From offer 2016 20 cameras + 20 licence Connection to fire alarm Tot: 30 000€ Cable and installation 10 000 € on newbuilding / 20 000€ on retrofit Service assume 1000€ / y	50 000	40 000	1 000
CCTV & Remote release	See above.	150 000	120 000	2 000

Table 4.3-1 Estimated costs RCM Fire Suppression

4.4. Quantification of RCM effects on extinction/suppression

A number of the RCMs addressing extinction and suppression failure, described above, were selected for quantification, namely:

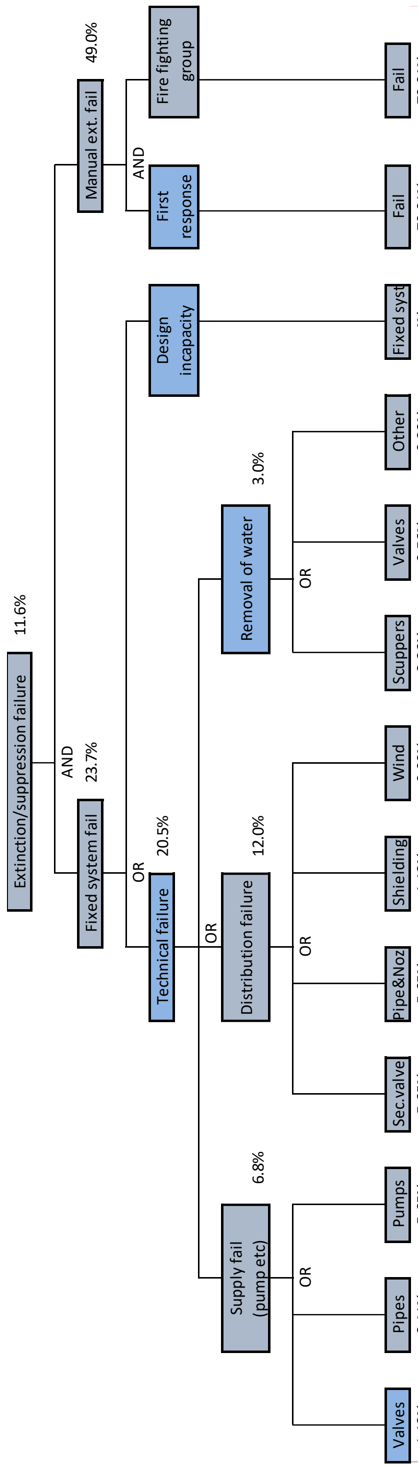
- Remote control
- Rolling shutters
- Efficient activation routines
- Fresh water activation/flushing
- CCTV
- CCTV + Remote control

Similar to the quantification process for the electrical fire ignition model, each RCM was discussed to ensure a common understanding of the RCMs and where (what nodes) they would affect the risk model. This was done at a meeting, where more detailed discussions of factors affecting each RCO were also carried out. For example, limitations of the RCO to affect the node, reliability of the RCO, procedures of the RCO, and other important factors which affect the effectiveness of each RCO on each node. Thereafter, estimations of the effects of each RCO on the agreed nodes were estimated individually. The estimations were mainly done by expert judgment, where each partner consulted the internal experts considered necessary to provide their appraisal of how much the contribution by each node could be reduced by each RCO. This resulted in a list of estimations, which was then distributed to all partners. This list was then discussed, with focus on large (relative) and noteworthy differences in appraisals. A few estimations were changed due to different ideas about details of the RCOs.

The list with the RCOs, affected nodes, important factors to consider, and the average values of the estimations are presented in Figure 4.4-1. The averaged estimated effects of the RCOs were linked to the risk model for suppression failure on ro-ro deck, as illustrated in Figure 4.4-2, Figure 4.4-3, Figure 4.4-4, and Figure 4.4-5. The concluding effects on the probability of extinction/suppression failure are presented in Table 4.4-1.

RCO r	RCMs for quantitative est.	Description	Affected nodes	Affecting factors	Early Closed	Early Open	Late Closed	Late Open
Su 1	**Remote control**	System releasable from bridge/ECR/safety center with confirmation of water on nozzles	Pumps-Supply-Technical-Fixed system	Pump is not affected, only operation of the pump Faster activation is considered as less probability of Design incapacity and should not be considered here. Pump in local mode is still possible, but is estimated to be as likely as without this RCM and should not be considered since it is included in faulure percentage. More complex system. Reliability is also increased. False security, a guy still must be sent to make sure valves are opened correctly (or CCTV)	2%	2%	3%	3%
			Sectioning valves-Distribution-Technical-Fixed system	Faster activation of section valves is considered as lower probability of Design incapacity and should not be considered here. Comunication failure is taken away. The reliability of remote control is not 100% (crew member may be sent to drencher station anyway) More complex system. Easier tactical fire fighting (e.g. switching sections to cooling and fire fighting) Remote control will work even if access to drencher station is not possible (hazardous)	27%	27%	33%	33%
			Scuppers-Removal-Technical-Fixed system	Faster extinguishment will give less water and less debris, which could give possibility to extinguish the fire before scupper design is compromised Probably a very small number Larger effect for spaces below waterline where water must be pumped up	4%	4%	10%	10%
			Design incapacity-Fixed system	Quicker activation decreases risk that fire grows more rapidly than system design fire	15%	17%	33%	37%
Su 3	**Rolling shutters**	Rolling shutters on ro-ro deck permanent openings (like in galleys). Remote controlled assumed. Only relevant for open ro-ro deck	Wind-Distribution-Technical-Fixed system	Only effects on suppression are considered Mechanical system gives risk of malfunction (maintenance required) Drencher not affected by wind conditions with shutters A0 std assumed	N/A	88%	N/A	57%
			Scuppers-Removal-Technical-Fixed system	Faster extinguishment will give less water and less debris, which could give possibility to extinguish the fire before scupper design is compromised Probably a very small number Larger effect for spaces below waterline where water must be pumped up	N/A	17%	N/A	14%
			Design incapacity-Fixed system	Effiency of extinguishment increased since less oxygen available	N/A	13%	N/A	9%
Su 4	**Efficient activation routines**	Improved, more efficient routine	Valves-Supply-Technical-Fixed system	Improved crew familiarization, (quicker activation considered in Design incapacity), decreased risk of comunication failures, crew at site to discover failures, increased awareness of possible failures, decreased risk of activating wrong section,	7%	7%	9%	9%
			Pipes-Supply-Technical-Fixed system	Changing of filters	2%	2%	2%	2%
			Pumps-Supply-Technical-Fixed system	See above	12%	12%	15%	15%
			Sectioning valves-Distribution-Technical-Fixed system	See above	47%	47%	53%	53%
			Scuppers-Removal-Technical-Fixed system	Faster extinguishment will give less water and less debris, which could give possibility to extinguish the fire before scupper design is compromised	15%	15%	30%	30%
			Valves-Removal of water-Technical-Fixed system	Probably a very small number	19%	19%	23%	23%
			Design incapacity-Fixed system	Quicker activation decreases risk that fire grows more rapidly than system design fire	23%	23%	37%	37%
Su 5	**Fresh water activation/flushing**	Use of distilled/fresh water during testing and increase of deluge system flushing frequency (from one to two times in a five-year period).	Valves-Supply-Technical-Fixed system	inlet valves closed during testing: more frequently used, small risk of being left closed (both positive and negative effects).	-15%	-15%	-15%	-15%
			Pumps-Supply-Technical-Fixed system	Increased flushing requires fresh water Decreased risk of "muddy" water Decreased risk of fouling (seagrass, mussels, etc,) Less corrosion (in particular in pipes) avoids debris and clogging in nozzles Increased possibility to discover faults Increased familiarization by crew but more complex system	17%	17%	17%	17%
			Sectioning valves-Distribution-Technical-Fixed system	See above	17%	17%	17%	17%
			Pipes&Nozzles-Distribution-Technical-Fixed system	See above	58%	58%	58%	58%
Su 6	**CCTV**	CCTV surveilance, one camera per drencher zone; conventional cameras are considered. Section markings should be visible in the cameras. There should be a connection to the fire alarm system, so that the correct camera apears on the screen	Sectioning valves-Distribution-Technical-Fixed system	Possibility to locate fire if not shielded by smoke or cargo Possibility to confirm activated drencher section if not shielded by smoke or cargo Smoke may confirm fire even though fire is not in sight	7%	10%	10%	15%
			Scuppers-Removal-Technical-Fixed system	Faster extinguishment will give less water and less debris, which could give possibility to extinguish the fire before scupper design is compromised	2%	2%	7%	7%
			Design incapacity-Fixed system	There might be quicker activation of the system since fire alarm can be confirmed by CCTV. Quicker activation decreases risk that fire grows more rapidly than system design fire. E.g. 1/3 of the time with trained crew.	3%	3%	8%	8%
Su 7	**CCTV & Remote release Only benefits in addition to remote control mentioned here; for remote release see above)**	Remote Control + CCTV surveilar	Sectioning valves-Distribution-Technical-Fixed system	Possibility to locate fire if not shielded by smoke or cargo Possibility to confirm activated drencher section if not shielded by smoke or cargo Smoke may confirm fire even though fire is not in sight	27%	28%	34%	36%
			Scuppers-Removal-Technical-Fixed system	Faster extinguishment will give less water and less debris, which could give possibility to extinguish the fire before scupper design is compromised	9%	9%	37%	37%
			Design incapacity-Fixed system	There should be quicker activation of the system since fire alarm can be confirmed by CCTV. Quicker activation decreases risk that fire grows more rapidly than system design fire	18%	18%	48%	48%
			Pumps-Supply-Technical-Fixed system	Pump is not affected, only operation of the pump Faster activation is considered as less probability of Design incapacity and should not be considered here. Pump in local mode is still possible, but is estimated to be as likely as without this RCM and should not be considered since it is included in faulure percentage. More complex system. Reliability is also increased.	4%	4%	5%	5%

Figure 4.4-1. Quantification of RCMs for Fire Suppression failure.



Ref	Conventional Design	Valves		Pipes		Pumps		Sec.valve		Pipe&Noz		Shielding		Wind		Scuppers		Valves		Other		Fixed syst		Fail		Fail	
		1.13%		0.11%		5.65%		5.65%		5.65%		1.13%		0.00%		2.26%		0.56%		0.23%		4%		70.01%		70.01%	
	The relative REDUCTION is shown in the WHITE fields on the RIGHT of the affected probabilities below																										
Su 1	Remote control	1.1%	0%	0.1%	0%	5.5%	2%	4.1%	27%	5.6%	0%	1.1%	0%	0.0%	0%	2.2%	4%	0.6%	0%	0.2%	0%	3.4%	15%	70.0%	0%	70.0%	0%
Su 3	Rolling shutters	1.1%	0%	0.1%	0%	5.6%	0%	5.6%	0%	5.6%	0%	1.1%	0%	0.0%	0%	2.3%	0%	0.6%	0%	0.2%	0%	4.0%	0%	70.0%	0%	70.0%	0%
Su 4	Efficient activation routines	1.0%	7%	0.1%	2%	5.0%	12%	3.0%	47%	5.6%	0%	1.1%	0%	0.0%	0%	1.9%	15%	0.5%	19%	0.2%	0%	3.1%	23%	70.0%	0%	70.0%	0%
Su 5	Fresh water activation/flushing	1.3%	-15%	0.1%	0%	4.7%	17%	4.7%	17%	2.4%	58%	1.1%	0%	0.0%	0%	2.3%	0%	0.6%	0%	0.2%	0%	4.0%	0%	70.0%	0%	70.0%	0%
Su 6	CCTV	1.1%	0%	0.1%	0%	5.6%	0%	5.3%	7%	5.6%	0%	1.1%	0%	0.0%	0%	2.2%	2%	0.6%	0%	0.2%	0%	3.9%	3%	70.0%	0%	70.0%	0%
Su 7	CCTV + Remote control	1.1%	0%	0.1%	0%	5.4%	4%	4.1%	27%	5.6%	0%	1.1%	0%	0.0%	0%	2.1%	9%	0.6%	0%	0.2%	0%	3.3%	18%	70.0%	0%	70.0%	0%

Figure 4.4-2. Model for suppression fail in case of early decision and closed deck, with RCM effects.

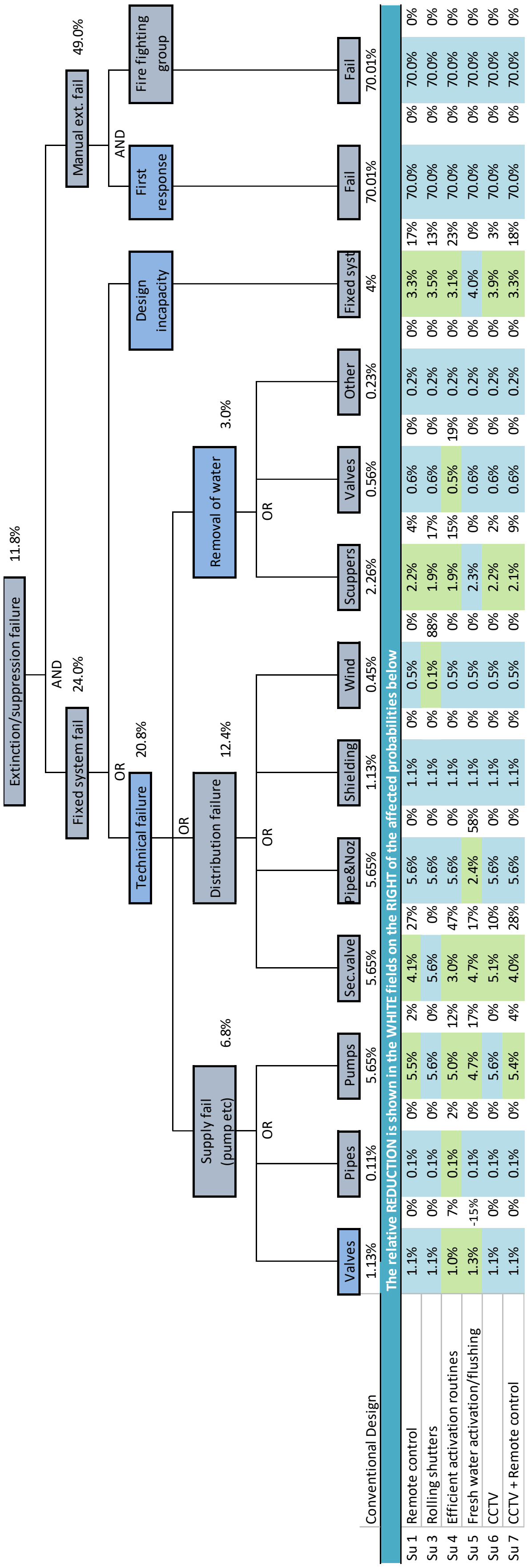


Figure 4.4-3. Model for suppression fail in case of early decision and open deck, with RCM effects.

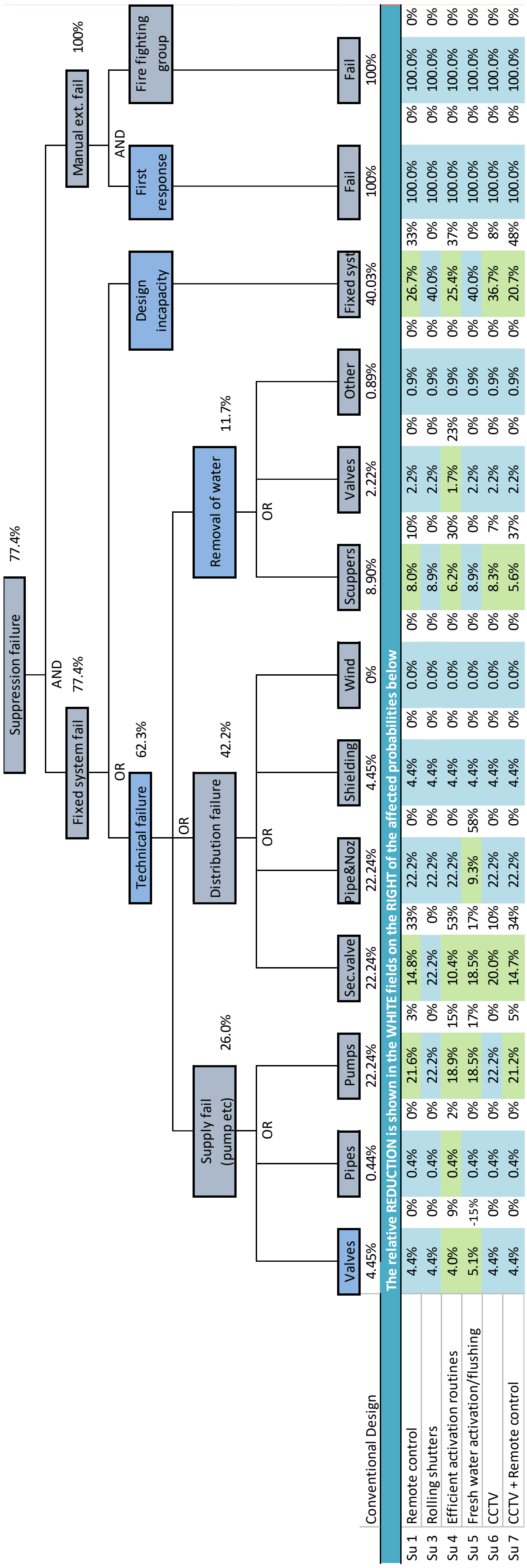
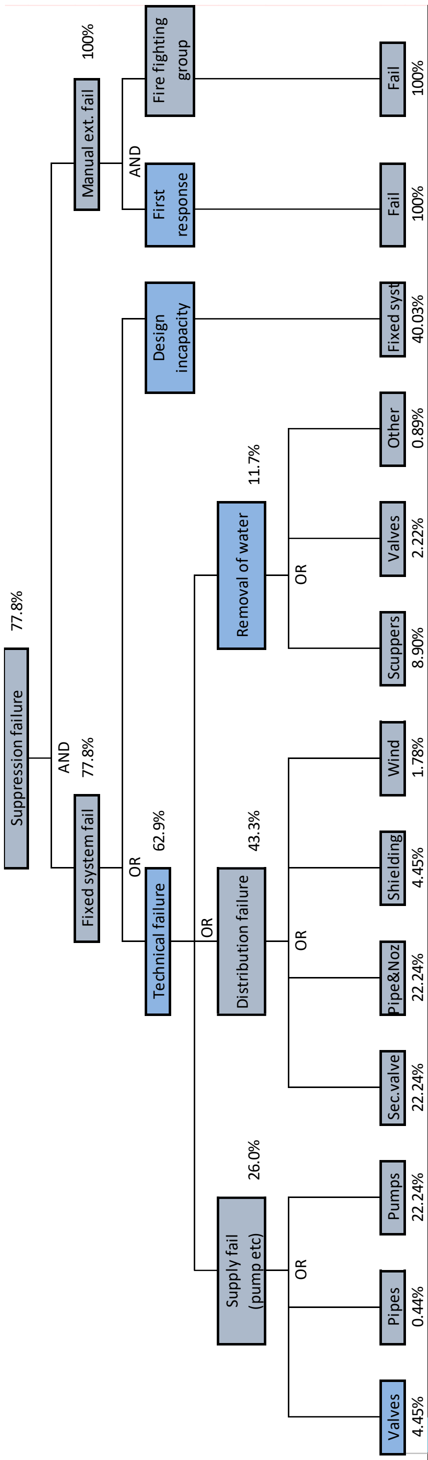


Figure 4.4-4. Model for suppression fail in case of late decision and closed deck, with RCM effects.



		Valves	Red.	Pipes	Red.	Pumps	Red.	Sec.valve	Red.	Pipe&Noz	Red.	Shielding	Red.	Wind	Red.	Scuppers	Red.	Valves	Red.	Other	Red.	Fixed syst	Red.	Fail	Red.	Fail	Red.
	Conventional Design	4.45%		0.44%		22.24%		22.24%		22.24%		4.45%		1.78%		8.90%		2.22%		0.89%		40.03%		100%		100%	
The relative REDUCTION is shown in the WHITE fields on the RIGHT of the affected probabilities below																											
Su 1	Remote control	4.4%	0%	0.4%	0%	21.6%	3%	14.8%	33%	22.2%	0%	4.4%	0%	1.8%	0%	8.0%	10%	2.2%	0%	0.9%	0%	25.4%	37%	100.0%	0%	100.0%	0%
Su 3	Rolling shutters	4.4%	0%	0.4%	0%	22.2%	0%	22.2%	0%	22.2%	0%	4.4%	0%	0.8%	57%	7.7%	14%	2.2%	0%	0.9%	0%	36.6%	9%	100.0%	0%	100.0%	0%
Su 4	Efficient activation routines	4.0%	9%	0.4%	2%	18.9%	15%	10.4%	53%	22.2%	0%	4.4%	0%	1.8%	0%	6.2%	30%	1.7%	23%	0.9%	0%	25.4%	37%	100.0%	0%	100.0%	0%
Su 5	Fresh water activation/flushing	5.1%	-15%	0.4%	0%	18.5%	17%	18.5%	17%	9.3%	58%	4.4%	0%	1.8%	0%	8.9%	0%	2.2%	0%	0.9%	0%	40.0%	0%	100.0%	0%	100.0%	0%
Su 6	CCTV	4.4%	0%	0.4%	0%	22.2%	0%	18.9%	15%	22.2%	0%	4.4%	0%	1.8%	0%	8.3%	7%	2.2%	0%	0.9%	0%	36.7%	8%	100.0%	0%	100.0%	0%
Su 7	CCTV + Remote control	4.4%	0%	0.4%	0%	21.2%	5%	14.3%	36%	22.2%	0%	4.4%	0%	1.8%	0%	5.6%	37%	2.2%	0%	0.9%	0%	20.7%	48%	100.0%	0%	100.0%	0%

Figure 4.4-5. Model for suppression fail in case of late decision and open deck, with RCM effects.

		Early Closed		Early Open		Late Closed		Late Open	
	Conventional Design	11,6%		11,8%		77,4%		77,8%	
		Prob.	Rel red.	Prob.	Rel red.	Prob.	Rel red.	Prob.	Rel red.
Su 1	Remote control	10,7%	7,9%	10,8%	8,0%	69,2%	10,6%	69,2%	11,1%
Su 3	Rolling shutters	11,6%	0,0%	11,3%	4,3%	77,4%	0,0%	75,9%	2,4%
Su 4	Efficient activation routines	9,7%	16,3%	9,9%	16,0%	64,8%	16,2%	65,4%	15,9%
Su 5	Fresh water activation/flushing	9,6%	17,5%	9,8%	17,1%	71,2%	8,0%	71,7%	7,8%
Su 6	CCTV	11,4%	1,9%	11,5%	2,5%	75,3%	2,7%	75,4%	3,1%
Su 7	CCTV + Remote control	10,5%	9,2%	10,7%	9,3%	65,5%	15,3%	66,0%	15,2%

Table 4.4-1. Concluding effects of quantified RCOs on the probability of extinction/suppression failure.

	RCO	Su 1	Su 3	Su 4	Su 5	Su 6	Su 7
Remote control	SU 1		No	Strong	No	Strong	
Rolling shutters	SU 3	No		Weak	No	Weak	Weak
Efficient activation routines	SU 4	Strong	Weak		No	Strong	Strong
Fresh water activation/flushing	SU 5	No	No	No		No	No
CCTV	SU 6	Strong	Weak	Strong	No		
CCTV & Remote control	SU 7		Weak	Strong	No		

Table 4.4-2. Interdependencies or RCOs effecting extinction/suppression

The effects of RCOs were estimated with the assumption that none of the other RCOs were implemented. In some cases there could be synergy effects of the RCMs and in some cases addition of a second RCO directing similar hazards will not be as effective. Therefore it is important to consider interdependencies between the RCOs, an estimation of the interdependencies could be seen in table 4.4-2.

4.5. Cost Benefit assessment Suppression failure

4.5.1. Net Present Value

Net present values have been calculated based on the assumptions presented in the section Cost benefit assessment. Results of these calculations are shown in Table 4.5-1.

The cost for the risk control option *Su7: CCTV and Remote control* is the sum of the cost of the risk control options *Su1: Remote Control* and *Su6: CCTV*.
Details of the cost have been provided in section 4.3. Costs of RCMs Fire Suppression.
All the costs provided in that section are additional costs compared to what is already installed in the reference ship.

		Newbuilding			Existing ship		
RCO #	Description	Initial cost	Periodic costs	NPV	Initial cost	Periodic costs	NPV
Su 1	Remote control	80 000 €	1 000 €	96 003 €	100 000 €	1 000 €	110 838 €
Su 3	Rolling shutters	840 000 €	14 000 €	1 064 036 €	1 260 000 €	14 000 €	1 411 729 €
Su 4	Efficient activation routines	200 €	- €	200 €	200 €	- €	200 €
Su 5	Fresh water activation/flushing	7 000 €	- €	7 000 €	14 000 €	- €	14 000 €
Su 6	CCTV	40 000 €	1 000 €	56 003 €	50 000 €	1 000 €	60 838 €
Su 7	CCTV + Remote control	120 000 €	2 000 €	152 005 €	150 000 €	2 000 €	171 676 €

Table 4.5-1: Lifetime implementation costs for the *fire suppression* RCOs in Net Present Value (NPV) in Euros

4.5.2. Effectiveness of Risk Control Options

Figure 4.5-1, Figure 4.5-2 and Figure 4.5-3 provide the PLL, PLC, and PLS, respectively, for the reference ship without RCOs and after the implementation of the individual RCOs.

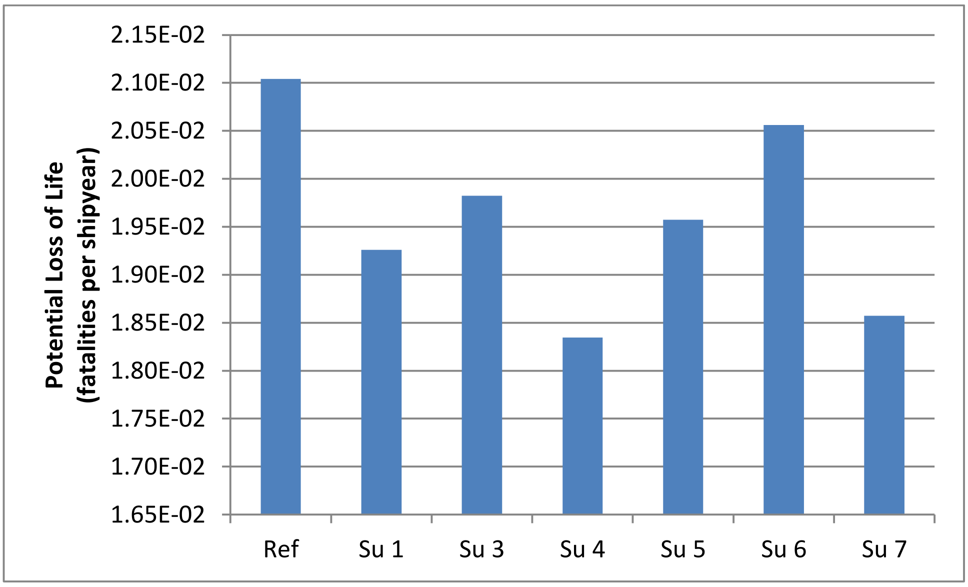


Figure 4.5-1: Potential loss of life for the generic vessel and after (individual) implementation of the RCOs (Fire suppression failure)

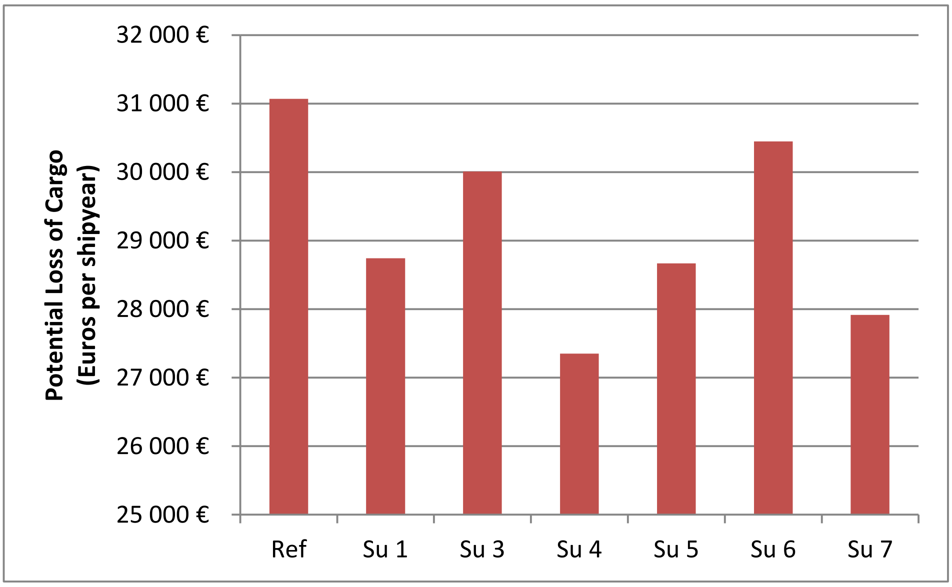


Figure 4.5-2: Potential loss of cargo for the generic vessel and after (individual) implementation of the RCOs (Fire suppression failure)

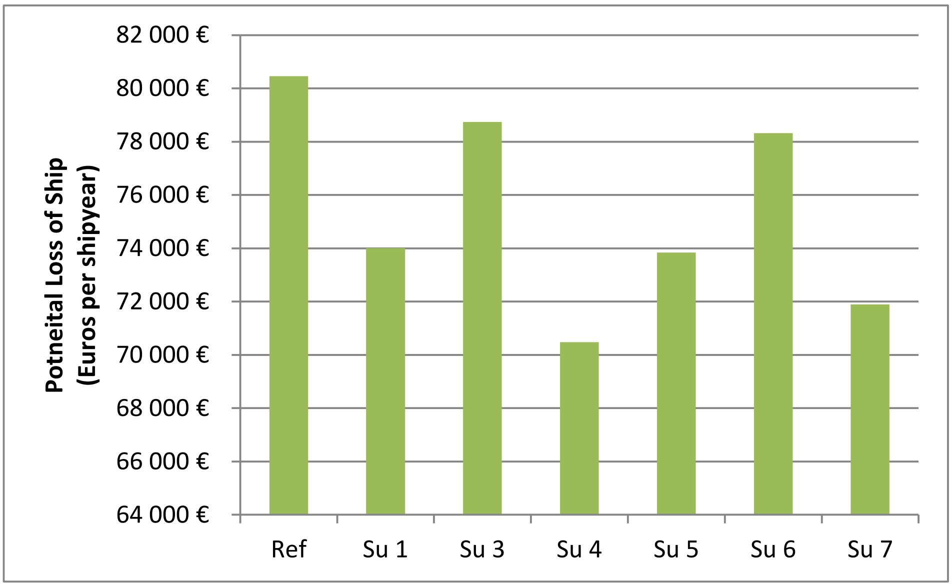


Figure 4.5-3: Potential loss of ship for the generic vessel and after (individual) implementation of the RCOs (Fire suppression failure)

Summary of the risk reduction efficiency is provided in Figure 4.5-4 to allow easier comparison of the efficiency of the RCOs with regard to loss of life, loss of cargo and loss of ship.
Since the RCOs for Fire suppression do not impact uniformly over the risk model branches and because the ship damage, cargo damage and life consequences are different from one branch to the other, the contribution of the RCO is different with respect to PLL, PLC and PLS. This is reflected by the color bars for one specific RCO.

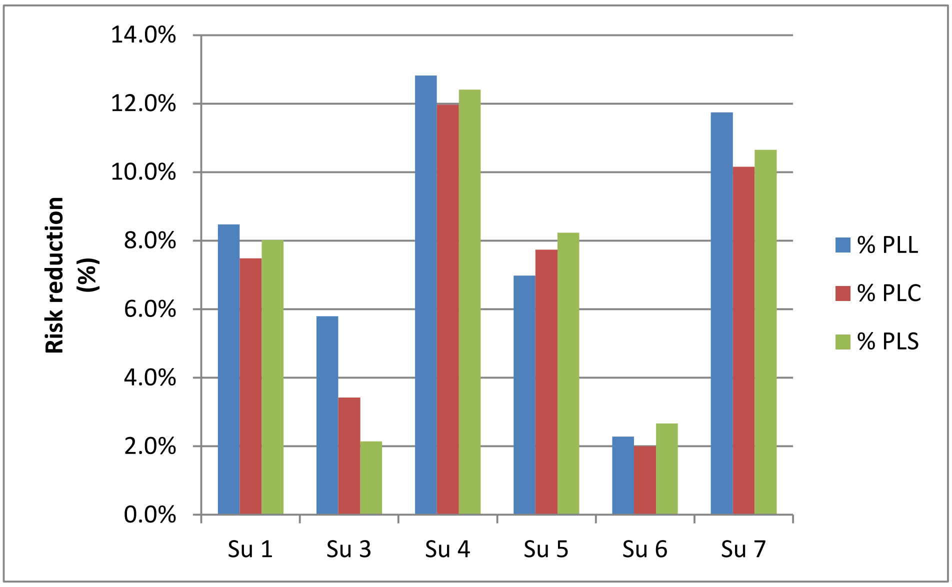


Figure 4.5-4: Risk reduction (Life, Cargo, Ship) in percentage after the (individual) implementation of the RCOs (Fire suppression failure)

The highest life risk reduction is achieved by the Su4: Efficient activation routines.
The important difference between the %PLL, %PLC, and %PLS for the Su3*: Rolling Shutters* can be explained by the high efficiency of that risk control options to contain the fire even when the suppression system has failed, therefore protecting evacuation. On the other side the cargo is lost as well as the ship.

For the other RCOs, Su1, 5 and 7 are quite equivalent and uniform in term of risk reduction. Su 6 is weak compared to the others.

4.5.3. GCAF

Table 4.5-2 and Table 4.5-3 summarize the inputs value for the calculation of the GCAF (as defined in the section 2.5.1 Review of Risk Acceptance Criteria), which are the Delta Risk (difference of the PLL after and before the implementation of the a RCO times the expected lifetime of the vessel) and the Delta Cost in Net Present values as listed in Table **4.5-1**. These tables also present the result of the cost benefit analysis and assessment by providing the GCAF.
The GCAF Factor is the ratio between the GCAF as calculated and the CAF criterion of $7.45M (6 913 600 €) that has been selected in the review of the Risk Acceptance Criteria (see section 2.5.2.Value for Preventing Fatality calculation) and indicates a cost efficiency with values less or equal to 1.00.

Newbuildings		Delta Risk	Delta Cost	GCAF			
RCO #	Description	(Averted) fat.	(NPV)	GCAF	GCAF Factor	Cost effective	GCAF Rank
Su 1	Remote control	5.89E-02	96 003 €	1 631 031 €	0.24	Yes	3
Su 3	Rolling shutters	4.02E-02	1 064 036 €	26 457 159 €	3.83	No	6
Su 4	Efficient activation routines	8.90E-02	200 €	2 247 €	0.00	Yes	1
Su 5	Fresh water activation/flushing	4.85E-02	7 000 €	144 451 €	0.02	Yes	2
Su 6	CCTV	1.59E-02	56 003 €	3 532 946 €	0.51	Yes	5
Su 7	CCTV + Remote control	8.15E-02	152 005 €	1 864 131 €	0.27	Yes	4

Table 4.5-2: GCAF for Suppression Failure RCOs for new buildings

Existing Ships		Delta risk	Delta Cost	GCAF			
RCO #	Description	(Averted) fat.	(NPV)	GCAF	GCAF Factor	Cost effective	Rank
Su 1	Remote control	2.85E-02	110 838 €	3 883 840 €	0.56	Yes	3
Su 3	Rolling shutters	1.95E-02	1 411 729 €	72 398 945 €	10.47	No	6
Su 4	Efficient activation routines	4.32E-02	200 €	4 634 €	0.00	Yes	1
Su 5	Fresh water activation/flushing	2.35E-02	14 000 €	595 858 €	0.09	Yes	2
Su 6	CCTV	7.69E-03	60 838 €	7 915 830 €	1.14	No	5
Su 7	CCTV + Remote control	3.95E-02	171 676 €	4 342 309 €	0.63	Yes	4

Table 4.5-3: GCAF for Suppression Failure RCOs for existing ships

Shutters for building industry have not been evaluated (A-0 has been taken here in the cost estimates while almost similar effects can be achieved probably with lower costs of the system).

4.5.4. NCAF

Newbuildings		Delta Risk	Delta Cost	Delta Benefits (Ship & cargo)	NCAF		
RCO #	Description	(Averted) fat.	(NPV)	(NPV)	NCAF	NCAF ratio	Cost effective
Su 1	Remote control	5.89E-02	96 003 €	289 720 €	- 3 291 161 €	-0.48	Yes
Su 3	Rolling shutters	4.02E-02	1 064 036 €	91 830 €	24 173 804 €	3.50	No
Su 4	Efficient activation routines	8.90E-02	200 €	452 189 €	- 5 077 541 €	-0.73	Yes
Su 5	Fresh water activation/flushing	4.85E-02	7 000 €	297 902 €	- 6 002 997 €	-0.87	Yes
Su 6	CCTV	1.59E-02	56 003 €	91 255 €	- 2 223 917 €	-0.32	Yes
Su 7	CCTV + Remote control	8.15E-02	152 005 €	386 930 €	- 2 881 031 €	-0.42	Yes

Table 4.5-4: NCAF for Suppression Failure RCOs for new buildings

Existing Ships		Delta risk	Delta Cost	Delta Benefits (Ship & cargo)	NCAF		
RCO #	Description	(Averted) fat.	(NPV)	(NPV)	NCAF	NCAF ratio	Cost effective
Su 1	Remote control	2.85E-02	110 838 €	95 149 €	549 740 €	0.08	Yes
Su 3	Rolling shutters	1.95E-02	1 411 729 €	30 159 €	70 852 290 €	10.25	No
Su 4	Efficient activation routines	4.32E-02	200 €	148 507 €	- 3 436 214 €	-0.50	Yes
Su 5	Fresh water activation/flushing	2.35E-02	14 000 €	97 836 €	- 3 568 180 €	-0.52	Yes
Su 6	CCTV	7.69E-03	60 838 €	29 970 €	4 016 357 €	0.58	Yes
Su 7	CCTV + Remote control	3.95E-02	171 676 €	127 075 €	1 128 123 €	0.16	Yes

Table 4.5-5: NCAF for Suppression Failure RCOs for existing ships

Table 4.5-4 and Table 4.5-5 present the NCAF related to Suppression failure RCOs for newbuildings and existing ships.

For existing ships, since CCTV was within the range of the CAF value (GCAF factor of 1.14), NCAF may also be considered. The RCO Su6: CCTV has been found cost-efficient when taking into account the economic benefits related to the averted loss of cargo and loss of ship.

Consideration of the economic benefits does not change the conclusion with regard to the cost efficiency status of the other RCOs (Su 3 remains above the cost effectiveness acceptance criterion).

However, it should be noted that for both Newbuildings and existing ships negative NCAF have been calculated for 2 of the investigated RCOs. As indicated in the FSA Guidelines, this means that the benefits in monetary units are higher than the costs associated with the RCO.

The Guidelines further recommend always considering high negative NCAFs in connection with the associated risk reduction capability since this may be due to either:

- benefits much higher than the costs associated with the RCO;
- RCO with a low risk reduction potential.

5. Conclusions

5.1. General

Fires on board ships are a complex problem and many different fire developments could be expected. In most cases a fire starts as a small smouldering fire and after an incipient phase it will start to grow. When it starts to grow it usually grows very quickly. The development of fires is also very dependent on ventilation and available fuel.

The two most important conclusions are that it is better to prevent a fire than having to fight it and that a small fire is easier to fight than a large, i.e. in this study prevention and quick activation of the drencher system. This has also been expressed in many other studies and fire investigations.

After analysing the outcome of the cost benefit assessment, the following conclusions could be drawn:

- Training is the most cost effective.
- In this study A-0 shutters were investigated but other solutions exist. More inexpensive shutters will likely be available in the near future.
- Robust connection boxes have the highest risk reduction for the electrical model.
- The number of accident cases was not sufficient for a full statistical study, (however it was higher than the statistics used in some other FSAs).
- Input values are not definitive, they will improve with more statistics and more assessment.
- Quick response to fire is the most important safety precaution.
- The outcome is also dependent on other aspects e.g. detection.
- RCOs is also influencing other aspects. If this had been considered some of the RCOs that were not selected for quantitative analysis might have been cost effective.

Annex 1 List of documents reviewed to find RCOs

The following documents have been reviewed to find RCOs already investigated in previous projects or mentioned in literature:

1. FSA - RoPax - Electric Mobility on Ro-ro RoPax vessels
   MSC 96/INF.3 Formal Safety Assessment, including general cargo ship safety - Electric mobility on ro-ro and ro-pax ships - Report of the Formal Safety Assessment (FSA) study, Maritime Safety Committee, 2016.
2. Interferry Ro Ro Deck Fire Safety - Operational Best Practice Guidance
   MSC 96/6/2, PASSENGER SHIP SAFETY - Best Practice guidance on ferry safety for ro-ro passenger ships, Maritime Safety Committee, 2016 (submitted by Interferry)
3. Investigation Report - Vincenzo Florio
4. Investigation Report - Pearl of Scandinavia
   Danish Maritime Accident Investigation Board, PEARL OF SCANDINAVIA - Fire - 17 November 2010, 2011
5. Investigation Report - Mecklenburg-Vorpommern
   Federal Bureau of Maritime Casualty Investigation - Summary Investigation Report 515/10 Serious Marine Casualty Fire on a semi-trailer on board the ferry MECKLENBURG-VORPOMMERN on the Warnow river on 19 November 2010
6. Investigation Report – Urd
   Danish Maritime Accident Investigation Board - MARINE ACCIDENT REPORT: URD Fire on 4 March 2014, published on June 2014
7. Investigation Report - Lisco Gloria
   Flag State Republic of Lithuania and the costal State Federal Republic of Germany - Investigation Report 445/10 Very Serious Marine Casualty Fire on the ro-ro passenger vessel LISCO GLORIA on 8 October 2010 north-west of Fehmarn
8. Investigation Report - Victoria Seaways
   MINISTRY OF TRANSPORTATION OF THE REPUBLIC OF LITHUANIA, MARINE SHIP ACCIDENT INVESTIGATION FINAL REPORT Victoria Seaways, 2013
9. Fires on Ro-Ro Decks
   DNV GL, Fires on Ro-Ro Decks, 2016.
10. Comments on proposed new unplanned output regarding fire safety of Ro-Ro ships - Submitted by France to GoE
11. Investigation Report - Commodore Clipper
    MAIB - Report on the investigation of the fire on the main vehicle deck of Commodore Clipper while on passage to Portsmouth 16 June 2010

Annex 2 List of RCMs proposed and discussed during the project

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RCM nr	Proposed risk control measures electric fires	
E1	Monitoring system where you can overview groups of sockets, connection boxes or individual connections - addressable.	
E2	Connection/box monitoring system to identify faulty connections/units, e.g. showing if the three phases are ok on the unit (light display on connection box).	
E3	Earth/ground monitor which is more addressable than today (only for groups today).	
E4	Portable equipment to show that the three phases are ok on the unit (with light display).	
E5	A main switch for car deck which can turn off all cables before arrival.	
E6	Residual-current device on connection boxes.	
E7	Routine to switch off transformers when they are not in use, to prevent overheating!	
E8	Make fire detection and fire suppression mandatory in electrical rooms	
E9	Disconnection of second-hand cars batteries	Issue an order to ferry captains to appoint members of their crews responsible for checking if the batteries of all transported second-hand cars are disconnected before the ship leaves the port.
E10	Banning of un-authorized charging of electric cars	Un-authorized charging of electric cars should be banned. Electric sockets should be marked and secured, and fire patrol on RoPax should be instructed to remove charging connections if found. This does not mean that a carefully designed charging arrangement could not be approved for a future design
E11	Ground alarm system	Power circuits serving reefer units shall be equipped with ground fault detection providing alarm to a manned control station
E12	Forbid charging of batteries in electric cars, caravans, auto campers, etc.	Forbid charging of batteries in electric cars, caravans, auto campers, etc.
E13	Training for increased crew awareness (of against smell, damaged vehicles, heat radiation, "smart installations", open windows, late and overheated buses), routine for reviewing units and performance of directed inspections as well as routine to send those units back ashore/location which imply high fire risk/localization with increased surveillance/monitoring/fire patrol.	
E14	Fire patrols (training also for fire response on how to act upon fire in various cargo, e.g. to turn off main power of truck or disconnect main power of reefer unit).	

E15	Include in SOLAS training manual, knowledge of equipment and their position by the crew	
E16	Cargo screening	Cargo should be screened, and old and towed second hand vehicles in particular should carefully checked before being allowed on board
E17	AFV policy	A policy on how to handle alternative-fuel vehicles should be developed, if applicable (know-how on correct firefighting strategy/challenges), although this is not identified as a major risk (it is an unknown risk)
E18	*Crew monitoring*	*Mandatory vessel loading / unloading supervised by trained officer on each deck*
E19	Only allow trained crew to connect and disconnect cables (any concerns should be raised to ETO).	
E20	Only allow ship cables and ship adapters.	
E21	Training to identify faulty and risky connections (develop manual) and routines for managing such connections, including long cables, routing close to combustibles	
E22	Electrical drills included as part of the emergency procedures (ISM code)	
E23	Power distribution for vehicles	To avoid damage to cables and sockets used to charge electrically powered vehicles and to connect refrigeration units which, in turn, might result in fires, only lockable sockets should be used. This prevents cables from being disconnected while they carry current, which usually results in premature wear of the connector contacts and thus increases the risk of fire.
E24	Ship's own connector and cables	The ship shall provide and only use its own connectors and cables for providing electrical power to 'reefer' units and for charging of electrical vehicles during the voyage.
E25	Qualified crew for (dis)connections	Only qualified ship's crew shall perform the connection and disconnections of 'reefer' units and electrical vehicles.
E26	Ground fault detection and alarm	The vessel's electrical circuit providing reefer connections should be fitted with a means of ground fault detection and an alarm to the engine control room.
E27	Affect the truck/unit association (if such exists) to introduce a standard on cables and connections.	
E28	Affect regulations for haulers to keep reefers up to date.	
E29	Affect drivers association to check and keep their equipment well maintained.	
E30	Drivers association to implement standard for signs for main switch.	
E31	Training and routines for control of, care for and maintenance of cables (cables are consumables).	
E32	Regular inspections and maintenance of the connection boxes.	
E33	Dedicated electrician officer for garage & make mandatory annual servicing of switchboards	

E34	Grouping of reefer units to better manage controls (in the stern could be most practicable).	
E35	Putting reefer units along the ship sides to simplify inspections and connections.	
E36	Develop internal standards for reefer units as for other high risk cargo (similar to DG) with regards to loading, safety systems, precautionary measures etc.	
E37	Forbid reefers on ships not designed/equiped for safe transportation of reefers	
E38	Reefer units policy	A policy on reefer units needs to be available. If accepted on board, they should be placed in dedicated areas (weather decks when possible, and preferably an area covered by CCTV). Power transfer cables should be in good condition, replaced frequently and only handled by designated crew. Reefer units of dubious quality should be rejected. Stowage area should be checked frequently during voyage.
E39	More socket installations "than needed" are important to be able to make short cable routings.	
E40	Weather proof connection boxes (very demanding environment: salt, vibrations, water), e.g. IP67	
E41	Coverage of electrical equipment (from sprinkler test)	
E42	Remove electrical equipment from ro-ro space.	
E43	Mandatory installation/use of cable reeling drums (at regular intervals) for power supply of reefers	
E44	Modifications done by the crew to be recorded in a record book (like on HSC)	
E45	Switchboards should be accessible without the need to pass through the garage	
E46	Information to drivers to switch off the main power.	
E47	Instruction to turn off cab heaters and other electrical equipment.	
E48	Help booklet or warning poster to assist with maintaining crew awareness of "smart" installations.	

RCM nr	Propose risk control measures for fire suppression systems	
S1	Possibility for activation by first responder.	
S2	System releasable from bridge.	
S3	Measures which reduce the consequences of faulty activation (fresh water during the first minutes, water-proof equipment on deck…).	

S4	Wet-pipe system would give quicker activation but there is a problem with bulb-activation if heat is not sufficient and potential problems with freezing during wintertime.	
S5	Loading/Storage of cargo/vehicles as per their specific risk	
S6	routine to acknowledge any alarm (different colors/sound to be used on mimic panels)	
S7	training of the crew with regards to modifications done by the crew	
S8	CCTV camera on ro-ro decks	Use of CCTV cameras to allow visual confirmation of a fire on ro-ro decks from the Bridge/ER.
S9	Addressable fire detectors	Addressable fire detectors are mandatory on new passenger ships after 2010. Operators should ensure that all vessels are fitted with addressable fire detectors.
S10	Automatic release of drencher system	Automatic release of existing sprinkler systems by a system where detection of a fire by both a flame detector and a heat detector within the same zone of the sprinkler system
S11	Recording of research and best practices	The company should note any future findings of on-going research on open ro-ro decks and update its practices accordingly.
S12	Emergency extinguishing system control panel in PC cargo	
S13	all procedures should be clear and well understood by the crew (to avoid wrong instruction)	
S14	Improved, more efficient routines for activation.	
S15	Emergency feeding of drencher pump.	
S16	Improved water filters.	
S17	Emergency feeding of emergency pump.	
S18	Redundancy of drencher pump.	
S19	Deluge system manufactured from non-corrosive materials	For installations on new ships, the deluge system should be manufactured from non-corrosive materials to prevent blockage.
S20	Deluge systems flushing period	For existing deluge systems installations, the frequency of flushing the deluge system as prescribed in MSC.1/Circ.1432 §9.3.1, should be increased from one to two times in a five-year period.
S21	Communication	The company should ensure a communication control loop in its internal fire suppression guidance and training, so that correct deployment of the deluge system is verified and reported to the Master and the Chief Engineer.
S22	Inspection of valves	In addition to the regular operation of the drencher system, all the valves should be tested to ensure free movement
S23	Training and drills	Time should be assigned for the crew to familiarize themselves with the fixed fire-extinguishing system

S24	Training and drills	Realistic training on the use of the fixed fire extinguishing system should be implemented with company defined goals for release times (for instance, 3 minutes for deluge systems and 15 minutes for CO_2 systems). Drills should be performed frequently in a realistic manner, preferably simulating failure of key components.
S25	Labelling of fire-extinguishing system	It should be verified that labelling and instructions (within CO_2 room or deluge station, and at pumps, ventilation dampers, etc.) are up to date and correct
S26	Important that the ship is designed with the drencher station readily accessible.	
S27	Improved design for drencher valve control.	
S28	Simple indication of drencher sections.	
S29	Simple and clear communication procedure with bridge regarding what section to open.	
S30	Painting the frame# and drencher zones on the ship sides (high and/or low), deck or ceiling (with regards to where markings are made, account must be taken to cargo, layout of walkways, potential smoke etc.)	
S31	Painting drencher sections on ro-ro deck, visible on CCTV screen, to confirm and ensure activation of correct section.	
S32	Flushing of the system with fresh water at full pressure after activation.	
S33	Use of distilled/fresh water during testing and initially after activation.	
S34	Air flushing.	
S35	N_2 in pipes.	
S36	Visual inspection of system pipes and nozzles, as in buildings.	
S37	Conventional relining of pipes or relining with temp coat insulation paint.	
S38	Use of GRE pipes (allowed in ro-ro spaces?).	
S39	Over-dimensioning the system (increased pipe dimensions).	
S40	Checking the nozzles more often than 1/yr.	
S41	Circulation of water.	
S42	Routine to test drenchers (and make a general evaluation of the fire safety standard onboard) when chartering a ship.	
S43	Nozzles in line with the ship structure, e.g. not below web frames, to protect them from damage.	
S44	Regular checks of nozzles.	
S45	Increased deck height.	

S46	Loading procedure where high cargo (trucks/trailers) are mixed with low cargo (cars).	
S47	Pop-up sprinkler head	
S48	Mandatory spacing of at least 60cm between vehicles every 4 vehicles (to facilitate fire patrol and extinguishment)	
S49	Automatically swith off ventilation when fixed fire extinguishing system is activated	
S50	High quality pipes and heads	
S51	Conduct drills in realistic situations (loaded deck)	
S52	Special areas - Passive separation	Partition could prevent smaller fires from spreading over the entire deck which may result in a loss of ship. As the partition may limit the usability of the cargo deck only a dedicated and limited area is envisaged to be separated. Especially HEV, BEV, FC vehicles and vehicles with refrigerating units shall be stored in this area. Mobile partition like roller shutter or sliding doors as well as fixed insulated walls may realize suitable protected to adjacent areas.
S53	Special areas - Water wall	This risk control option pursues the same objective as the mobile or fixed partition of the cargo deck which has been discussed before. Instead of a solid structure a water wall is intended to be used to separate the cargo hold.
S54	Sprinkler system and fluorescent light	Extend car deck sprinkler system piping so that the nozzles are well below the fluorescent light fixtures in the places where these close together
S55	Marking of sprinkler sections	Mark showing the sprinkler sections on the car deck in eye height
S56	Water wall	Water wall sections concept in enclosed ro-ro spaces Water wall system advantages : - loading/unloading sequences not impaired by water wall system equipment - convection cells limited by transverse bounds created by water wall system - fire containment enhanced - smoke containment allowing fire-fighting team to tackle the fire - retrofit opportunity
S57	*Rolling shutters*	*Add rolling shutters (like in galleys)*
S58	*Glycol*	*Glycol to be used and/or electric heating system (on emergency supply) to avoid freezing of water*
S59	*Ventilation access*	*access to fans and dampers should not pass through garage*
S60	Efficient scupper system.	
S61	Heater at scuppers.	
S62	Grids (see MSC/Circ.1234).	

S63	Super elevated screen grids over scupper	Have the scuppers in the garages fitted with super elevated screen grids capable of preventing the obstruction of the scuppers by residues of the combustion

References

- Arvidson, Magnus, Sprinkler design guidelines relevant for ro-ro decks – IMPRO, SP Report 2010:33, SP Technical Research Institute of Sweden, Borås, 2010
- BRE, 2006 BRE Fire and Security, Assessment of the Fire Behaviour of Cargo Loaded on Ro-Ro Vehicle Decks in Relation to the Design Standards for Fire Suppression Systems, 2006.
- DNV GL, 2015 Tosseviken A., Ro-ro deck fires – still a hot topic!, Ferry and ro-ro update ferry and ro-ro update, 2016.
- DNV GL, 2016 DNV GL, Fires on Ro-Ro Decks, 2016.
- EC, 2009 DIRECTIVE 2009/45/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 6 May 2009 on safety rules and standards for passenger ships, 2009.
- EMSA, 2014 European Maritime Safety Agency, Risk Level and Acceptance Criteria for Passenger Ships. First interim report, part 1: Risk level of current fleet, 2014.
- EMSA, 2015 EMSA 3 – Risk Acceptance Criteria and Risk Based Damage Stability. Final Report, part 1: Risk Acceptance Criteria, European Maritime Safety Agency, 2015.
- EMSA, 2015 European Maritime Safety Agency, 1st Correspondence of the Group of Experts on fires on ro-ro decks, 2015.
- EMSA, 2015 European Maritime Safety Agency, Combined assessment of cost-effectiveness of previous parts, FSA compilation and recommendations for decision making, 2015.
- Frid and Palm, 2010 Frid R., Palm D., An analysis of fixed water sprinkler systems on ro-ro decks, 2010.
- HBMCI, 2014 Hellenic Bureau for Marine Casualties Investigation, 01/2012: Fire on board Ro-Pax "KRITI II", 2014.
- IACS, 2016 International Association of Classification Societies, http://www.iacs.org.uk/Explained/members.aspx, last accessed in November 2016.
- IMO, 2008 MSC 85/INF.3 Formal Safety Assessment - FSA – RoPax ships - Details of the Formal Safety Assessment, Maritime Safety Committee, 2008.
- IMO, 2009 FP 54/INF.2 Review of fire protection requirements for on-deck cargo areas - FSA – Container fire on deck Details of the Formal Safety Assessment, Sub-Committee on Fire Protection, 2009.
- IMO, 2012 SLF 55/INF.9 Revision of the damage stability regulations for ro-ro passenger ships – The GOAL based Damage Stability project GOALDS - Development of a new risk-based damage stability requirement for passenger ships based on Cost-Benefit Assessment, Sub-Committee on Stability and Load Lines on Fishing vessels safety, 2012.
- IMO, 2012a FSI 21/5 Casualty Statistics and Investigation - Report of the Correspondence Group on Casualty Analysis, Sub-Committee on Flag State Implementation, 2012.
- IMO, 2012b MSC.1/Circ.1430 Revised guidelines for the design and approval of fixed water-based fire-fighting systems for ro-ro spaces and special category spaces, Maritime Safety Committee, 2012.
- IMO, 2012c SLF 55/INF.9 Revision of the damage stability regulations for ro-ro passenger ships – The GOAL based Damage Stability project GOALDS - Development of a new risk-based damage stability requirement for passenger ships based on Cost-Benefit Assessment, Sub-Committee on Stability and Load Lines on Fishing vessels safety, 2012.

- IMO, 2015 MSC-MEPC.2/Circ.12/Rev.1 Revised guidelines for Formal Safety Assessment FSA for use in the IMO rule-making process, Maritime Safety Committee and Marine Environment Protection Committee, 2015.
- IMO, 2015b SDC 3/3/4 Amendments to SOLAS regulations II-1/6 and II-1/8-1 - Report of the intersessional meeting of the Experts Group on Formal Safety Assessment FSA, Sub-Committee on Ship Design and Construction, 2015.
- IMO, 2016 MSC 96/INF.3 Formal Safety Assessment, including general cargo ship safety - Electric mobility on ro-ro and ro-pax ships Report of the Formal Safety Assessment FSA study, Maritime Safety Committee, 2016.
- IMO, 2016a III 3/4/5 Lessons learned and safety issues identified from the analysis of marine safety investigation reports – Use of accident data, Sub-committee on Implementation of IMO Instruments, 2016.
- Karlsson, B. and J.G. Quintiere, Enclosure Fire Dynamics. 2000, Boca Raton: CRC Press
- Kidd A.L., Discriminating RCCBs for installation protection. WIRING — INSTALLATIONS — SUPPLIES Issue 24 1985
- Larsson, Ida, Ingason, H., Arvidson, M., Model Scale Fire Tests on a Vehicle Deck on Board a Ship, SP Report 2002:05, SP Technical Research institute of Sweden, Borås, 2002
- Li, Y., Assessment of Vehicle Fires in New Zealand Parking Buildings, in Christchurch, New Zealand. 2004: University of Canterbury.
- MAIB, 2011 Marine Accident Investigation Branch, Report on the investigation of the fire on the main vehicle deck of Commodore Clipper while on passage to Portsmouth 16 June 2010, 2011.
- MSC 97/19/3; 2016 Fire safety of ro-ro passenger ships, Maritime Safety Committee, International Maritime Organization, London. MAIB, 2011 Marine Accident Investigation Branch, Report on the investigation of the fire on the main vehicle deck of Commodore Clipper while on passage to Portsmouth 16 June 2010, 2011.
- SDC 1/24/1; 2013: Outcome of FSI 21 and MSC 92 Consideration of casualty reports, Sub-Committee on Ship Design and Construction, International Maritime Organization, London.
- SDC 1/26; 2014: Report to the Maritime Safety Committee, Sub-Committee on Ship Design and Construction, International Maritime Organization, London.
- SSE 1/20; 2013: Consideration of casualty reports, Sub-Committee on Ship Systems and Equipment, International Maritime Organization, London.