FIRESAFE II
Combined Assessment

Final Report

Version 1.1 – December 2018

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WP:	Part 2.1: Combined Assessment
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1 ABSTRACT

In 2016, EMSA initiated the first FIRESAFE study in order to investigate cost-efficient measures for reducing the risk from fires on ro-ro spaces with a focus on *Electrical Fire as ignition source* as well as *Fire Extinguishing Failure*. In 2017, EMSA initiated the FIRESAFE II study to investigate risk control options in relation to *Detection* and *Decision* as well as *Containment* and *Evacuation*, following a ro-ro space fire incident on any ro-ro passenger ship.

The main objective of FIRESAFE and FIRESAFE II was to improve the fire safety of ro-ro passenger ships by cost-efficient safety measures reducing the risk of ro-ro space fire, with an aim to discuss specific proposals for rule making.

This report presents the results of the combined assessment of cost effectiveness based on the results from the different parts previously considered separately in FIRESAFE and FIRESAFE II.

The combined cost-effectiveness assessment was performed on 21 Risk Control Options (RCOs) for three generic ships representing the world fleet of RoPax ships (Cargo, Standard and Ferry RoPax), taking into account potential differences between Newbuildings and Existing ships.

Recommendations for decision making were provided based on the results of the combined cost-effectiveness assessment.

2 EXECUTIVE SUMMARY

The main objective of FIRESAFE II was to improve the fire safety of ro-ro passenger ships by cost-efficient safety measures reducing the risk of ro-ro space fire, with an aim to discuss specific proposals for rule making. In Part 2.1 of the study, reported here, the objective was to summarise the results from the different parts previously considered separately in FIRESAFE and FIRESAFE II and to conduct a combined cost-effectiveness assessment.

Since this report was based on FIRESAFE and FIRESAFE II, it should be read in conjunction with the reports from these studies, as referred below, in a view to consider the basis for this study as well as the assumptions made:

- FIRESAFE: Study investigating cost efficient measures for reducing the risk from fires on ro-ro passenger ships, focusing on *Electrical fires as ignition risk* and *Fire extinguishing failure*;
- FIRESAFE II: Second study investigating cost efficient measures for reducing the risk from fires on ro-ro passenger ships, focusing on *Detection and Decision* (Part 1) and *Containment and Evacuation* (Part 2).

The combined assessment considered open ro-ro spaces, closed ro-ro spaces as well as weather decks, for both Newbuildings and Existing ships.

The relevant steps of the Formal Safety Assessment (FSA) methodology, as described in the Guidelines MSC-MEPC.2/Circ.12/Rev.2, were followed. The FSA is a structured and systematic methodology aimed at enhancing maritime safety and consists of the following five steps:

- Step 1: Hazard identification;
- Step 2: Risk analysis;
- Step 3: Risk control options;
- Step 4: Cost-effectiveness assessment; and
- Step 5: Recommendations for Decision-Making.

All the results related to the first two steps of the FSA methodology are summarised in this report to provide a foundation for the combined cost-effectiveness assessment. These steps are discussed in further detail in the above-mentioned reports.

To consider the diverse world fleet of RoPax ships in the study, three generic categories of ships were defined based on a lane metre to passenger capacity ratio:

- *Ferry RoPax*, represent RoPax ships or ferries with focus on carriage of passengers but which can also carry cargo similar to a Standard RoPax. These ships typically only have closed ro-ro spaces or mainly closed ro-ro spaces and a small weather deck;
- *Standard RoPax*, represent the RoPax ships with focus on both carriage of cargo and of passengers. These vessels typically have each of the three types of ro-ro spaces: closed ro-ro spaces, open ro-ro spaces and weather decks. The size of the weather deck/s is generally medium to large within this category; and
- *Cargo RoPax*, represent RoPax ships with focus on carriage of cargo and basically have a passenger capacity just enough to carry the number of drivers necessary to load the ro-ro spaces with accompanied trailers. These vessels typically have closed ro-ro spaces and large weather deck/s.

The main fire risk model developed in FIRESAFE and upgraded in FIRESAFE II was consolidated with all the fault trees and sub-risk models that were previously developed with an aim to analytically investigate each of the fire protection chain components separately (namely Ignition, Detection, First Response, Decision, Extinguishment, Containment and Evacuation). The Potential Loss of Life (PLL) for the three ship categories considered was estimated on the basis of the consolidated main fire risk model.

A review of the RCOs investigated in FIRESAFE and FIRESAFE II was made to identify and quantify effects on other parts of the main fire risk model than that for which they were identified, with a view to conduct a combined cost-effectiveness assessment.

The comprehensive quantifications of the RCOs were integrated into the consolidated main fire risk model, from which effects on the overall risk could be calculated, thereby providing the benefit part of the cost-effectiveness assessment.

Thereafter, the costs associated with the implementation of the RCOs, estimated in FIRESAFE and FIRESAFE II, were recapitulated. However, the costs for the RCOs *Electrical fire* and *Suppression*, were only estimated for *Standard RoPax* in FIRESAFE and were hence necessary to derive also for *Cargo* and *Ferry RoPax*.

Based on the overall risk reductions and costs of the RCOs, the combined assessment was conducted with estimations of the Gross Cost of Averting a Fatality (GCAF) and Net Cost of Averting a Fatality (NCAF) for each RCO.

A few RCOs that were not found cost-effective in FIRESAFE and the first parts of FIRESAFE II were found cost-effective when considering their additional impacts on the rest of the fire protection chain. These RCOs were:

- Combined heat & smoke detectors and Alarm System Design & Integration (on *Cargo RoPax* Newbuildings, *Standard RoPax* Existing ships, and *Ferry RoPax* Existing ships);
- CCTV (for *Standard RoPax* Newbuildings and Existing ships, and *Ferry RoPax* Existing ships); and
- CCTV and Remote control (for *Standard RoPax* Existing ships).

The RCOs achieving the highest risk reduction in a cost-effective manner were:

- Regardless of the ship category:
  - Fire monitors on weather decks;
  - Robust connection boxes;
  - Combined heat and smoke and alarm system design and integration;
  - Alarm system design and integration (smoke);
  - IR camera; and
  - Improved markings/signage for wayfinding and localization.
- For Standard RoPax and Ferry RoPax:
  - Precondition for early activation of drencher system
  - CCTV and Remote control;
  - CCTV;
  - Remote control; and
  - Only ship cables.
- For Standard RoPax:
  - Safe distance
- For Ferry RoPax:
  - Safe distance (only for Newbuildings).

In addition to the above RCOs, the following RCOs were found cost effective and associated with a low cost:

  - Training for awareness;
  - Efficient activation routines;
  - Fresh water activation/flushing; and
  - Only crew connections

In view of the above combined cost-effectiveness assessment results, proposed amendments to IMO regulations are presented in this report for the implementation of Risk Control Options that proved to be cost-effective when considering their impacts along the whole fire protection chain.

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6 INTRODUCTION

6.1 Scope and Objectives

The main objective of FIRESAFE II was to improve the fire safety of ro-ro passenger ships by cost-efficient safety measures reducing the risk of ro-ro space fire, with an aim to discuss specific proposals for rule making. In Part 2.1 of the study, reported here, the objective was to conduct a combined assessment of all risk control options (RCOs) investigated in the FIRESAFE and FIRESAFE II studies, considering open ro-ro spaces, closed ro-ro spaces as well as weather decks, for both newbuildings and existing ships.

6.2 Background

In 2016, EMSA initiated the FIRESAFE study in order to investigate cost-efficient measures for reducing the risk from fires on ro-ro passenger ships with a focus on Electrical Fire as ignition source as well as Fire Extinguishing Failure. These areas were considered the greatest risk contributors by the EMSA Group of Experts on fires on ro-ro decks.

The study produced a coarse risk model covering the various stages of a fire incident on a ro-ro passenger ship, namely: Ignition, Detection/Decision, Extinguishment, Containment and Evacuation.

In 2017, EMSA initiated the FIRESAFE II study to investigate risk control options for mitigating the risk from fires in ro-ro spaces in relation to Detection and Decision (Part 1) as well as Containment and Evacuation (Part 2), which are items which were not addressed specifically in FIRESAFE.

Two additional parts, one focusing on alternative fixed fire-extinguishing systems for ro-ro decks (Part 3), and one part focusing on detection systems in open ro-ro spaces and weather decks (Part 4) were also included.

In this new study, a combined assessment of all risk control options investigated in the FIRESAFE and FIRESAFE II studies was performed.

6.3 Methodology

In order to achieve the objectives described in section 6.1, the following steps were followed:

- Problem Definition: The objective of this section is to clarify the objectives and clearly define the scope of the study. This was done through an analysis of the RoPax fleet and of relevant regulations, requirements. Three generic categories ships were defined to consider the diverse world fleet of RoPax ships. A summary of the results is provided in Chapter 7;
- Identification of Hazards and Risk Analysis: These steps of the FSA methodology were conducted for each of the parts in FIRESAFE and FIRESAFE II. The purpose of the Hazard Identification is to identify relevant hazards to the safety matter under consideration. Consecutively, the Risk Analysis step investigates in further detail the causes and initiating events of the accident scenarios identified in the Identification of Hazards. The different risk models and dedicated fault trees developed in FIRESAFE and FIRESAFE II were consolidated and recapitulated. A summary of these steps is detailed in Chapter 8;
- Risk Control Options: An overview of the various RCOs that were investigated in FIRESAFE and FIRESAFE II is provided. The RCOs were screened to identify the ones that were considered to affect other parts of the risk model (at different stages of the fire development phases) than that for which they were identified. The results of this step is provided in Chapter 9;
- Combined cost-effectiveness assessment: The RCOs are analysed in a way to facilitate the understanding of the costs and benefits resulting from the potential adoption of such RCOs. This results in a ranking of the RCOs from a cost-efficiency perspective. The results of this step are provided in Chapter 10; and
- Recommendations for Decision-Making: Based on the above tasks, and in particular the combined cost-effectiveness assessment, specific proposals for rule making are discussed. These discussions are presented in Chapter 11.

7 BACKGROUND INFORMATION

7.1 Analysis of the RoPax fleet

All information necessary to the completion of the FSA study were extensively detailed in the report for Part 1 (detection and decision) of the FIRESAFE II study. Only a summary of the results and details related to containment and evacuation are provided below.

7.1.1 *FIRESAFE II Fleet: Selection criteria & analysis*

The fleet under consideration was 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 build date on or after 01/01/1970;
- Froude number less than 0.5[1]; and
- Classed or having been classed by one the IACS members.

The FIRESAFE II fleet is composed of 811 ships active during the period 2002-2016 leading to a total of 7001 shipyears over the period 2002 – 2016 (very slight increase over the years).

The average age of the fleet is 20 years old in 2016, with an average loss age of 32 years old, (and maximum age of 46 years old.). The life expectancy (at delivery) over the period 2002-2016 was estimated to 39.2 years old.

7.1.2 *Definitions*

7.1.2.1 Ro-ro space, vehicle space and special category space

As per SOLAS II-2/3:

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

7.1.2.2 Closed, open and weather deck

As per SOLAS II-2/3:

- A "weather deck is a deck which is completely exposed to the weather from above and from at least two sides."
- IACS UI SC 86 additionally details that: "For the purposes of Reg. II-2/19 a ro-ro space fully open above and with full openings in both ends may be treated as a weather deck."

[1] To exclude High Speed Crafts.

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

7.2 Generic ships

Interested readers can refer to the first part FIRESAFE II (EMSA, 2018) for more detail on the generic ships selection process.

7.2.1 *Description of the generic ships chosen for the study*

7.2.1.1 Cargo RoPax

This sample ship is a representative design of a *Cargo RoPax* of a size of 13 294 GT. It was designed with a capacity of 186 persons onboard. The vessel is compliant with all relevant international rules and regulations. The ship is designed to SOLAS A.265 and later reconstructed to operate as per the SOLAS 90. Ship has 6 MVZ.

Passenger cabins are located in the superstructure on Deck 4, 5 and 6. Restaurant is located on Deck 6. The remaining part of Deck 4 consists in a garage and weather deck. Deck 2 is the main deck with ro-ro lanes throughout the full length of the ship. Lower hold on Deck 1 is for trailers and trucks. Picture of this ship is provided in Figure 1.

The total ro-ro area (excluding casings etc.) on the *Cargo RoPax* is 4 364m². 67% of this area is located in closed spaces (lower hold, main deck and garage), the remaining 33% being the weather deck.

Figure 1: Picture of the Stena Gothica (*Cargo RoPax* ship)

The main characteristics of the *Cargo RoPax* ship are detailed in Table 1 and the cargo decks particulars are further described in Table 2.

Table 1: Main characteristics of the *Cargo RoPax* ship

GENERAL	*Cargo RoPax*
Length overall	171,05 m
Breath moulded	20,25 m
Draught	5,27 m
Built	1982
Deadweight	4 750 t
Gross tonnage	13 294 t
Net tonnage	3 988 t
Cargo capacity	1 600 lm
Pax capacity	186 pax
Route	Göteborg - Frederikhamn, day and night
Passage time	3,5 hrs
Fire pump 1	71 m^3/h
Fire pump 2	70 m^3/h
Emergency fire pump	90 m^3/h
Drencher pump	288 m^3/h

Table 2: Description of the cargo decks of the *Cargo RoPax* ship

General description	Weather deck(+ garage), deck 4
Extinguish	Drencher (garage) Fire monitors[2] (WD)
Detection	Heat detectors (garage)
Containment	WD + garage with open aft
Ventilation	Mechanical
Cargo	Standard trailers/trucks
General description	**Main Deck, deck 2**
Extinguish	Drencher
Detection	Smoke detectors + Heat detectors (Heat det. in drencher section 6, ships length extended)
Containment	Closed ro-ro space
Ventilation	Mechanical
Cargo	Standard trailers/trucks
General description	**Lower Hold, deck 1**
Extinguish	Drencher
Detection	Smoke detectors
Containment	Closed ro-ro space
Ventilation	Mechanical
Cargo	Standard trailers/trucks

7.2.1.2 Standard RoPax

This sample ship is a common and popular design of a RoPax of a size of 26904 GT. It was designed for with a capacity of more than 880 persons onboard. The vessel is compliant with all relevant international rules and regulations. The ship is designed to and operating as per the SOLAS, 1974. Ship has 6 MVZ.

Passenger cabins are located in the superstructure on Deck 6, above the restaurant on Deck 5. The remaining part of Deck 5 consists of a weather deck for cars. Below on Deck 4 is located an open ro-ro space with a small weather deck in the aft. Deck 3 is the main deck with ro-ro lanes throughout the full length of the ship. A small car deck seldom used (about 82 cars) is located on Deck 2 and some 250 lane metres for trailers and trucks are situated in the lower hold on Deck 1. Picture of the ship is provided in Figure 2.

The total ro-ro area (excluding casings etc.) on the *Standard RoPax* is 9446m². The repartition between the different ro-ro spaces is as follows: 53% of closed spaces (lower hold, main deck and car deck), 32% of open spaces (garage) and 5% of weather deck.

[2] For the purpose of the study, in order to represent the most common situation in the world fleet, it is considered that a Cargo RoPax ship is not equipped with fire monitors

Figure 2: Picture of the Stena Flavia (*Standard RoPax ship)*

The main characteristics of the *Standard RoPax* ship are detailed in Table 3 and the cargo decks particulars are further described in Table 4.

Table 3: Main characteristics of the *Standard RoPax* ship

GENERAL	*Standard RoPax*
Length overall	186,5 m
Breath moulded	25,5 m
Draught	6,16 m
Built	2008
Deadweight	5 875 t
Gross tonnage	26 904 t
Net tonnage	8 912 t
Cargo capacity	2 200 lm
Pax capacity	830 pax
Route	Nynäshamn - Ventspils, day and night
Passage time	6-9 hrs, pending timetable
Fire pump 1	110 m^3/h
Fire pump 2	n/a
Emergency fire pump	110 m^3/h
Drencher pump	960 m^3/h

Table 4: Description of the cargo decks of the *Standard RoPax* ship

<table>
<tr><td>General description</td><td colspan="3">Weather Deck for cars, deck 5</td></tr>
<tr><td>Extinguish</td><td colspan="3">None</td></tr>
<tr><td>Detection</td><td colspan="3">None</td></tr>
<tr><td>Containment</td><td colspan="3">Weather deck</td></tr>
<tr><td>Ventilation</td><td colspan="3">None</td></tr>
<tr><td>Cargo</td><td colspan="3">Standard cars, minivans</td></tr>
<tr><td>General description</td><td colspan="3">Open ro-ro space/Weather Deck, deck 4</td></tr>
<tr><td>Extinguish</td><td colspan="3">Drencher (except for WD part)</td></tr>
<tr><td>Detection</td><td colspan="3">Smoke detectors (except for WD part)</td></tr>
<tr><td>Containment</td><td colspan="3">Open ro-ro space, side openings >10%, open aft towards small WD and ramp</td></tr>
<tr><td>Ventilation</td><td colspan="3">Natural + partly mechanical</td></tr>
<tr><td>Cargo</td><td colspan="3">Standard trailers/trucks</td></tr>
<tr><td>General description</td><td colspan="3">Main Deck, deck 3</td></tr>
<tr><td>Extinguish</td><td colspan="3">Drencher</td></tr>
<tr><td>Detection</td><td colspan="3">Smoke detectors</td></tr>
<tr><td>Containment</td><td colspan="3">Closed ro-ro space</td></tr>
<tr><td>Ventilation</td><td colspan="3">Mechanical</td></tr>
<tr><td>Cargo</td><td colspan="3">Standard trailers/trucks, Various ro-ro units</td></tr>
<tr><td>General description</td><td>Lower Hold, deck 1</td><td>General description</td><td>Car Deck in lower hold, deck 2</td></tr>
<tr><td>Extinguish</td><td>Drencher</td><td>Extinguish</td><td>Drencher</td></tr>
<tr><td>Detection</td><td>Smoke detectors</td><td>Detection</td><td>Smoke detectors</td></tr>
<tr><td>Containment</td><td>Closed ro-ro space</td><td>Containment</td><td>Closed ro-ro space</td></tr>
<tr><td>Ventilation</td><td>Mechanical</td><td>Ventilation</td><td>Mechanical</td></tr>
<tr><td>Cargo</td><td>Standard trailers/trucks</td><td>Cargo</td><td>Standard cars</td></tr>
</table>

7.2.1.3 Ferry RoPax

This sample ship is a common and popular design of a Ferry RoPax of a size of 30 285 GT. It was designed for with a capacity of more than 1 200 persons onboard. The vessel is compliant with all relevant international rules and regulations. The ship is designed to and operating as per the SOLAS 1997 including Stockholm Agreement. Ship has 5 MVZ.

Passenger cabins are located in the superstructure on Deck 8, above the restaurant on Deck 7. The remaining part of Decks 7 and 8 consists of decks for engine casing, life boats and rafts. Below on Deck 5/6 is located a closed ro-ro space with open end to a small weather deck in the aft. Deck 3 is the main deck with ro-ro lanes throughout the full length of the ship. A small car deck is located on Deck 2 and cars and vans are stowed in the lower hold on Deck 1. Picture of the ship is provided in Figure 3.

The total ro-ro area (excluding casings etc.) on the *Standard RoPax* is 9 446m². The repartition between the different ro-ro spaces is as follows: 53% of closed spaces (lower hold, main deck and car deck), 32% of open spaces (garage) and 5% of weather deck.

Figure 3: Picture of the Stena Superfast VIII (*Ferry RoPax* ship)

The main characteristics of the *Ferry RoPax* ship are detailed in Table 5 and the cargo decks particulars are further described in Table 6.

Table 5: Main characteristics of the *Ferry RoPax* ship

GENERAL	*Ferry RoPax*
Length overall	203,3 m
Breath moulded	25 m
Draught	6,6 m
Built	2001
Deadweight	5 920 t
Gross tonnage	30 285 t
Net tonnage	10 703 t
Cargo capacity	1 900 lm
Pax capacity	1 200 pax
Route	Belfast - Cairnryan, day and night
Passage time	2,5-3 hrs, pending timetable
Fire pump 1	150 m^3/h
Fire pump 2	n/a
Emergency fire pump	150 m^3/ h
Drencher pump	285 m^3/h

Table 6: Description of the cargo decks of the *Ferry RoPax* ship

General description	**Cargo Deck, deck 5**		
Extinguish	Drencher (except for WD part)		
Detection	Smoke/heat detector (except for WD part)		
Containment	Closed ro-ro space with open aft towards small WD		
Ventilation	Mechanical		
Cargo	This deck has 4 lanes which can take high freight traffic full 50% of crossings, the 2 outside lanes normally have drop trailers or cars.		
General description	**Main Deck, deck 3**		
Extinguish	Drencher		
Detection	Smoke/heat detector		
Containment	Closed ro-ro space		
Ventilation	Mechanical		
Cargo	Mix of running freight traffic and drop trailers. Cars/vans on busy trips.		
General description	**Lower Hold, deck 1**	**General description**	**Car Deck in lower hold, deck 2**
Extinguish	Drencher	**Extinguish**	Drencher
Detection	Smoke detectors	**Detection**	Smoke detectors
Containment	Closed ro-ro space	**Containment**	Closed ro-ro space
Ventilation	Mechanical	**Ventilation**	Mechanical
Cargo	Cars, vans.	**Cargo**	Cars, vans

8 HAZARD IDENTIFICATION AND RISK ANALYSIS

8.1 Identification of Hazards

For the first step of the Formal Safety Assessment methodology, as described in (IMO, 2018), Hazard Identification (HazId) workshops were conducted in FIRESAFE and FIRESAFE II in order to identify the causes and effects of accidents and relevant hazards, in relation to each of the fire protection chain components considered. Both hazards that have materialized in the past and those that have not been experienced (yet) were identified through analytical and creative techniques.

Interested readers can refer to the FIRESAFE and FIRESAFE II reports for the detailed results of the HazId workshops.

Furthermore, an analysis of the casualty historical data was performed in FIRESAFE (EMSA, 2016) and updated in FIRESAFE II (EMSA, 2018).

8.2 Background

The purpose of risk analysis in step 2 of the FSA process, as described in MSC-MEPC.2/Circ.12/Rev.2, is to undertake a detailed investigation of the frequencies and consequences of identified accident scenarios. This is 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.

This methodology has been acknowledged in document III 3/4/5 (IMO, 2016) and was used in the FIRESAFE study where three risk models (one event tree and two "fault trees") were developed to investigate the topics *Electrical Fires as ignition risk* and *Fire Extinguishing Failure*.

In particular, the main fire risk model (event tree) identified the pivotal events which affect the outcome of different fire scenarios in ro-ro spaces and had been developed in such a way that it could be used in future investigations into specific nodes beyond the scope of the first FIRESAFE study. The main fire risk model was subsequently updated in the first part of FIRESAFE II where a review and update of the model was conducted, leading to the introduction of dedicated branches in the event tree for *Detection*, *First response*, and *Decision* as well as *Containment* and *Evacuation* (or *fire integrity of evacuation routes and LSAs*).

The main fire risk model and the associated sub-models were developed in such a way that it is possible to assess, in quantitative values, the consequences of additional preventing and mitigating measures addressing the risks of containment and evacuation failures.

For *Detection, Decision Suppression,* and *Containment*, dedicated fault trees were developed focusing on the main fire hazards identified during the HazId. The trees were quantified to gain an understanding of the impacts on risks and to investigate in further detail the important causes and initiating events of the accident scenarios identified. This allowed quantification of the contributing failures as well as to calculate the overall failure rate. In order to consider the different types of ro-ro spaces, different trees were developed and quantified by investigation of available failure data, fire simulations and expert judgement, in case none of the previous options were available. For *Evacuation*, a sub-risk model was developed for investigating the impact on the safety distance to protect stowage areas, embarkation stations and LSA from fire.

All the fault trees and sub-risk models were consolidated within the main fire risk model.

8.3 Consolidated main fire risk model

The updated chain of events for FIRESAFE II is presented in Figure 4.

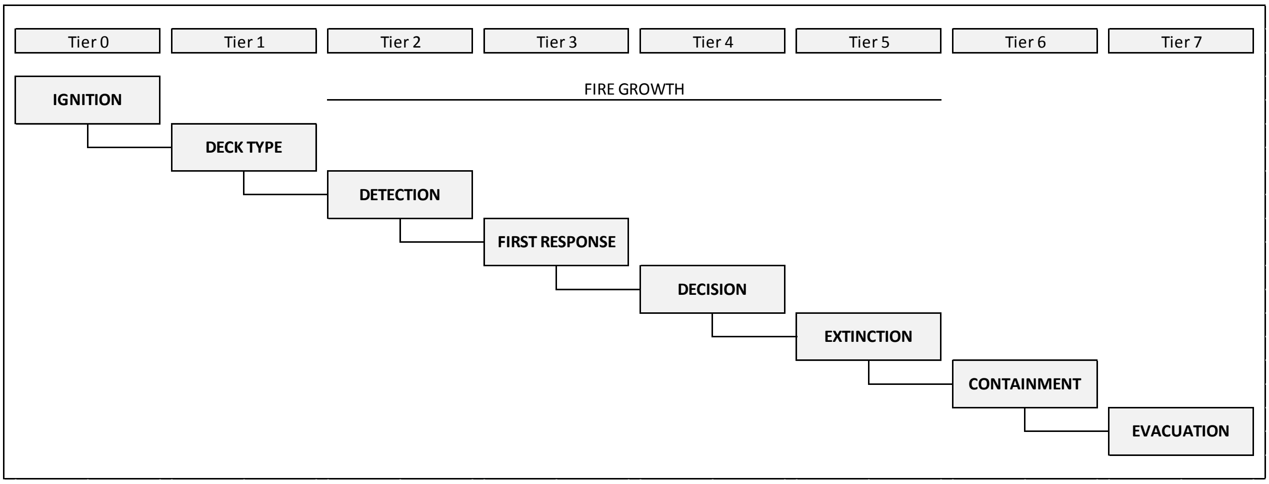

Figure 4: Updated chain of events for FIRESAFE II

As an illustration, the updated Main Fire Risk Model for the *Standard RoPax Newbuilding* (*Open ro-ro spaces* part only) is shown in Figure 5. The three parts (*Closed ro-ro spaces*, *Open ro-ro spaces*, and *Weather Deck*) are shown in the Annex A1.2. The event tree for the *Cargo RoPax* and the *Ferry RoPax* are provided in Annexes A1.1 and A1.3 respectively.

Altogether, the consolidated main fire risk model for the *Standard RoPax* consists of:

- The main event tree;
- One "fault tree" for the *Ignition risk;*
- Three fault trees for *Detection* (considering separately closed ro-ro spaces, open ro-ro spaces and weather decks)*;*
- Four fault trees for *Decision* (focusing on decision following an early detection and decision following a late detection, separating the closed and open ro-ro spaces fires where fixed detection systems are available from the weather deck case);
- Four fault trees for *Suppression* (considering the suppression of a fire in a closed ro-ro space following an early decision and following a late decision, and the suppression of a fire in an open ro-ro space taking into account the decision time);
- Six fault trees for Containment (for the following cases: Suppressed fire in a closed ro-ro space, Unsuppressed fire in a closed ro-ro space, Suppressed fire in an open ro-ro spaces, Unsuppressed fire in an open ro-ro space, Suppressed fire in a weather deck, Unsuppressed fire in a weather deck)
- Six sub-risk models for *Evacuation* (uncontained suppressed fire and uncontained unsuppressed fire for fires in a closed ro-ro space, in an open ro-ro space, and on a weather deck).

The fault trees were adapted to each generic ship (*Cargo RoPax*, *Standard RoPax* and *Ferry RoPax*) and potential differences between Newbuildings and Existing ships were taken into account. The structure of the trees remained identical but the quantifications differed.

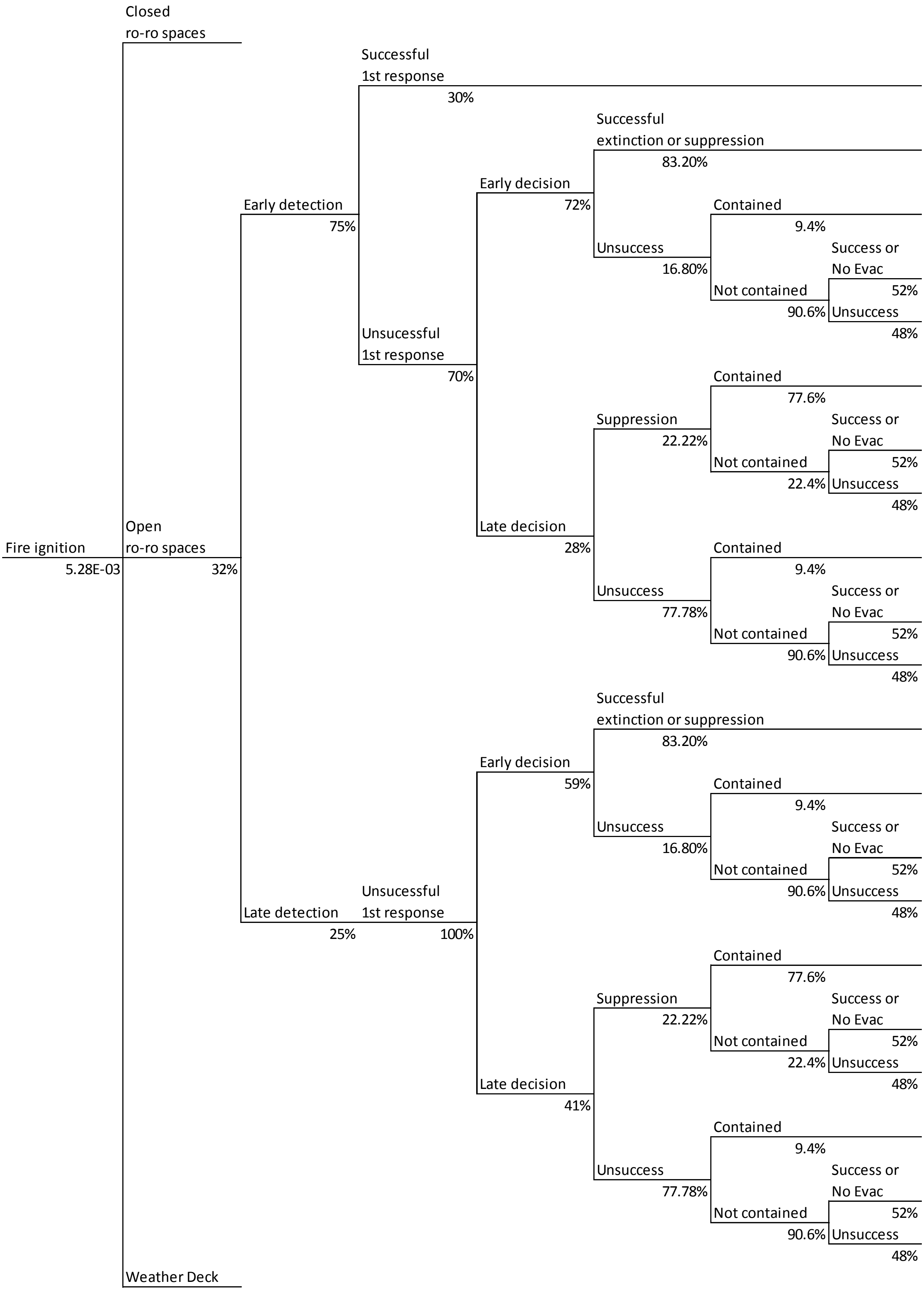

Figure 5: Updated Main Fire Risk Model for the *Standard RoPax* Newbuildings (*Open ro-ro spaces* part)

8.3.1 *Review of the nodes*

8.3.1.1 Ignition

The Ignition node is extensively elaborated in the FIRESAFE report (EMSA, 2016). The initial accident frequency was updated based on the findings described in the first part of FIRESAFE II (EMSA, 2018). The frequency of fires in ro-ro space was estimated to 5.28E-03 fires in ro-ro spaces per shipyear. However, the apportionment of fire causes was kept identical to FIRESAFE.

8.3.1.2 Deck type

The *Closed ro-ro spaces* / *Open ro-ro spaces* / *Weather Deck* proportion varies according to the specific design of the ships. As in FIRESAFE, it was assumed that the risk of ignition is evenly distributed on the different decks, i.e. 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 also to the amount of equipment.

8.3.1.3 Detection

The Detection node was investigated in detail in a dedicated part of FIRESAFE II (EMSA, 2018). The findings from this part were used to quantify the event tree.

The new concept introduced for Early/Late detection is related to whether it is possible to successfully perform first response and extinguish the fire in its initial stage. The criterion for “Early” detection was defined as that the *Available Time for Safe First Response* (the time available until conditions become untenable around the fire, disallowing first response) is longer than the *Required Time for Safe First Response* (the time to detect the fire and to set up actions for first response). Otherwise, the detection was considered to be too late to be able to extinguish the fire at its initial stage (for example with a hand-held fire extinguisher), based on that this cannot be done safely.

8.3.1.4 First response

As first response was out of the scope of this study, the figure found in FIRESAFE for *First response failure* (following an *Early detection*) was kept and no specific fault tree was developed. By definition, first response failure after a *Late detection* was set to 100%.

8.3.1.5 Decision

The Decision node was investigated in detail in a dedicated part of FIRESAFE II (EMSA, 2018). The findings from this part were used to quantify the event tree.

“Early” and “Late” decision should be understood in relation to the fire growth rate. “Early” means that the Decision to activate the system has been taken early enough to have a chance to extinguish the fire. “Late” means that the fire is already quite developed, and that it is too late to have a chance to extinguish it. However, the fire will still be suppressed upon system activation.

8.3.1.6 Extinguishment

The Extinguishment node was investigated in detail in the first FIRESAFE study (EMSA, 2016). As the focus of FIRESAFE was on the failure of the fixed fire extinguishing system, the branch *Weather Deck* was collapsed.

In FIRESAFE II, the findings from FIRESAFE were used to quantify the *Closed ro-ro space* and *Open ro-ro spaces* branches of the event tree. Failure of fire extinguishment on weather deck was set to 70% following an *Early Decision* (finding from FIRESAFE) and to 90% following a *Late Decision*.

8.3.1.7 Containment

The Containment node was investigated in detail in a dedicated part of FIRESAFE II (EMSA, 2018). The findings from this part were used to quantify the event tree.

The expression "fire containment" was defined as avoidance of fire and smoke propagation impeding a safe stay on board. If fire or smoke spreads to other parts of the ship than the originating ro-ro space of the fire, the fire was thus considered uncontained. With regard to fire spread, both flame spread (e.g. through openings) and heat spread causing fire in adjacent areas were considered. Various potential failures were considered for each of these main nodes, but for weather deck a simplified fault tree was used including only the main nodes. With regard to smoke spread, both internal and external smoke spread were considered and elaborated, with focus on the potential for internal smoke spread. External smoke spread for example includes external spread to the accommodation or engine room air intakes.

The success or failure of containment affects whether evacuation is necessary. In case of fire containment, no evacuation was assumed to be necessary, while in case of failure of fire containment, evacuation was assumed necessary.

8.3.1.8 Evacuation

The Evacuation node was investigated in detail in a dedicated part of FIRESAFE II (EMSA, 2018).

Evacuation failure was defined as an event during which at least one LSA is rendered inoperable due to fire or other modes of failure not related to fire. The latter includes failure due to adverse weather conditions, technical failure, and operational failure. These are henceforth encompassed in the definition "intrinsic failure of the evacuation". An event tree related to evacuation of RoPax ships developed by (Vanem & Skjong, 2004) was adapted to take into account both evacuation impeded by fire and intrinsic failure of evacuation.

8.3.1.9 Consequences

The findings of FIRESAFE (EMSA, 2016) were kept to populate the consequence part of the risk model. While the variety of outcomes was recognized, an average value for the number of fatalities is sufficient to calculate a PLL.

A fatality rate of 8% of the Persons On Board was hence used to calculate the average fatalities following the scenario: fire on vehicle deck / escalation / unsuccessful evacuation. When evacuation is successful, a 1 equivalent fatality fixed value was assigned to take into account the frequent injuries and possible indirect fatalities following such evacuation. No fatalities were considered in the other cases.

Consequences for property (cargo and ship) were also discussed in FIRESAFE and the same values were assumed in FIRESAFE II. The consequences following a fire put out by the crew (manual first response) was considered identical as a fire detected early and put out by means of the drencher system.

8.5 Risk quantification

Based on the consolidated main fire risk model described above, the Potential Loss of Life were compiled for the three vessel categories (Newbuildings and Existing ships), as presented in Figure 6.

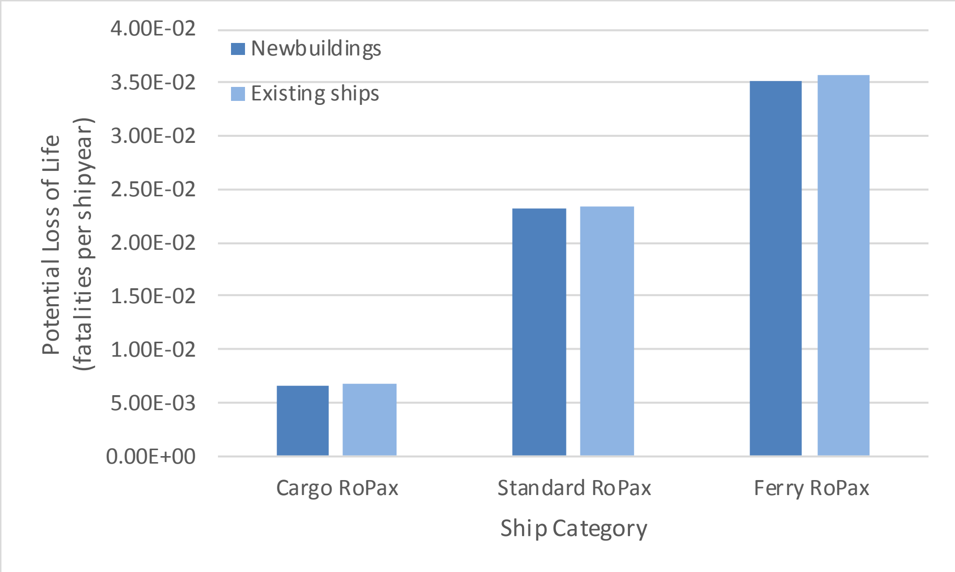

Figure 6: Potential Loss of Life (PLL) for the three generic ships considered

In comparison with the PLL derived from historical data, the PLL figures derived from the event risk model are lower. Although the consequence part of the main fire risk model was developed to be representative of the average consequences of accidents, it should be noted that a single accident leading to a high number of fatalities within a limited period in time may skew the estimated historical societal risk. This may create a difference between the estimated historical societal risk and the risk estimated with the risk model.

It should be noted that the PLL of the *Cargo RoPax* is much lower than the PLL of the *Standard RoPax* and *Ferry RoPax*, mainly due to the low passenger capacity of the *Cargo RoPax*. A low difference between the PLLs for Newbuildings and Existing ships was found, mainly due to the fact that the only difference considered in this study is the non-addressability of the detection systems on Existing ships.

In addition to the risk to human life, the risks to the property (cargo and ship) were considered. The Potential Loss of Cargo and Potential Loss of Ship were estimated and are presented in Figure 7. Similar to the first FIRESAFE study, no differences in ship damages were considered between Existing ships and Newbuildings.

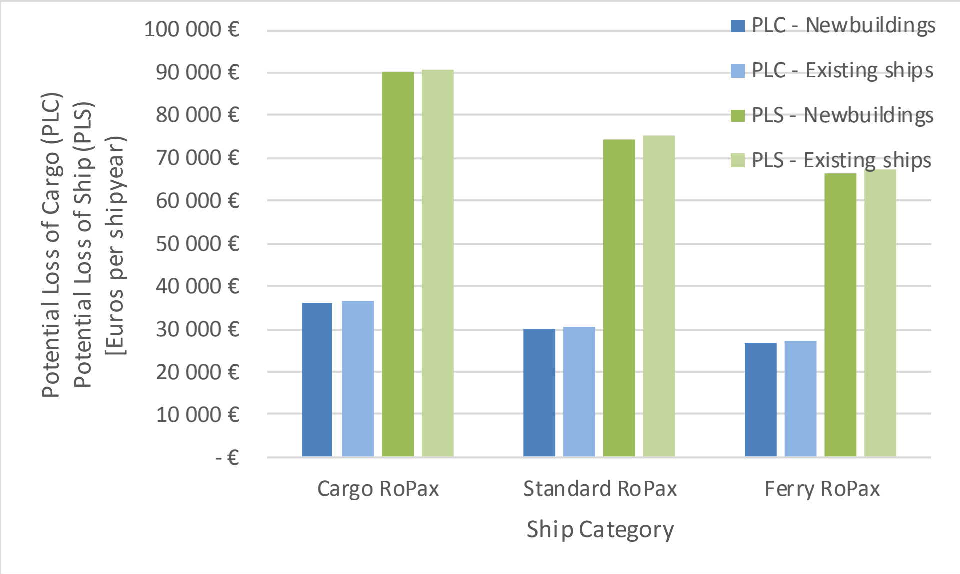

Figure 7: Potential Loss of Cargo (PLC) and Potential Loss of Ship (PLS) for the three generic ships considered

9 RISK CONTROL OPTIONS

9.1 RCOs investigated in FIRESAFE and FIRESAFE II

An overview of the various RCOs that were investigated in FIRESAFE and FIRESAFE II is provided below:

- El1 Robust connection boxes
- El2 Only ship cables
- El3 IR camera
- El4 Training for awareness
- El5 Only crew connections
- El6 Cable reeling drums
- Det1 Combined heat & smoke
- Det2 Ban / closure of side (PS & SB) openings (open ro-ro spaces)
- Det3 Increased frequency fire patrols
- Dec1 Alarm System Design & Integration
- Dec2 Improved markings/signage for wayfinding and localization
- Dec3 Preconditions for Early Activation of Drencher System
- Su 1 Remote control
- Su 3 Rolling shutters (PS & SB side) (Open ro-ro spaces)
- Su 4 Efficient activation routines
- Su 5 Fresh water activation/flushing
- Su 6 CCTV
- Su 7 CCTV + Remote control
- Cont1 Ban/closure of side & end openings
- Cont2 Fire monitors on weather deck
- Evac1 Safe distance

9.1.1 *Description*

Short descriptions of the RCOs are provided in the following paragraphs. For more detailed descriptions, interested readers may refer to FIRESAFE (EMSA, 2016), FIRESAFE II Part 1 (EMSA, 2018) and FIRESAFE II Part 2 (EMSA, 2018).

9.1.1.1 Robust connection boxes

This RCO focused on the protection of the connection boxes. Some or all of the features suggested 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;
- Increased maintenance of the connection boxes;
- IP-class (e.g. IP56);
- Individual circuit breakers;
- Individual and interlocked switches; and
- Secured cables.

9.1.1.2 Only ship cables

The purpose of this RCO was to avoid unknown cables being 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 were to be further developed (cables shall be treated as consumables).

9.1.1.3 IR camera

This RCO proposed that portable thermographic cameras were to be used for screening during fire rounds or upon suspicion to detect hot areas and overheated electrical equipment as many of the fires caused by an electrical problem starts with overheating. Such cameras could also be useful to detect mechanically overheated equipment which also could start a fire. The cameras were to be dedicated to the ro-ro space personnel (no sharing).

9.1.1.4 Training for awareness

This RCO dealt with knowledge and training. All crew involved in cargo operations were to be made aware of the hazards of substandard installations and other possible electrical fire hazards of the cargo. This were to be part of a training program that should be included in familiarization and ongoing training processes. Routines for reviewing units and performance of directed inspections were to be included as well as routines about how to handle the risk.

9.1.1.5 Only crew connections

The RCO proposed to only allow trained crew to connect and disconnect cables. A training program were to be developed which should include training and routines for control of, care for and maintenance of cables. The crew were to 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.

9.1.1.6 Cable reeling drums

This RCO focused on protecting cables and facilitating their handling through the installation of cable reeling drums. These were to be 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.

9.1.1.7 Combined smoke and heat detection

This RCO proposed that conventional integrated point smoke and heat detection system (i.e. detector is a conventional point smoke detector with an extra temperature sensor) were to be installed in ro-ro spaces. The same coverage as the one required for the smoke detectors in the FSS code were considered.

9.1.1.8 Ban / closure of side (PS&SB) openings (open ro-ro spaces)

This risk control option consists in forbidding the design of RoPax with open ro-ro spaces and closing the existing side openings of the open ro-ro spaces for Existing ships. For Newbuildings, the design of RoPax without open spaces shall be designed according to the regulations. No additional safety improvement is investigated in the context of this RCO. For Existing ships, the side openings shall be closed with steel plates. The “new” closed ro-ro space shall comply with the regulations applicable to closed ro-ro spaces.

9.1.1.9 Increased frequency of fire patrols

This RCO implied increasing the frequency of fire patrols from every 60 minutes to every 30 minutes. No change in the quality of the fire patrol is investigated.

9.1.1.10 Alarm System Design & Integration

This RCO considered an alarm system that fully supports fire incident decision-making, as well as other resources on the bridge relevant for fire-related decision-making designed to provide immediate, precise and accessible information to support the localisation of a fire.

9.1.1.11 Improved markings/signage for wayfinding and localization

This RCO investigated the impact of improved signage and markings in the ro-ro space supporting wayfinding and orientation in case of fire. They were to be designed for easy identification and interpretation by a variety of users representing normal individual variations.

9.1.1.12 Preconditions for Early Activation of Drencher System

This RCO consisted in the inclusion of the early activation of the drencher system in fire management procedures while also ensuring that a large portion of the crew has the knowledge and mandate for drencher activation, without fear of negative consequences for the individual crewmember.

9.1.1.13 Remote control

This RCO investigated a remote control of drencher system from the bridge or the ECR or the safety centre. A runner were still to be sent to the drencher station upon fire alarm even if remote control is installed.

9.1.1.14 Rolling shutters (PS & SB side) (Open ro-ro spaces)

This RCO consisted in the installation of remotely controlled rolling shutters (A-0 fire rated) on the side openings of open ro-ro spaces to reduce the impact of wing on the ability of the drencher systems ability to put out a fire.

9.1.1.15 Efficient activation routines

This RCO investigated improved and more efficient routines for activation of the drencher system This RCO resulted in an increase of the crew understanding and knowledge about the drencher system and of possible fire development in ro-ro-spaces to increase the probability that the crew discovers possible faults even before a real fire starts and improve the capability of the crew to handle and quickly solve unexpected problems during a fire. Simple and clear communication procedures were to be developed.

9.1.1.16 Fresh water activation/flushing

This RCO consisted 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 was also assumed that in a real fire sea water will be used.

9.1.1.17 CCTV

This RCO considered the use of CCTV camera to have fire confirmation when a fire alarm is received. The cameras should be placed in a pattern to cover the most of a space with at least one camera per section. The camera covering the detector that gives fire alarm should be automatically displayed on the screen with information on which drencher section.

9.1.1.18 CCTV + Remote control

This RCO combined the previously described RCOs *CCTV* and *Remote Control* to allow quicker confirmation of the fire in addition to the quicker release of the drencher. The normal procedure to send a runner to the site were still to be maintained.

9.1.1.19 Ban/closure of side & end openings

This risk control measure implies to forbid open ro-ro spaces on new ships and to reduce openings (including aft openings) in general as far as practicable. Openings in the sides of the ship were in this RCO assumed to be welded shut on existing ships and omitted on newbuildings, making the spaces permanently enclosed. The fire integrity of the covered openings should achieve the same requirements as the rest of the division, which towards external areas or open deck generally is A-0, in accordance with SOLAS II-2/9.

9.1.1.20 *Fire monitors on weather deck*

This RCO implied that weather deck on ro-ro passenger ships were to be provided fixed fire monitors for the purpose of containing a fire in the space/area of origin. All systems are chosen so that existing drencher pumps and sea chests can be used for water supply. The chosen system has possibility for remote control.

9.1.1.21 *Safe distance*

The purpose of this RCO was to ensure safe evacuation on RoPax ships. The RCO prescribed a design with:

- A [13 m] safety distance between LSA embarkation stations and weather deck/ro-ro space aft openings;
- An [8 m] safety distance between stowed LSAs (including survival craft, not embarked onboard) and weather deck/ro-ro space aft openings; and
- No LSAs or embarkation station within the full vertical range 6 m forward and aft of a side opening larger than 0.01 m^2.

9.1.2 *Summary of results of FIRESAFE and FIRESAFE II*

The above quantifications of the selected containment RCOs were integrated into the consolidated main fire risk model, from which effects on the total risk could be calculated. The relative risk reductions of the RCOs for each of the generic ships are presented in Figure 8 for Newbuildings and in Figure 9 for Existing ships. The results are presented in terms of relative risk reductions to standardize the impact (reduction) of the RCO on the PLL, which is different for the three generic ships, for example depending on their varying passenger capacities.

9.1.2.1 *Newbuildings*

Three RCOs exceed 15% relative risk reduction. All these RCOs are related to Containment or Evacuation. On the *Cargo RoPax* and *Standard RoPax*, the RCO with the highest risk reduction potential is *Fire monitors on weather deck* with a relative risk reduction of approximately 42% and 23% respectively. This can be explained by the relatively important size of the weather decks, which are relatively unprotected. For the *Standard RoPax,* an RCO providing an almost as high impact is the RCO *Ban / Closure of all side openings*, with a relative risk reduction of 17%. On the *Ferry RoPax,* the RCO with the highest risk reduction is the RCO *Safe distance.*

Three RCOs provide risk reduction above 10% (but below 15%). These are *Robust Connection Boxes, Training for Awareness* and *Precondition for early activation of the drencher system* (except for *Cargo RoPax*).

It should be noted that the relative risk reductions presented and discussed above only take into account the effects of the RCOs on their respective nodes in the main fire risk model event tree. However, any effects that the RCOs could have directly on the other main branches of the main fire risk model event tree were disregarded in FIRESAFE and the first parts of FIRESAFE II. It is the intent of this Combined Assessment to consider these interactions.

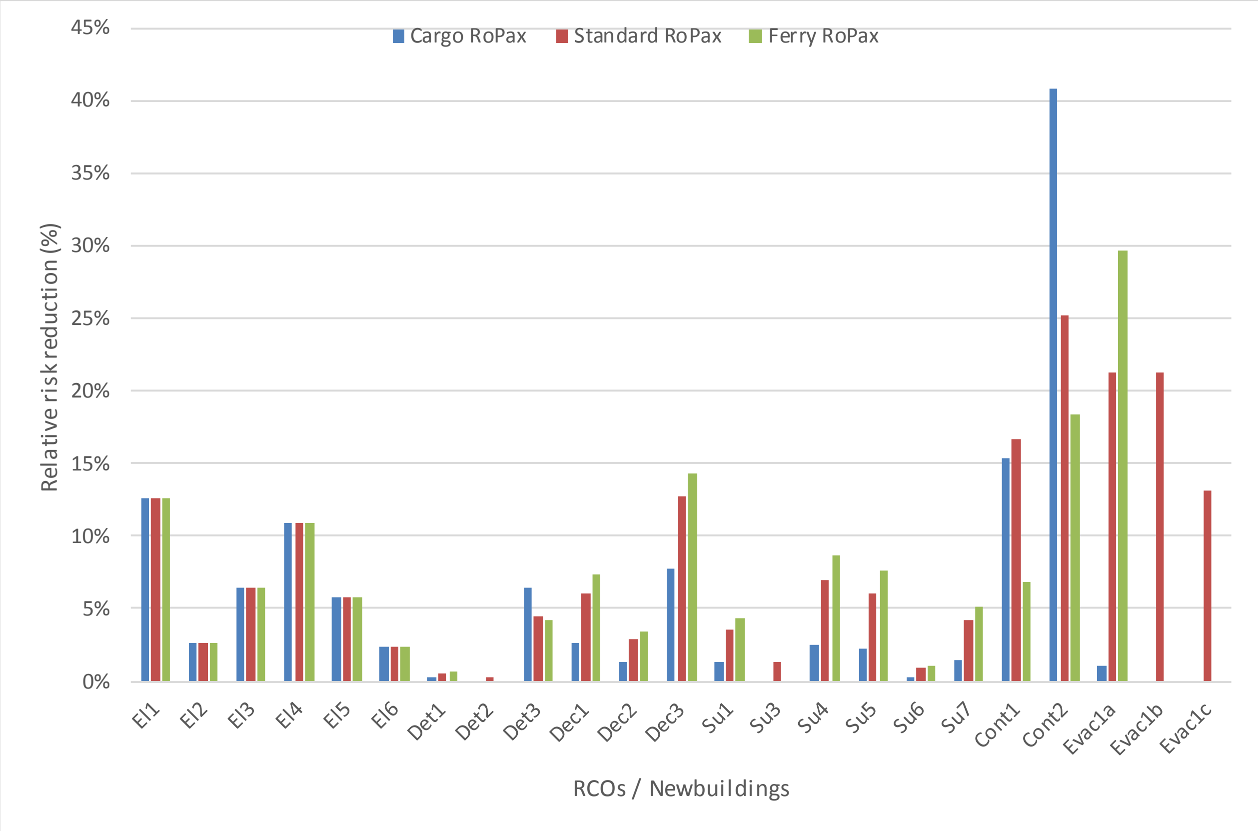

Figure 8: Relative risk reduction of all investigated RCOs in FIRESAFE and FIRESAFE II on Newbuildings (only impact on their respective node is accounted for)

For all evaluated RCOs, the GCAF Factors calculated in FIRESAFE and Parts 1 and 2 of FIRESAFE II (i.e. only taking into account impact on their respective node) are summarised in Table 7.

Table 7: GCAF Factor of all investigated RCOs in FIRESAFE and FIRESAFE II on Newbuildings (only impact on their respective node is accounted for)

		Newbuildings		
RCO #	**Description**	**Cargo RoPax**	**Standard RoPax**	**Ferry RoPax**
El 1	Robust connection boxes	0.08	0.04	0.03
El 2	Only ship cables	1.49	0.49	0.32
El 3	IR camera	0.19	0.06	0.04
El 4	Training for awareness	0.02	0.01	0.00
El 5	Only crew connections	0.02	0.01	0.00
El 6	Cable reeling drums	5.07	3.88	2.55
Det1	Combined heat & smoke detection	3.66	0.53	0.28
Det2	Ban / closure of side (PS & SB) openings (open ro-ro spaces)	N/A	210.36	N/A
Det3	Increased frequency of fire patrols	10.80	2.49	3.12
Dec1	Alarm system design & integration	0.40	0.05	0.03
Dec2	Improved markings for wayfinding and localisation	0.12	0.02	0.01
Dec3	Preconditions for early activation of drencher system	1.48	0.26	0.15
Su 1	Remote control	4.34	0.44	0.24
Su 3	Rolling shutters	N/A	13.55	N/A
Su 4	Efficient activation routines	0.00	0.00	0.00
Su 5	Fresh water activation/flushing	0.17	0.02	0.01
Su 6	CCTV	11.27	1.00	0.62
Su 7	CCTV + Remote control	5.94	0.60	0.32
Cont1	Ban/closure of side & end openings (closed and open ro-ro spaces)	2.43	3.30	1.99
Cont2	Fire monitors on weather deck	0.13	0.07	0.04
Evac1a	Safe distance / Closing all significant openings	35.34	2.59	0.46
Evac1b	Safe distance / Closing all side openings	N/A	3.60	N/A
Evac1c	Safe distance / Closing openings near LSAs	N/A	0.00	N/A

9.1.2.2 Existing ships

The same elements are provided for Existing ships in Figure 9 and Table 8.

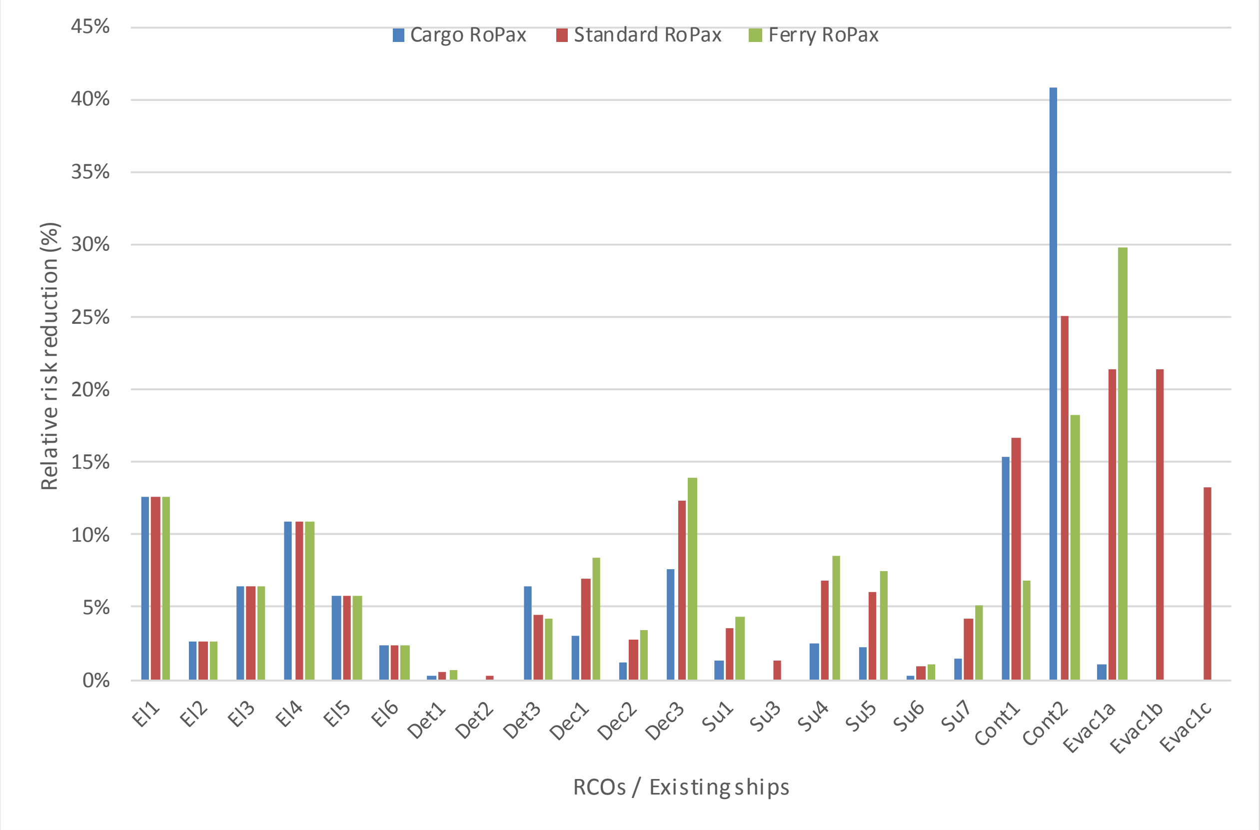

Figure 9: Relative risk reduction of all investigated RCOs in FIRESAFE and FIRESAFE II on Existing ships (only impact on their respective node is accounted for)

Table 8: GCAF Factor of all investigated RCOs in FIRESAFE and FIRESAFE II on Existing ships (only impact on their respective node is accounted for)

		Existing ships		
RCO #	**Description**	**Cargo RoPax**	**Standard RoPax**	**Ferry RoPax**
El 1	Robust connection boxes	0.13	0.08	0.06
El 2	Only ship cables	2.05	0.70	0.46
El 3	IR camera	0.27	0.08	0.05
El 4	Training for awareness	0.04	0.01	0.01
El 5	Only crew connections	0.04	0.01	0.01
El 6	Cable reeling drums	8.09	6.16	4.04
Det1	Combined heat & smoke detection	59.17	9.11	1.67
Det2	Ban / closure of side (PS & SB) openings (open ro-ro spaces)	N/A	315.23	N/A
Det3	Increased frequency of fire patrols	14.26	3.26	4.06
Dec1	Alarm system design & integration	5.02	0.67	0.13
Dec2	Improved markings for wayfinding and localisation	0.24	0.04	0.02
Dec3	Preconditions for early activation of drencher system	1.98	0.35	0.20
Su 1	Remote control	9.69	0.97	0.53
Su 3	Rolling shutters	N/A	34.30	N/A
Su 4	Efficient activation routines	0.01	0.00	0.00
Su 5	Fresh water activation/flushing	0.66	0.07	0.04
Su 6	CCTV	23.41	2.07	1.28
Su 7	CCTV + Remote control	12.92	1.31	0.70
Cont1	Ban/closure of side & end openings (closed and open ro-ro spaces)	4.56	5.31	76.77
Cont2	Fire monitors on weather deck	0.34	0.18	0.11
Evac1a	Safe distance / Closing all significant openings	65.80	4.13	17.58
Evac1b	Safe distance / Closing all side openings	N/A	5.46	N/A
Evac1c	Safe distance / Closing openings near LSAs	N/A	0.04	N/A

9.2 Additional Impacts of the RCOs

The relative risk reductions and cost efficiency of the RCOs described above only take into account the effects of the RCOs on the respective main nodes (fault trees) of the main fire risk model for which they were identified.

A workshop gathering some of the experts involved in FIRESAFE and the two first parts of FIRESAFE II was held to identify and quantify the effects of RCOs on other parts of the main fire risk model.

Several RCOs were considered to affect other parts of the risk model (at different stages of a fire development) than that for which they were identified. Not all of the RCOs were considered applicable for the three generic ships. In particular, all the risk control options focusing on the ban or closure of openings for open ro-ro spaces (namely *Det2: Ban / closure of side (PS & SB) openings (open ro-ro spaces)* and *Su3: Rolling shutters*) were only applicable for the selected *Standard RoPax* ship. The RCO *Safe distance* was not relevant for the *Cargo RoPax* ship.

Table 9: Impact of the RCOs on the different nodes of the consolidated main fire risk model - Grey: RCO investigated within the considered node: Light grey: additional impact

		Nodes						
RCO#	**RCO**	**Ign**	**Det**	**1st R.**	**Dec**	**Ext**	**Cont**	**Evac**
El1	Robust connection boxes							
El2	Only ship cables							
El3	IR camera							
El4	Training for awareness							
El5	Only crew connections							
El6	Cable reeling drums							
Det1	Combined heat & smoke and alarm integration system							
Det2	Ban / closure of side (PS & SB) openings (open ro-ro spaces)							
Det3	Increased frequency fire patrols							
Dec1	Alarm System Design & Integration							
Dec2	Improved markings/signage for wayfinding and localisation							
Dec3	Preconditions for Early Activation of Drencher System							
Su 1	Remote control							
Su 3	Rolling shutters (PS & SB side) (Open ro-ro spaces)							
Su 4	Efficient activation routines							
Su 5	Fresh water activation/flushing							
Su 6	CCTV							
Su 7	CCTV + Remote control							
Cont1	Ban/closure of side & end openings (closed and open ro-ro spaces)							
Cont2	Fire monitors on weather deck							

9.3 Quantification of RCO effectiveness

9.3.1 *Additional risk reduction potential on other relevant nodes*

9.3.1.1 EI1: Robust connection boxes

9.3.1.1.1 Decision

The robust connection boxes are equipped with an earth fault indication. By combining these indications with the information received from the fire alarm system panel, a faster and more accurate localisation of the fire is expected.

The findings from FIRESAFE demonstrated that 18% of the fires were caused by reefers connected to the electrical system of the ship. The experts estimated that the additional information provided by robust connection boxes will contribute to improved localisation for one third of these fires in closed and open ro-ro spaces. Hence, a 6% risk reduction potential was allocated to the node *Late confirmation* - *Late manual confirmation* - *Late localisation* - ***Inadequate strategy*** for fires detected early.

9.3.1.2 EI2: Only ship cables

This Risk Control Option is a purely preventive RCO. Its implementation was only considered to impact fire ignition, without relevance for the other nodes.

9.3.1.3 EI3: IR camera

This RCO was initially intended as a preventive measure. It has been observed that many of the fires were caused by an electrical problem starts with overheating. Hence, it was proposed that potential fires could be detected and avoided if overheated equipment could be found. With the IR cameras becoming part of the equipment of the fire patrols, this can be beneficial for *Detection* and *Decision*. However, this type of IR cameras are not meant to be used by the fire-fighting team during manual firefighting, hence no effect was considered on the Suppression node. The below risk reduction applies for closed and open ro-ro spaces as well as weather decks.

9.3.1.3.1 Detection

The IR camera can be used after a suspicion has already been raised (e.g. due to smell, hearing a miss sound, seeing a connection that does not look right, or sensing abnormal heat when passing a vehicle/cargo). However, relevant training and experience is needed for the equipment to give an improvement. In that sense, the experts estimated a 50% the risk reduction for *Late/no manual detection* - *Fire patrol failure* - *Quality failure* - ***Lack of equipment***.

9.3.1.3.2 Decision

Following an early detection, an IR camera also allows to investigate areas not reachable for the patrol due to height or accessibility problems, and to localise the seat of the fire. However, experts estimated that such equipment could be relevant in only a small proportion of these fires, since the equipment will likely mainly be used following identification of previous suspicion, leading to a risk reduction of only 5% for *Late confirmation* - *Late manual confirmation* - *Late localisation* - ***Inadequate equipment***

9.3.1.4 EI4: Training for awareness

This RCO was also initially intended as a preventive measure. However, the increased crew awareness of the hazards of substandard installations and other possible electrical fire hazards of the cargo benefits the *Detection* and *Decision*. The below risk reductions are independent from the type of ro-ro spaces where the fire occurs.

9.3.1.4.1 Detection

It was expected from the experts that the routines for reviewing units and the performance of directed inspections implied by the RCO would lead to increase surveillance and monitoring by the fire patrol of the cargo considered as hazardous by the crew members. In addition, the training programme involving increased awareness of smell, damaged vehicles, heat radiation, "smart installations", open windows, late and overheated buses and other signs of possible fire risks were expected to reduce the failure due to lack of training and experience. Therefore, a 75% risk reduction has been assigned to the node *Late/no manual detection - Fire patrol failure - Quality failure - **Lack of training / experience***.

This training is also expected to affect the motivation of the fire patrol members since some additional rationale is provided on what to look for, how and why. Nevertheless, a lot of other aspects are susceptible to influence the motivation. The risk reduction associated with the node *Late/no manual detection - Fire patrol failure - Quality failure - **Low motivation*** has been estimated to 30%.

9.3.1.4.2 Decision

The swiftness of the decision process is impacted by the training for awareness as the runner sent to confirm the fire directly knows what is most relevant to look for and where (through the awareness of the most common ignition sources). Some ways of guiding the fire confirmation action were considered to also be part of this RCO. Therefore, a tenfold reduction (90%) was estimated for the node *Late confirmation - Late manual confirmation - Late localisation - **Inadequate strategy***.

9.3.1.5 EI5: Only crew connections

This Risk Control Option is a purely preventive RCO. Its implementation was only considered to impact fire ignition, without relevance for the other nodes.

9.3.1.6 EI6: Cable reeling drums

This Risk Control Option is a purely preventive RCO. Its implementation was only considered to impact fire ignition, without relevance for the other nodes.

9.3.1.7 Det1: Combined heat & smoke and Alarm System Design & Integration

This Risk Control Option required that conventional integrated point smoke and heat detection system were to be installed in ro-ro spaces. Due to the additional amount of information received compared to a smoke detection system, this RCO is considered hand in hand with the RCO Alarm System Design & Integration.

9.3.1.7.1 Detection

It was checked that the Alarm System Design and Integration does not affect the system internal or external detection failure and has no impact on manual detection. Consequently the same risk reduction was used for quantifying the risk reduction of this RCO in the Detection Fault tree as for the Combined heat and smoke detection RCO.

9.3.1.7.2 Decision

In the first part of FIRESAFE II (EMSA, 2018), experts estimated that the node “alarm is wrongly dismissed” benefits from a 33% risk reduction thanks to the Alarm System Design and Integration. Considering a combined heat and smoke detection system, in addition to this improved alarm system, will reduce the risk of alarms being mistaken for known ongoing activities, such as maintenance work or loading/unloading of cargo, since both smoke and fire alarms are received. It is also believed that heat detection is given greater consideration than smoke detection. Therefore, the node *Late alarm interpretation - **Alarm is wrongly dismissed*** was assigned a 67.5% risk reduction following Early detection and a 83% risk reduction following Late detection. The latter implies a more developed fire, increasing the chance of both heat and smoke detection.

In a similar way as for the additional information provided by the robust connection boxes, additional information provided by the heat detection, which proved to be less prone to be sensitive to wind and high airflow, contributes to faster and more accurate localisation of the fire by the runner. It was estimated by the experts that this additional information, received in 35% of the time in case of Early Detection, can be efficiently used in half of the situations. This led to a risk reduction of 17.5% for the node *Late confirmation - Late manual confirmation - Late localisation -* ***Inadequate strategy***.

All the others risk reductions brought by the Alarm System Design and Integration on the different nodes remain unchanged when considering the additional heat and smoke detection feature.

9.3.1.7.3 Extinguishment

Heat detectors along with an improved alarm system offer clear and unambiguous information about the location, context and spread of the fire, providing valuable information for making better informed decisions with regard to fire extinguishment. In particular, it allows a tactical usage of the drencher system, which decrease the probability of the fire to exceed the capability of the drencher system. For these reasons, the experts estimated that, following an Early Decision, this RCO decreases by 50% the quantification of the node *Fixed system fail - Design incapacity -* ***Fixed system***. The RCO was expected to have no impact on this node following a Late decision.

9.3.1.7.4 Containment

The features discussed above also provide some benefits with regard to containment, as relevant information is made available to the decision maker for how manual and fixed fire suppression measures can be used as for active containment (to cool down some critical parts for containment). The RCO was then expected to have a 30% impact on the node *Failure of fire containment - Heat spread -* ***Failure of boundary cooling***.

The Alarm System Design & Integration feature will allow to react to "small containment failure", such as small smoke leaks, allowing crew members to act accordingly to avoid severe consequence worsening the situation (e.g. close doors, check seals and fire dampers, choose inlet ventilation). These were translated by the experts as a 15% risk reduction in all the nodes of the *Failure of smoke containment - Internal smoke spread - Weakness of division smoke tightness,* except for the node *Prescriptive design according to the FTP code*.

9.3.1.8 Det2 Ban / closure of side (PS & SB) openings (open ro-ro spaces)

This RCO was investigated in the first part of the study in the context of Detection. However, the presence or absence of side openings also influences some of the subsequent parts of the fire protection chain: extinguishment, containment and evacuation. This RCO only applies for open ro-ro spaces (*Standard RoPax* only).

9.3.1.8.1 Extinguishment

FIRESAFE reported that extinguishment in an open ro-ro space may be impeded by crosswinds. By closing the side openings, crosswinds are avoided. A 100% risk reduction was assigned to the node *Fixed system fail - Technical failure - Distribution failure -* ***Wind***.

9.3.1.8.2 Containment

This RCO only aimed at closing or forbidding the side openings, and closing the aft openings was not considered. Therefore, based on the discussions in the Containment part, all the risk reductions (positive and negative) considered for the RCO Ban/closure of side & end openings (closed and open ro-ro spaces) were decreased by 50%.

9.3.1.8.3 Evacuation

Closing all side openings was one of the design investigated in order to achieve the Evacuation RCO “Safe distance”. The findings from this part is used for the Combined Assessment.

9.3.1.9 Det3 Increased frequency fire patrols

This RCO was initially intended to increase the likelihood that a fire patrol passes during the incipient phase of a fire, therefore increasing the probability of early detection.

9.3.1.9.1 Decision

Consequently, this RCO changes the proportion of fire discovered by fire patrol, which makes the failure modes *Late deployment of runner and Long travel time to detection point* irrelevant in those cases. A 12% reduction has been assigned to the nodes *Late confirmation - Late manual confirmation - Late arrival at detector point - **Late deployment of runner*** and *Late confirmation - Late manual confirmation - Late arrival at detector point - **Long travel time to detection point***, as well as in the node *Late confirmation - Late manual confirmation - **Failure of communication*** as the members of the fire patrol are more likely to be swift and accurate in their communication than non-dedicated crew members or passengers.

9.3.1.10 Dec1 Alarm System Design & Integration

Although this system provides an improved integration of information on the bridge allowing better informed decision, without the combined heat and smoke detection feature, it is unlikely that the system provides a good overview of the severity of the situation as the ceiling of the ro-ro space quickly becomes saturated with smoke in the event of fire.

The Alarm System Design & Integration feature will still allow to react to "small containment failure", such as small smoke leaks, allowing crew members to act accordingly to avoid severe consequence worsening the situation (e.g. close doors, check seals and fire dampers, choose inlet ventilation). These were translated by the experts as a 15% risk reduction in all the nodes of the *Failure of smoke containment - Internal smoke spread - Weakness of division smoke tightness,* except for the node *Prescriptive design according to the FTP code*.

9.3.1.11 Dec2 Improved markings/signage for wayfinding and localisation

This RCO proved to be very efficient with regard to fire confirmation and communication between the runner and the bridge during the decision part.

9.3.1.11.1 Containment

The improvement in bridge/deck communications in the way of shared vocabulary and common ground also benefits the containment node, avoiding miscommunications during the boundary cooling activities. The proportion of boundary cooling failure due to miscommunication was estimated to 10% by the experts. Assuming that this RCO allows to avoid 100% of this miscommunication, the node *Failure of fire containment - Heat spread - **Failure of boundary cooling*** was attributed a 10% risk reduction.

9.3.1.12 Dec3 Preconditions for Early Activation of Drencher System

This Risk Control Option was reviewed but was considered to not affect any other of the main nodes (fault trees) in the main fire risk model than the one for which it was identified.

9.3.1.13 Su1 Remote control

9.3.1.13.1 Decision

An “immediate” activation of the drencher system following reduces the probability of a Late decision. In other words, it is less likely that the time available for decision-making of extinguishing system activation is exceeded with such feature. (Same decision time would lead to more fire suppression success as the time to manually activate the drencher system is taken into account). For that reason, a 10% risk reduction was applied in the top node of the tree *Decision failure.*

9.3.1.14 Su3[3] Rolling shutters (PS & SB side) (Open ro-ro spaces)

Detection is not affected since the openings are closed only after a fire alarm. Closing of the openings in the open ro-ro-space has positive effects, such as restricting the possible spread of smoke and fire which are taken into account in the Containment and Evacuation nodes.

9.3.1.14.1 Containment

This RCO only aimed at closing the side openings of open ro-ro spaces upon fire alarm. However, closing the aft openings was not considered. Therefore, based on the discussions in the Containment part and taking into account a 70% reliability and efficiency of the system (estimated in FIRESAFE), all the risk reductions (positive and negative) considered for the RCO Ban/closure of side & end openings (closed and open ro-ro spaces) were multiplied by 35%.

9.3.1.14.2 Evacuation

Considering the reliability of the system discussed in FIRESAFE and the fact that 20 openings in total (4 close to the LSAs) need to be closed, there is a high probability that one of the rolling shutter is dysfunctional close to the LSAs and a probability close to one that at least one rolling shutter is dysfunctional. Therefore, the impact of this RCO on *Evacuation* has been considered very limited and disregarded in this study.

9.3.1.15 Su4 Efficient activation routines

In addition to the beneficial impacts already considered in the Extinguishment node (increase the probability that the crew discovers possible faults even before a real fire starts and possibility to handle and quickly solve unexpected problems during a fire), this RCO fosters faster activation of the drencher system which has an impact on the Decision node.

9.3.1.15.1 Decision

In a similar way as the RCO Remote Control, a 10% risk reduction was applied in the top node of the tree *Decision failure.*

9.3.1.16 Su5 Fresh water activation/flushing

This Risk Control Option was reviewed but was considered to not affect any other of the main nodes (fault trees) in the main fire risk model than the one for which it was identified.

9.3.1.17 Su6 CCTV

9.3.1.17.1 Detection

As the screens are not expected to be monitored continuously, the RCO CCTV has no impact on the Detection node.

9.3.1.17.2 Decision

However, this RCO was found beneficial to confirm that a fire has started when a fire alarm is received decision. The review of accident investigation reports informed that the CCTV provided fire confirmation in two cases (out of 6 fire incidents where the CCTV was used). Therefore, a 33% risk reduction was assigned to the node *Late confirmation - Late tech.* ***Conf*** following a Late Detection. Furthermore, it was estimated considered by the experts that CCTV could only provide relevant information in one third of the time in case of Early detection due to the fairly small size of fire and small amount of smoke that may not be visible on the screens.

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[3] No RCO Su2 was considered in the first FIRESAFE study

Additionally, the CCTV was considered to reduce by 5% the failure mode *Late confirmation - Late manual confirmation - Late localisation - **Inadequate strategy*** as it provides relevant information that may guide the actions of the runner in case following Early Detection.

9.3.1.18 Su7 CCTV + Remote control

The combination of CCTV and remote control benefits from the risk reduction of both the CCTV and the remote control.

9.3.1.18.1 Decision

A 10% risk reduction was applied in the top node of the tree Decision failure in addition to the risk reduction discussed in paragraph 9.3.1.17.

9.3.1.19 Cont1 Ban/closure of side & end openings (closed and open ro-ro spaces)

9.3.1.19.1 Detection

This risk control measure implies to forbid open ro-ro spaces on new ships and to reduce openings (including aft openings) in general as far as practicable. Therefore, from a detection point of view, open ro-ro spaces were considered as closed ro-ro spaces.

No improvements related to detection were found due to closing the openings of a closed ro-ro space.

9.3.1.19.2 Extinguishment

From a suppression point of view, open ro-ro spaces were considered as closed ro-ro spaces. No improvements related to extinguishment were found due to closing the closing the minor side and potential aft openings of a closed ro-ro space.

9.3.1.19.3 Evacuation

Closing all openings was one of the design investigated in order to achieve the Evacuation RCO “Safe distance”. The findings from this part is used for the Combined Assessment.

9.3.1.20 Cont2 Fire monitors on weather deck

Fire monitors on weather deck were identified as a containment RCO, preventing fire spread to and from weather deck, but it will naturally also affect the potential for extinguishing or suppressing the fire. If comparing the system effectiveness for extinguishment with that of a drencher system, it should be noted that water monitors imply a different extinguishment strategy, mainly with a steam of water, while a drencher system give a relatively homogenous distribution of water over an area. The technical specification of the system with 90% coverage and 1000 l/min should nevertheless be sufficient to manage a bus or car fire onboard.

9.3.1.20.1 Extinguishment

With regard to unsuccessful suppression, the system was in the containment part of the study assumed to have 90% reliability, where failure will lead to loss of containment with a high probability (unless manual firefighting is enough).

Furthermore, loss of containment may be reached despite activation of the system. The system was considered to have at least 90% coverage, where the 10% was assumed to be distributed in several areas. These minor uncovered areas were not considered to significantly affect the potential for loss of containment; the areas may be relatively easily extinguished manually if the rest of the space is suppressed and will not generate a fire impossible to extinguish on their own). However, the cases where this would nevertheless occur was considered included in the probability of the system having insufficient capacity to suppress the fire, despite early decision for extinguishing system activation. This probability was estimated to 4%, which was the same probability used for design incapacity for the drencher system. This failure probability was considered to also include potential wind conditions making extinguishment difficult. In total (considering the system reliability), an 86.4% reduction was estimated for the node *Early decision – Suppression for weather deck* with this RCO.

Late decision could be assumed to not be as likely for this node, as the system is outside and always exposed to salt and water. Activation should hence generally be possible without potential damage to equipment, cargo, etc. and may support a quick decision for system activation. However, this particular effect was considered to have a small total impact on the decision and was not considered. With regard to late decision and the effectiveness of the system, reference was again made to the corresponding probability for the drencher system design incapacity (40%). Considering the sensitivity of the performance of the system to the manual operation (large fire in case of late decision) and that personnel may not be perfectly capable/trained to manage the firefighting system, this high figure was assumed for unsuccessful or no suppression in case of late decision. In total (considering the system reliability), a 54% reduction was estimated for the node *Late decision – Suppression for weather deck* with this RCO.

9.3.1.21 Evac1: Safe distance

The risk reduction of this RCO depends on the initial design and the design selected to comply with this RCO. Most of the design solutions considered to achieve the safe distance were considered in the previous nodes (see paragraphs 9.3.1.14 and 9.3.1.19).

However, for the *Standard RoPax*, the design Evac 1c Closing openings near LSA is expected to have no impact on the previous nodes since only four of the openings are closed.

It is recalled here (cf 9.3.1.8.3) that for the *Standard RoPax*, the design Ban / closure of side (PS & SB) openings (open ro-ro spaces) fulfils Det 2 *Ban / closure of side (PS & SB) openings (open ro-ro spaces)* and *Evac1b: Safe distance / Closing side openings*. The results will be presented in next figures Figure 10 and Figure 11 with code Det 2*.

For *Cargo RoPax*, *Standard RoPax* and *Ferry RoPax*, the design Closing all significant openings fulfils the RCO Cont1 *Ban/Closure of side and aft openings* and the RCO Evac1a: Safe distance/Closing all significant openings (cf 9.3.1.19.3). The results will be presented in next figures Figure 10 and Figure 11 with code Cont1**.

9.4 Estimation of Risk Reduction by the implementation of RCO

Figure 10 presents the Combined Relative Risk Reduction of RCOs investigated in FIRESAFE and FIRESAFE II for Newbuildings. This figure may be compared to Figure 8, except for the RCO Evac1, as explained in 9.3.1.21.

For the *Cargo RoPax* (blue bars in Figure 10), taking into account the combined effects of RCOs, the following RCOs showed a significant improvement in risk reduction:

- Cont2: *Fire monitors on weather deck* due the high potential for suppression of fire occurring on weather decks.

For the *Standard RoPax* (red bars in Figure 10), taking into account the combined effects of RCOs, the following RCOs showed a significant improvement in risk reduction:

- Det1: *Combined heat & smoke and Alarm System Design & Integration* due the good combination with decision, extinguishment and containment nodes.
- Det2* Ban / closure of side (PS & SB) openings (open ro-ro spaces) / Evac1: Safe distance (Closing of side openings near LSA) due to the protection of LSA on the side.

For the *Ferry RoPax* (green bars in Figure 10), taking into account the combined effects of RCOs, the following RCOs showed a significant improvement risk reduction:

- Det1: *Combined heat & smoke and Alarm System Design & Integration* due the improved decision, extinguishment and containment; and

- Cont1**: Permanent closure of openings / Evac1: Safe distance (Closing of aft openings near LSA) due to the protection of LSA on the aft.

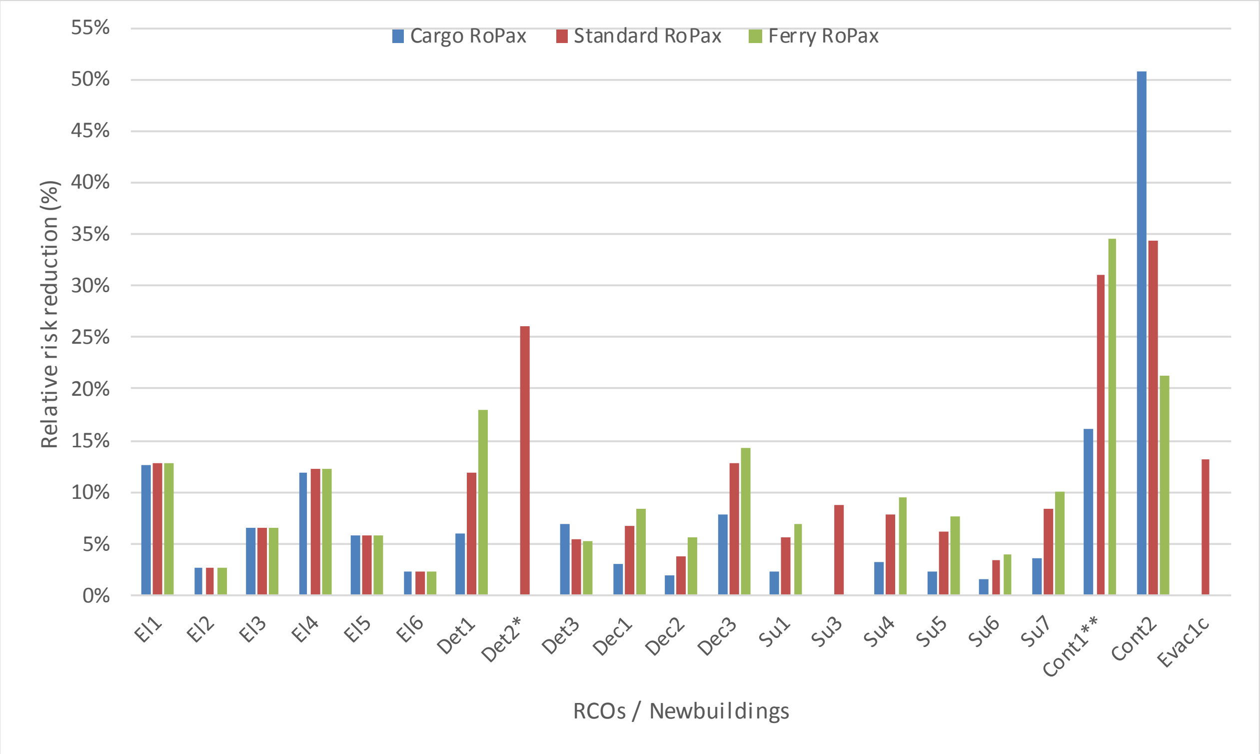


Figure 10: Combined Relative Risk Reduction of RCOs investigated in FIRESAFE and FIRESAFE II for Newbuildings

The same observations were applicable for Existing RoPax ships, for which the combined Relative Risk Reductions are presented in Figure 11.

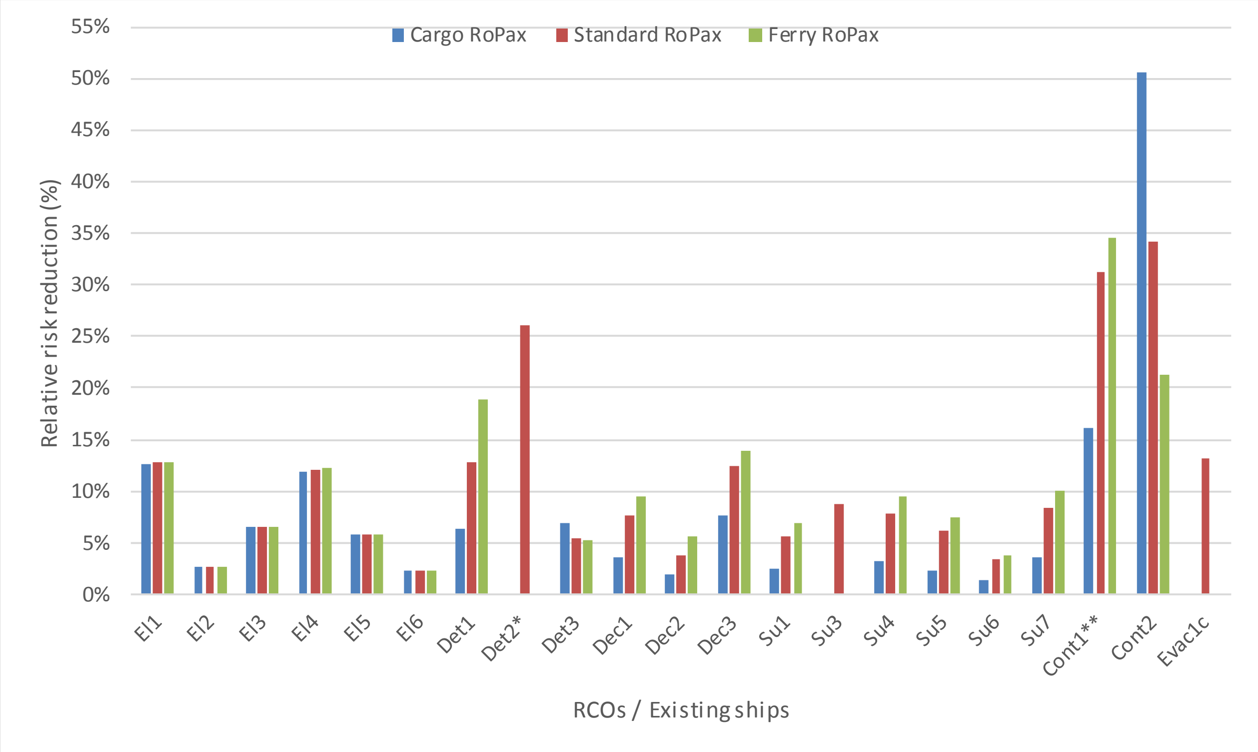


Figure 11: Combined Relative Risk Reduction of RCOs investigated in FIRESAFE and FIRESAFE II for Existing ships

9.5 Interdependencies between RCOs

The risk reduction provided by each RCO was estimated with the assumption that none of the other RCOs were implemented (i.e. each RCO was assessed independently). However, the risk reduction attributed to the implementation of a second RCO (in addition to the first one) may be reduced compared to if the second RCO was implemented on its own, especially if both are affecting the same hazards. This will lead to reduced cost-effectiveness of the second RCO, when considered together with the first one.

Where several RCOs are proposed to be implemented at the same time, the risk reduction effectiveness of such a combination should be assessed. For RCOs with strong dependency, a quantitative assessment of the combined effects should be conducted, while combinations of RCOs with weak dependencies could be quantitatively or qualitatively assessed.

A qualitative evaluation of interdependencies between all RCOs was performed, looking at the functional and computational dependencies of RCOs and respective impacts in the main fire risk model. The results of this evaluation are presented in an interdependency matrix in Annex A3.

The interdependency matrix lists the RCOs both vertically and horizontally. Reading horizontally, the table indicates in the first row any dependencies between El1 and each of the other proposed RCOs. For example, in this case the table states that if El1 is implemented, El2, being strongly dependent on El1, needs to be re-evaluated before adopting it in conjunction with El1. On the other hand, Det1 is not dependent on El1, and therefore the cost-effectiveness of Det1 will not be affected by the combined adoption of El1. Furthermore, El3 is weakly dependent on El1, so a re-evaluation may or may not be necessary before a combined adoption of the two RCOs.

10 COMBINED COST-EFFECTIVENESS ASSESSMENT

10.1 Cost-effectiveness assessment – background

The background and assumptions of the cost-effectiveness assessment were provided in the report for Part 1 of the FIRESAFE II study (EMSA, 2018), while the main information is summarized below.

It was proposed to use 7 000 000€ as the cost effectiveness criterion in FIRESAFE II. The expected lifetime (T) of a RoPax ship was set to 40 years, whereas the average age of the fleet was estimated to 20 years. The delta cost and benefits were calculated in Net Present Value (NPV) with a depreciation rate of 3.5% for the period of years 1 – 30 and 3.0% for the period of years 31 – 40 (HM Treasury, 2018).

10.2 Estimation of costs

The costs associated with the implementation of the above considered RCOs were estimated in FIRESAFE and FIRESAFE II. As far as possible, technical items available on the market were quantified by system supplier offers and cost estimations were based on existing costs for material from ship operator's internal projects, specifications, reconstructions, etc. The main component systems of each RCO was identified and respective costs were estimated. For operational RCOs, manning and training costs were used based on ship operator's experience. Other cost items affecting for example operations were included in the quantification when necessary.

The costs associated with the RCOs investigated in FIRESAFE targeting *Electrical fire as ignition risk* and *Fixed fire suppression system failure* were only estimated for the *Standard RoPax*. A review of the costs was performed for the purpose of the Combined Assessment. Most of the costs estimated were found independent of the ship considered. However, for the RCOs *El 1 Robust connection boxes, El2 Only ship cables,* and *El6 Cable reeling drums,* costs were derived based on the respective total area of closed and open ro-ro spaces for each ship (using the *Standard RoPax* as basis).

Details of the cost estimations can be found in the respective reports. Nonetheless, a summary of the costs (investment, annual, and lifetime costs) is provided in Annex A3 for all RCOs on each of the ships, taking into account the potential difference between Newbuildings and Existing ships.

10.3 GCAF / NCAF ratio and RCOs ranking

Table 10 to Table 15 list the input values ΔRisk and ΔCost, as well as the resulting cost effectiveness ratios GCAF, and GCAF Factors for the considered Detection RCOs on Existing ships.

10.3.1 *Cargo RoPax - Newbuildings*

Table 10: ΔRisk, ΔCosts, ΔBenefits, GCAF, GCAF Factor, and NCAF Factor values for the RCOs on Cargo RoPax Newbuildings

	Newbuildings		ΔRisk	ΔCost	ΔCost-ΔBenefits	GCAF			NCAF	
		RCO	Averted fat.	Present Value	Present Value	GCAF	GCAF Factor	Rank	NCAF	NCAF Factor
Cargo RoPax	EI1	Robust connection boxes	3.38E-02	19 116 €	- 325 464 €	565 312 €	0.08	5	- 9 625 096 €	-1.38
	EI2	Only ship cables	7.14E-03	74 579 €	1 906 €	10 450 026 €	1.49	12	267 027 €	0.04
	EI3	IR camera	1.75E-02	23 431 €	- 154 366 €	1 340 556 €	0.19	9	- 8 831 697 €	-1.26
	EI4	Training for awareness	3.15E-02	4 000 €	- 317 629 €	126 905 €	0.02	2	- 10 077 197 €	-1.44
	EI5	Only crew connections	1.55E-02	2 000 €	- 156 217 €	128 722 €	0.02	3	- 10 054 278 €	-1.44
	EI6	Cable reeling drums	6.16E-03	218 586 €	155 819 €	35 462 398 €	5.07	17	25 279 398 €	3.61
	Det1	Combined heat & smoke and alarm system design & integration	1.58E-02	17 500 €	- 146 972 €	1 109 387 €	0.16	7	- 9 317 066 €	-1.33
	Det2	Ban / closure of side (PS & SB) openings (open ro-ro spaces)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Det3	Increased frequency fire patrols	1.83E-02	1 285 861 €	1 129 470 €	70 372 433 €	10.05	18	61 813 462 €	8.83
	Dec1	Alarm system design & integration (smoke)	8.15E-03	20 000 €	- 86 043 €	2 453 808 €	0.35	10	- 10 556 600 €	-1.51
	Dec2	Improved markings/signage for wayfinding and localisation	5.08E-03	2 850 €	- 51 392 €	561 311 €	0.08	4	- 10 121 631 €	-1.45
	Dec3	Preconditions for early activation of drencher system	2.07E-02	214 310 €	- 55 053 €	10 338 756 €	1.48	11	- 2 655 852 €	-0.38
	Su1	Remote control	6.24E-03	101 431 €	7 885 €	16 262 556 €	2.32	15	1 264 275 €	0.18
	Su3	Rolling shutters (PS & SB side) (Open ro-ro spaces)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Su4	Efficient activation routines	8.35E-03	200 €	- 127 620 €	23 950 €	0.00	1	- 15 282 429 €	-2.18
	Su5	Fresh water activation/flushing	6.02E-03	7 000 €	- 91 404 €	1 163 002 €	0.17	8	- 15 186 228 €	-2.17
	Su6	CCTV	3.90E-03	61 431 €	4 214 €	15 751 865 €	2.25	13	1 080 612 €	0.15
	Su7	CCTV + Remote control	9.48E-03	162 862 €	22 279 €	17 175 548 €	2.45	16	2 349 534 €	0.34
	Cont1**	Ban/closure of side & end openings (closed and open ro-ro spaces)	4.30E-02	694 310 €	554 536 €	16 138 865 €	2.31	14	12 889 898 €	1.84
	Cont2	Fire monitors on weather deck	1.35E-01	99 330 €	- 110 824 €	734 682 €	0.10	6	- 819 697 €	-0.12

Comparing the Combined GCAF Factors with the GCAF Factors obtained in FIRESAFE and FIRESAFE II, it is observed that the following RCO became cost-effective based on the combined assessment:

- Det1: Combined heat & smoke and Alarm System Design & Integration

10.3.2 *Cargo RoPax - Existing ships*

Table 11: ΔRisk, ΔCosts, ΔBenefits, GCAF, GCAF Factor, and NCAF Factor values for the RCOs on Cargo RoPax Existing ships

	Existing ships		ΔRisk	ΔCost	ΔCost-ΔBenefits	GCAF			NCAF	
		RCO	Averted fat.	Present Value	Present Value	GCAF	GCAF Factor	Rank	NCAF	NCAF Factor
Cargo RoPax	EI1	Robust connection boxes	1.70E-02	15 506 €	- 214 520 €	912 894 €	0.13	4	- 12 629 411 €	-1.80
	EI2	Only ship cables	3.59E-03	51 480 €	2 964 €	14 359 387 €	2.05	10	826 716 €	0.12
	EI3	IR camera	8.78E-03	16 212 €	- 102 475 €	1 846 553 €	0.26	6	- 11 671 672 €	-1.67
	EI4	Training for awareness	1.58E-02	4 000 €	- 210 573 €	252 743 €	0.04	2	- 13 305 215 €	-1.90
	EI5	Only crew connections	7.81E-03	2 000 €	- 103 623 €	256 244 €	0.04	3	- 13 276 428 €	-1.90
	EI6	Cable reeling drums	3.10E-03	175 274 €	133 372 €	56 606 297 €	8.09	17	43 073 625 €	6.15
	Det1	Combined heat & smoke and alarm system design & integration	8.48E-03	145 000 €	24 565 €	17 096 834 €	2.44	11	2 896 402 €	0.41
	Det2	Ban / closure of side (PS & SB) openings (open ro-ro spaces)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Det3	Increased frequency fire patrols	9.17E-03	852 744 €	748 355 €	92 980 079 €	13.28	18	81 597 895 €	11.66
	Dec1	Alarm system design & integration (smoke)	4.67E-03	145 000 €	63 321 €	31 069 157 €	4.44	13	13 567 694 €	1.94
	Dec2	Improved markings/signage for wayfinding and localisation	2.53E-03	2 850 €	- 32 670 €	1 128 017 €	0.16	5	- 12 930 831 €	-1.85
	Dec3	Preconditions for early activation of drencher system	1.03E-02	142 124 €	- 34 538 €	13 849 905 €	1.98	9	- 3 365 667 €	-0.48
	Su1	Remote control	3.18E-03	114 212 €	50 907 €	35 887 661 €	5.13	15	15 996 011 €	2.29
	Su3	Rolling shutters (PS & SB side) (Open ro-ro spaces)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Su4	Efficient activation routines	4.24E-03	200 €	- 85 919 €	47 155 €	0.01	1	- 20 257 645 €	-2.89
	Su5	Fresh water activation/flushing	3.02E-03	14 000 €	- 51 542 €	4 641 193 €	0.66	8	- 17 086 734 €	-2.44
	Su6	CCTV	1.92E-03	64 212 €	26 834 €	33 445 425 €	4.78	14	13 976 753 €	2.00
	Su7	CCTV + Remote control	4.78E-03	178 425 €	84 443 €	37 343 963 €	5.33	16	17 673 654 €	2.52
	Cont1**	Ban/closure of side & end openings (closed and open ro-ro spaces)	2.17E-02	657 124 €	563 314 €	30 299 958 €	4.33	12	25 974 365 €	3.71
	Cont2	Fire monitors on weather deck	6.78E-02	129 000 €	- 11 508 €	1 903 197 €	0.27	7	- 169 780 €	-0.02

Despite some GCAF reductions, it can be observed that none of the RCO became cost-effective based on the combined assessment compared to FIRESAFE and FIRESAFE II results.

10.3.3 *Standard RoPax - Newbuildings*

Table 12: ΔRisk, ΔCosts, ΔBenefits, GCAF, GCAF Factor, and NCAF Factor values for the RCOs on Standard RoPax Newbuildings

	Newbuildings		ΔRisk	ΔCost	ΔCost-ΔBenefits	GCAF			NCAF	
		RCO	Averted fat.	Present Value	Present Value	GCAF	GCAF Factor	Rank	NCAF	NCAF Factor
Standard RoPax	El1	Robust connection boxes	1.18E-01	33 116 €	- 252 224 €	280 700 €	0.04	8	- 2 137 943 €	-0.31
	El2	Only ship cables	2.48E-02	84 579 €	24 499 €	3 405 536 €	0.49	16	986 454 €	0.14
	El3	IR camera	6.09E-02	23 431 €	- 123 693 €	384 858 €	0.05	11	- 2 031 677 €	-0.29
	El4	Training for awareness	1.13E-01	4 000 €	- 266 932 €	35 500 €	0.01	3	- 2 369 027 €	-0.34
	El5	Only crew connections	5.41E-02	2 000 €	- 128 799 €	36 989 €	0.01	4	- 2 382 094 €	-0.34
	El6	Cable reeling drums	2.15E-02	582 896 €	531 006 €	27 174 351 €	3.88	21	24 755 268 €	3.54
	Det1	Combined heat & smoke and alarm system design & integration	1.10E-01	17 500 €	- 195 107 €	158 641 €	0.02	7	- 1 768 682 €	-0.25
	Det2*	Ban / closure of side (PS & SB) openings (open ro-ro spaces)	2.41E-01	3 081 722 €	3 034 825 €	12 788 165 €	1.83	18	12 593 555 €	1.80
	Det3	Increased frequency fire patrols	4.99E-02	728 655 €	617 854 €	14 609 862 €	2.09	20	12 388 264 €	1.77
	Dec1	Alarm system design & integration (smoke)	6.19E-02	20 000 €	- 115 771 €	323 091 €	0.05	9	- 1 870 236 €	-0.27
	Dec2	Improved markings/signage for wayfinding and localisation	3.50E-02	3 300 €	- 64 682 €	94 265 €	0.01	5	- 1 847 659 €	-0.26
	Dec3	Preconditions for early activation of drencher system	1.18E-01	214 310 €	- 57 701 €	1 818 952 €	0.26	12	- 489 738 €	-0.07
	Su1	Remote control	5.21E-02	101 431 €	- 20 185 €	1 948 102 €	0.28	13	- 387 670 €	-0.06
	Su3	Rolling shutters (PS & SB side) (Open ro-ro spaces)	8.10E-02	1 140 034 €	1 099 305 €	14 073 797 €	2.01	19	13 570 990 €	1.94
	Su4	Efficient activation routines	7.18E-02	200 €	- 168 485 €	2 787 €	0.00	2	- 2 348 200 €	-0.34
	Su5	Fresh water activation/flushing	5.66E-02	7 000 €	- 128 675 €	123 643 €	0.02	6	- 2 272 807 €	-0.32
	Su6	CCTV	3.15E-02	61 431 €	- 10 498 €	1 948 163 €	0.28	14	- 332 930 €	-0.05
	Su7	CCTV + Remote control	7.74E-02	162 862 €	- 16 525 €	2 105 231 €	0.30	15	- 213 612 €	-0.03
	Cont1**	Ban/closure of side & end openings (closed and open ro-ro spaces)	2.89E-01	3 573 722 €	3 484 145 €	12 382 980 €	1.77	17	12 072 595 €	1.72
	Cont2	Fire monitors on weather deck	3.19E-01	112 035 €	- 304 627 €	351 615 €	0.05	10	- 956 055 €	-0.14
	Evac1c	Optimal distance / Closing LSA near openings	1.22E-01	61 431 €	- €	- €	0.00	1	- €	0.00

Comparing the Combined GCAF Factors with the GCAF Factors obtained in FIRESAFE and FIRESAFE II, it can be observed that the following RCO became cost-effective based on the combined assessment:

- Su6: CCTV

10.3.4 *Standard RoPax - Existing ships*

Table 13: ΔRisk, ΔCosts, ΔBenefits, GCAF, GCAF Factor, and NCAF Factor values for the RCOs on Standard RoPax Existing ships

	Existing ships		ΔRisk	ΔCost	ΔCost-ΔBenefits	GCAF			NCAF	
		RCO	Averted fat.	Present Value	Present Value	GCAF	GCAF Factor	Rank	NCAF	NCAF Factor
Standard RoPax	El1	Robust connection boxes	5.96E-02	35 106 €	- 156 023 €	588 945 €	0.08	8	- 2 617 458 €	-0.37
	El2	Only ship cables	1.25E-02	61 480 €	21 233 €	4 898 859 €	0.70	16	1 691 891 €	0.24
	El3	IR camera	3.08E-02	16 212 €	- 82 333 €	527 055 €	0.08	7	- 2 676 586 €	-0.38
	El4	Training for awareness	5.69E-02	4 000 €	- 177 262 €	70 352 €	0.01	2	- 3 117 678 €	-0.45
	El5	Only crew connections	2.73E-02	2 000 €	- 85 621 €	73 201 €	0.01	3	- 3 133 767 €	-0.45
	El6	Cable reeling drums	1.08E-02	467 398 €	432 638 €	43 121 789 €	6.16	21	39 914 821 €	5.70
	Det1	Combined heat & smoke and alarm system design & integration	5.96E-02	155 000 €	530 €	2 601 624 €	0.37	11	8 891 €	0.00
	Det2*	Ban / closure of side (PS & SB) openings (open ro-ro spaces)	1.22E-01	2 365 488 €	2 334 311 €	19 374 546 €	2.77	18	19 119 184 €	2.73
	Det3	Increased frequency fire patrols	2.52E-02	483 222 €	409 000 €	19 190 248 €	2.74	17	16 242 676 €	2.32
	Dec1	Alarm system design & integration (smoke)	3.56E-02	155 000 €	50 677 €	4 351 531 €	0.62	14	1 422 721 €	0.20
	Dec2	Improved markings/signage for wayfinding and localisation	1.74E-02	3 300 €	- 41 240 €	189 958 €	0.03	4	- 2 373 911 €	-0.34
	Dec3	Preconditions for early activation of drencher system	5.81E-02	142 124 €	- 35 886 €	2 444 882 €	0.35	10	- 617 320 €	-0.09
	Su1	Remote control	2.66E-02	114 212 €	31 933 €	4 300 221 €	0.61	13	1 202 295 €	0.17
	Su3	Rolling shutters (PS & SB side) (Open ro-ro spaces)	4.05E-02	1 458 974 €	1 431 936 €	35 993 094 €	5.14	20	35 326 079 €	5.05
	Su4	Efficient activation routines	3.64E-02	200 €	- 113 438 €	5 488 €	0.00	1	- 3 112 828 €	-0.44
	Su5	Fresh water activation/flushing	2.84E-02	14 000 €	- 76 450 €	492 228 €	0.07	6	- 2 687 925 €	-0.38
	Su6	CCTV	1.56E-02	64 212 €	17 158 €	4 128 395 €	0.59	12	1 103 113 €	0.16
	Su7	CCTV + Remote control	3.90E-02	178 425 €	58 430 €	4 573 751 €	0.65	15	1 497 797 €	0.21
	Cont1**	Ban/closure of side & end openings (closed and open ro-ro spaces)	1.46E-01	2 892 488 €	2 832 629 €	19 785 064 €	2.83	19	19 375 618 €	2.77
	Cont2	Fire monitors on weather deck	1.60E-01	145 500 €	- 131 537 €	907 858 €	0.13	9	- 820 733 €	-0.12
	Evac1c	Optimal distance / Closing LSA near openings	6.18E-02	30 000 €	30 000 €	485 084 €	0.07	5	485 084 €	0.07

Comparing the Combined GCAF Factors with the GCAF Factors obtained in FIRESAFE and FIRESAFE II, it can be observed that the following RCOs became cost-effective based on the combined assessment:

- Det1: Combined heat & smoke and Alarm System Design & Integration
- Su6: CCTV
- Su7: CCTV + Remote Control

10.3.5 *Ferry RoPax - Newbuildings*

Table 14: ΔRisk, ΔCosts, ΔBenefits, GCAF, GCAF Factor, and NCAF Factor values for the RCOs on Ferry RoPax Newbuildings

	Newbuildings		ΔRisk	ΔCost	ΔCost-ΔBenefits	GCAF			NCAF	
		RCO	Averted fat.	Present Value	Present Value	GCAF	GCAF Factor	Rank	NCAF	NCAF Factor
Ferry RoPax	El1	Robust connection boxes	1.80E-01	33 116 €	-221 780 €	184 340 €	0.03	8	-1 234 556 €	-0.18
	El2	Only ship cables	3.78E-02	84 579 €	30 978 €	2 238 566 €	0.32	15	819 890 €	0.12
	El3	IR camera	9.27E-02	23 431 €	-108 000 €	252 767 €	0.04	9	-1 165 072 €	-0.17
	El4	Training for awareness	1.73E-01	4 000 €	-241 470 €	23 083 €	0.00	2	-1 393 492 €	-0.20
	El5	Only crew connections	8.23E-02	2 000 €	-114 695 €	24 314 €	0.00	3	-1 394 362 €	-0.20
	El6	Cable reeling drums	3.26E-02	582 896 €	536 602 €	17 862 552 €	2.55	18	16 443 876 €	2.35
	Det1	Combined heat & smoke and alarm system design & integration	2.53E-01	17 500 €	-241 662 €	69 222 €	0.01	6	-955 906 €	-0.14
	Det2	Ban / closure of side (PS & SB) openings (open ro-ro spaces)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Det3	Increased frequency of fire patrols	7.32E-02	1 285 861 €	1 190 242 €	17 566 559 €	2.51	17	16 260 270 €	2.32
	Dec1	Alarm system design & integration (smoke)	1.19E-01	20 000 €	-139 062 €	168 610 €	0.02	7	-1 172 357 €	-0.17
	Dec2	Improved markings for wayfinding and localisation	8.00E-02	3 300 €	-79 966 €	41 237 €	0.01	4	-999 261 €	-0.14
	Dec3	Preconditions for Early Activation of Drencher System	2.02E-01	214 310 €	-70 742 €	1 063 364 €	0.15	12	-351 008 €	-0.05
	Su1	Remote control	9.64E-02	101 431 €	-37 479 €	1 052 499 €	0.15	11	-388 902 €	-0.06
	Su3	Rolling shutters (PS & SB side) (Open ro-ro spaces)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Su4	Efficient activation routines	1.34E-01	200 €	-190 836 €	1 498 €	0.00	1	-1 429 403 €	-0.20
	Su5	Fresh water activation/flushing	1.07E-01	7 000 €	-142 769 €	65 434 €	0.01	5	-1 334 560 €	-0.19
	Su6	CCTV	5.54E-02	61 431 €	-19 031 €	1 109 334 €	0.16	13	-343 658 €	-0.05
	Su7	CCTV + Remote control	1.41E-01	162 862 €	-41 677 €	1 152 424 €	0.16	14	-294 908 €	-0.04
	Cont1**	Ban/closure of side & end openings (closed and open ro-ro spaces)	4.87E-01	1 339 775 €	1 286 921 €	2 751 776 €	0.39	16	2 643 218 €	0.38
	Cont2	Fire monitors on weather deck	3.01E-01	77 385 €	9 732 €	256 904 €	0.04	10	32 309 €	0.00

Comparing the Combined GCAF Factors with the GCAF Factors obtained in FIRESAFE and FIRESAFE II, it can be observed that the following RCO became cost-effective based on the combined assessment:

- Cont1: Ban/closure of side & end openings

However, it should be noted that this change is mainly due to the beneficial effects of closing the aft openings on the evacuation. For ships already achieving the *Safety distance*, only the benefits of closing the side opening on the containment part should be considered, which makes this RCO not cost effective (see Table 7). Therefore, only the RCO Evac1 should be recommended (which in turn will benefit the probability of containment as a side effect of the RCO).

10.3.6 *Ferry RoPax – Existing ships*

Table 15: ΔRisk, ΔCosts, ΔBenefits, GCAF, GCAF Factor, and NCAF Factor values for the RCOs on Ferry RoPax Existing ships

	Existing ships		ΔRisk	ΔCost	ΔCost-ΔBenefits	GCAF			NCAF	
		RCO	Averted fat.	Present Value	Present Value	GCAF	GCAF Factor	Rank	NCAF	NCAF Factor
Ferry RoPax	El1	Robust connection boxes	9.10E-02	35 106 €	-136 137 €	385 954 €	0.06	7	-1 496 681 €	-0.21
	El2	Only ship cables	1.91E-02	61 480 €	25 465 €	3 213 285 €	0.46	15	1 330 932 €	0.19
	El3	IR camera	4.69E-02	16 212 €	-72 081 €	345 432 €	0.05	6	-1 535 814 €	-0.22
	El4	Training for awareness	8.76E-02	4 000 €	-160 628 €	45 667 €	0.01	2	-1 833 830 €	-0.26
	El5	Only crew connections	4.17E-02	2 000 €	-76 408 €	48 014 €	0.01	3	-1 834 339 €	-0.26
	El6	Cable reeling drums	1.65E-02	467 398 €	436 293 €	28 284 664 €	4.04	17	26 402 311 €	3.77
	Det1	Combined heat & smoke and alarm system design & integration	1.35E-01	53 000 €	-135 452 €	392 599 €	0.06	8	-1 003 362 €	-0.14
	Det2	Ban / closure of side (PS & SB) openings (open ro-ro spaces)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Det3	Increased frequency of fire patrols	3.70E-02	852 744 €	788 485 €	23 024 049 €	3.29	16	21 289 045 €	3.04
	Dec1	Alarm system design & integration (smoke)	6.79E-02	53 000 €	-69 051 €	780 990 €	0.11	10	-1 017 515 €	-0.15
	Dec2	Improved markings for wayfinding and localisation	3.99E-02	3 300 €	-51 341 €	82 695 €	0.01	4	-1 286 550 €	-0.18
	Dec3	Preconditions for Early Activation of Drencher System	9.94E-02	142 124 €	-44 164 €	1 430 529 €	0.20	11	-444 527 €	-0.06
	Su1	Remote control	4.92E-02	114 212 €	20 231 €	2 323 390 €	0.33	12	411 562 €	0.06
	Su3	Rolling shutters (PS & SB side) (Open ro-ro spaces)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Su4	Efficient activation routines	6.78E-02	200 €	-128 484 €	2 949 €	0.00	1	-1 894 800 €	-0.27
	Su5	Fresh water activation/flushing	5.38E-02	14 000 €	-85 771 €	260 396 €	0.04	5	-1 595 311 €	-0.23
	Su6	CCTV	2.73E-02	64 212 €	11 611 €	2 352 084 €	0.34	13	425 297 €	0.06
	Su7	CCTV + Remote control	7.13E-02	178 425 €	41 615 €	2 503 305 €	0.36	14	583 861 €	0.08
	Cont1	Ban/closure of side & end openings (closed and open ro-ro spaces)	2.47E-01	26 203 078 €	26 167 321 €	105 998 119 €	15.14	18	105 853 472 €	15.12
	Cont2	Fire monitors on weather deck	1.51E-01	100 500 €	55 022 €	664 035 €	0.09	9	363 546 €	0.05

Comparing the Combined GCAF Factors with the GCAF Factors obtained in FIRESAFE and FIRESAFE II, it can be observed that the following RCOs became cost-effective based on the combined assessment:

- Det1: Combined heat & smoke and Alarm System Design & Integration
- Su6: CCTV

10.4 Results of the uncertainty analysis

A number of uncertainties were introduced while developing the risk model. As listed in (IMO, 2007), various degrees of uncertainty were associated with the following areas and factors:

- Scope and limitations: three generic ships were selected to represent the RoPax world fleet;
- Statistics: historical data are scarce and may be uncomplete;
- Outlined models: omitted branches, and not time-dependent event tree;
- The expert judgments: other set of experts may have provided slightly different estimates;
- The assumptions: yes/no probabilities; and
- Assumptions on the number of fatalities per final outcome of each event branch.

Some of the assumptions made in the risk assessment part are conservative, leading to a potential over estimation of the societal risk. As far as practicable, a high level of attention was given to explicit all assumptions used in the study with the aim to ease any potential modifications or updates of the assumptions with new data sets or different expert judgements.

An uncertainty analysis was performed as part of the study, where the quantifications of the risk model and in the effectiveness quantifications of RCOs were evaluated. No uncertainty was considered for the cost estimations.

Uncertainty of the estimated parameters was explicitly modelled with probability distributions for each bottom nodes of the sub risk models. Additional details on the methodology followed were provided in Annex A2 of the report for Part 1 of the FIRESAFE II study (EMSA, 2018). The risk assessment software @Risk (Palisade Decision Tool ©), an add-in to Microsoft Excel, was then used to perform Monte Carlo simulations (sampling of the parameters from their probability distribution) to estimate confidence intervals for the PLL and GCAF Factors.

The results of the uncertainty analysis of all RCOs considered in the combined assessment are summarized in Table 16 and elaborated subsequently.

The uncertainty analysis showed that most of the results from the static values are reliable. The RCOs found cost-effective with the static values but with a confidence lower than 90% are listed below:

- Fresh water activation/flushing (for *Cargo RoPax* Existing ships);
- Only ship cables (for Standard RoPax Existing ships);
- Alarm system design & integration (smoke) (for *Standard RoPax* Existing ships);
- Remote control(for *Standard RoPax* Existing ships);
- CCTV (for *Standard RoPax* Existing ships); and
- CCTV + Remote control (for *Standard RoPax* Existing ships).

Table 16: Confidence (conf) of RCOs having GCAF<1 based on uncertainty analysis

		Newbuildings						Existing ships					
		Cargo		Standard		Ferry		Cargo		Standard		Ferry	
		GCAF stat	GCAF conf	GCAF stat	GCAF conf	GCAF stat	GCAF conf	GCAF stat	GCAF conf	GCAF stat	GCAF conf	GCAF stat	GCAF conf
El 1	Robust connection boxes	0.08	100%	0.04	100%	0.03	100%	0.13	100%	0.08	100%	0.05	100%
El 2	Only ship cables	1.49	11%	0.49	93%	0.31	99%	2.04	2%	0.70	74%	0.46	93%
El 3	IR camera	0.19	100%	0.05	100%	0.04	100%	0.26	100%	0.08	100%	0.05	100%
El 4	Training for awareness	0.02	100%	0.01	100%	0.00	100%	0.04	100%	0.01	100%	0.01	100%
El 5	Only crew connections	0.02	100%	0.01	100%	0.00	100%	0.04	100%	0.01	100%	0.01	100%
El 6	Cable reeling drums	5.04	0%	3.88	0%	2.51	2%	8.0	0%	6.16	0%	4.02	0%
Det1	Combined heat & smoke and Alarm System Design & Integration	0.16	100%	0.02	100%	0.01	9%	2.4	2%	0.37	98%	0.06	100%
Det2	Ban / closure of side (PS & SB) openings (open ro-ro spaces)	N/A	N/A	1.83	3.0%	N/A	N/A	N/A	N/A	2.77	0%	N/A	N/A
Det3	Increased frequency fire patrols	10.0	0%	2.09	2.9%	2.47	1%	13.2	0%	2.74	0%	3.27	0%
Dec1	Alarm System Design & Integration (smoke)	0.35	96%	0.05	100%	0.02	100%	4.42	0%	0.62	72%	0.11	100%
Dec2	Improved markings/signage for wayfinding and localisation	0.08	100%	0.01	100%	0.01	100%	0.16	100%	0.03	100%	0.01	100%
Dec3	Preconditions for Early Activation of Drencher System	1.47	11%	0.26	100%	0.15	100%	1.97	3%	0.35	99%	0.20	100%
Su 1	Remote control	2.31	4%	0.28	98%	0.15	100%	5.10	0%	0.61	74%	0.33	96%
Su 3	Rolling shutters (PS & SB side) (Open ro-ro spaces)	N/A	N/A	2.01	3.4%	N/A	N/A	N/A	N/A	5.1	0%	N/A	N/A
Su 4	Efficient activation routines	0.00	100%	0.00	100%	0.00	100%	0.01	100%	0.00	100%	0.00	100%
Su 5	Fresh water activation/flushing	0.17	100%	0.02	100%	0.01	100%	0.66	74%	0.07	100%	0.04	100%
Su 6	CCTV	2.24	3%	0.28	100%	0.16	100%	4.8	0%	0.59	83%	0.33	98%
Su 7	CCTV + Remote control	2.44	1%	0.30	100%	0.16	100%	5.3	0%	0.65	85%	0.36	99%
Cont1	Permanent closure of openings	2.29	1%	1.77	4.2%	0.39	99%	4.31	0%	2.83	0%	15.1	0%
Cont2	Fire monitors on weather deck	0.10	100%	0.05	100%	0.03	100%	0.27	100%	0.13	100%	0.09	100%
Evac1c	Optimal distance / Closing LSA near openings	N/A	N/A	0.00	100%	N/A	N/A	N/A	N/A	0.07	100%	N/A	N/A

10.5 Objective comparison of alternative options

Table 17 presents the GCAF Factors for all RCOs considered in the combined assessment.

Table 17: GCAF Factors for the different RCOs on each generic vessel (for both Newbuildings and Existing ships)

		Newbuildings			Existing ships		
RCO#	RCO	Cargo RoPax	Standard RoPax	Ferry RoPax	Cargo RoPax	Standard RoPax	Ferry RoPax
El1	Robust connection boxes	0.08	0.04	0.03	0.13	0.08	0.06
El2	Only ship cables	1.49	0.49	0.32	2.05	0.70	0.46
El3	IR camera	0.19	0.05	0.04	0.26	0.08	0.05
El4	Training for awareness	0.02	0.01	0.00	0.04	0.01	0.01
El5	Only crew connections	0.02	0.01	0.00	0.04	0.01	0.01
El6	Cable reeling drums	5.07	3.88	2.55	8.09	6.16	4.04
Det1	Combined heat & smoke and alarm system design & integration	0.16	0.02	0.01	2.44	0.37	0.06
Det2	Ban / closure of side (PS & SB) openings (open ro-ro spaces)	N/A	1.83	N/A	N/A	2.77	N/A
Det3	Increased frequency fire patrols	10.05	2.09	2.51	13.28	2.74	3.29
Dec1	Alarm System Design & Integration (smoke)	0.35	0.05	0.02	4.44	0.62	0.11
Dec2	Improved markings/signage for wayfinding and localisation	0.08	0.01	0.01	0.16	0.03	0.01
Dec3	Preconditions for Early Activation of Drencher System	1.48	0.26	0.15	1.98	0.35	0.20
Su1	Remote control	2.32	0.28	0.15	5.13	0.61	0.33
Su3	Rolling shutters (PS & SB side) (Open ro-ro spaces)	N/A	2.01	N/A	N/A	5.14	N/A
Su4	Efficient activation routines	0.00	0.00	0.00	0.01	0.00	0.00
Su5	Fresh water activation/flushing	0.17	0.02	0.01	0.66	0.07	0.04
Su6	CCTV	2.25	0.28	0.16	4.78	0.59	0.34
Su7	CCTV + Remote control	2.45	0.30	0.16	5.33	0.65	0.36
Cont1	Ban/closure of side & end openings (closed and open ro-ro spaces)	2.31	1.77	0.39	4.33	2.83	15.14
Cont2	Fire monitors on weather deck	0.10	0.05	0.04	0.27	0.13	0.09
Evac1c	Optimal distance / Closing LSA near openings	N/A	0.00	N/A	N/A	0.07	N/A

Some RCOs achieved a very high cost-effectiveness for both Newbuildings and Existing ships, as a direct consequence of their low implementation cost. All of these RCOs are operational or procedural:

- *Training for awareness*;
- *Only crew connections*;
- *Efficient activation routines*; and
- *Fresh water activations/flushing*.

Some other RCOs did not pass the cost-effectiveness criterion mainly due to the high costs associated with their implementation, although they achieved fairly high risk reduction. The cost drivers were of different types: material costs for the *Cable reeling drums* and *Rolling shutters*; personnel costs for the *Increased frequency of fire patrols* (with the need to hire an additional AB or divert an AB from its maintenance work for some time); or operational costs (associated to cargo loss) for *Ban/closure of side openings* and *Ban/closure of side & end openings*.

Some RCOs achieved cost-effectiveness after the combined assessment, such as the RCOs *CCTV* and *CCTV + Remote control*. This could be attributed to the significant increase in the risk reduction following the consideration of the impacts of these RCOs in the decision node. Notwithstanding the foregoing, none of these RCOs were found cost-effective for the *Cargo RoPax* in particular due to the low passenger capacity (leading to low risk reductions) and the large weather deck (where CCTV and remote control of the fixed fire-extinguishing systems are irrelevant).

Some RCOs proved to be cost-effective with a high risk reduction and an associated fairly low lifetime costs. For example, this was the case for the RCO *Fire monitors on weather deck* (with a relative risk reduction of up to 50% on the *Cargo RoPax* induced by the improved suppression and containment capability). The RCO *Robust connection boxes* falls within this category with an implementation cost below 40 000€ and a significant risk reduction achieved by reducing the probability of electrical fire by 13% through robust connection boxes. To a lesser extent, the RCO *Combined heat & smoke and alarm system design and integration* can be classified in this category (except on the *Cargo RoPax Existing ships*). This RCO improves the detection time and decision process, also allowing for improved tactical fire-fighting and boundary cooling, and has an implementation cost of 20 000€ for Newbuildings and 160 000€ for Existing ships.

11 RECOMMENDATION FOR DECISION-MAKING

11.1 Recommendation for decision-making

The risk assessment and cost-effectiveness parts of this study were developed and quantified through investigation of available failure data, fire simulations, and in case none of the previous options were available, qualitative considerations and expert judgement. Although this study is believed to be based on the best available techniques and estimates, the results presented in this study should be considered carefully, bearing in mind the inherent limitations of the modelling and the data available.

The results are considered to be meaningful and to represent the best estimates to date, considering the data available. Furthermore, as far as practicable, a high level of attention was given to explicit all assumptions used in the study with the aim to ease any potential modifications or updates of the assumptions with new data sets or different expert judgements.

Some of the assumptions made in the risk assessment part were conservative, leading to a potential over estimation of the societal risk. Although the consequence part of the main fire risk model was developed to be representative to the average consequences of accidents, it should be noted that a single accident leading to a high number of fatalities within a limited period in time may skew the estimated historical societal risk. This may create a difference between the estimated historical societal risk and the risk estimated with the risk model. An over-estimation of the societal risk will generally increase the risk reduction potential of RCOs.

The costs estimated in this study were based on the estimates provided by a single ship operator. Although many efforts were made to make this study applicable for the world fleet, the cost estimates are necessarily influenced by the geographical area considered and the inherent safety culture of the ship operator involved, which already implements some of the risk control options recommended in this study on a voluntarily basis.

Quantifying the effects of all of the above assumptions and their cross-effects with a high level of precision is not realistic and some of the various assumptions might skew the overall results. However, the sensitivity and uncertainty analyses performed in the context of this study allowed, to some extent, consideration to these effects and should be considered along with the best estimates for decision making.

A Risk Control Option was considered cost-effective if the Gross Cost of Averting a Fatality (GCAF) is below €7 M.

No criteria for evaluating the acceptability of risks associated with a particular hazard (here fires in ro-ro spaces) are available to support decision-making at the IMO. However, several cost-effective risk control options were identified and could be recommended to improve the safety level of the RoPax world fleet (listed below in order of risk reduction potential)[4]:

[4] As a general guidance, when several RCOs are cost-effective, the risk control options selection process should focus on preventive rather than mitigating measures, design rather than procedural measures, and should consider the risk reduction potential and the GCAF ranking, along with the uncertainty.

- Regardless of the ship category:
    - Fire monitors on weather decks;
    - Robust connection boxes;
    - Combined heat and smoke and alarm system design and integration;
    - Alarm system design and integration (smoke);
    - IR camera; and
    - Improved markings/signage for wayfinding and localization.
- For Standard RoPax and Ferry RoPax:
    - Precondition for early activation of drencher system
    - CCTV + Remote control;
    - CCTV;
    - Remote control; and
    - Only ship cables.
- For Standard RoPax:
    - Safe distance
- For Ferry RoPax:
    - Safe distance (only for Newbuildings).

It is worth noting that, the RCO *Precondition for early activation of drencher system* was found to have a GCAF value above € 7M on *Cargo RoPax,* but that this RCO achieved a negative NCAF value, and therefore, should be regarded as cost-effective.

The following RCOs, associated with a low cost, were also found cost effective:

- Training for awareness
- Efficient activation routines
- Fresh water activation/flushing
- Only crew connections

The risk reduction provided by each RCO was estimated with the assumption that none of the other RCOs were implemented (i.e. each RCO was assessed independently). If a combination of RCOs was to be considered, their interdependencies should be considered.

In addition to the recommendations of the above RCOs, the following recommendations were formulated based on the combined assessment:

It should be noted that the assumptions made to estimate the cost of implementing the RCO *Ban of side openings* on *Standard RoPax* (not considering any major change on ship design to accommodate for the loss of cargo due to the closure of the side openings) was very influential on the cost effectiveness results (high recurring costs for 40 years instead of a significant investment cost). In view of the results of the Combined Assessment (GCAF factor below 2), it is recommended to further investigate this RCO considering a reconstruction of the ship layout or adding safety systems to allow for “no cargo loss”.

Although not studied as a particular RCO, the findings of the simulations and the risk assessment part indicated that a fire detection system in ro-ro spaces based on heat detection only (considering conventional point heat detectors) should not be allowed.

Some RCOs are already (voluntarily or mandatory) implemented by some ship owners, operating their ships above minimum SOLAS requirements. Such actions are encouraged regardless of the cost-effectiveness reported above. The results of the cost-effectiveness assessment reported in FIRESAFE II are believed to be representative for the world fleet, but they may be impacted by the intrinsic safety culture and specific procedures of the specific ship operator.

11.2 Discussion on how recommendations could be implemented by decision-makers

11.2.1 *Background*

In view of the above combined cost-effectiveness assessment results, proposed amendments to IMO regulations are discussed below, for the implementation of Risk Control Options that proved to be cost-effective when considering their impacts along the whole fire protection chain.

11.2.1.1 Graphic codes

Amendment proposals are presented with the convention used in IMO papers i.e.:

- Deletions are stroke through: ~~Example~~
- Additions are shown with a grey background: Example

11.2.1.2 Retroactivity

The amendment proposals detailed in the section below would, as amendments of SOLAS or FSS Code, be applicable only to ships built after their date of entry into force. In case it is decided to make these requirements also applicable to existing ships, the following requirement should be added in SOLAS II-2/1.2

2.9 Ships constructed before XXX* shall comply with regulations 20.4.1, 20.2.2.4, 20.3.1.5.2, 20.4.3.1, 20.4.4, 20.6.1.5, 20.6.1.6 and 20.6.2 not later than the first renewal survey on or after YYY*

*XXX Date of entry into force of the amendments for newbuildings

YYY Date by which existing ships would have to comply with the new requirements. Delay may be needed, especially if it is considered to close any opening on the side.

<u>Note:</u> The requirements to be included in FSS Code are not covered by this proposal, and indeed, it is not deemed really practical to ask for retroactive application of the requirements given in 11.2.3.2.3. Should they need to be considered retroactive too, it could be proposed to include the following paragraph in FSS Code Chapter 1, after existing 1.3:

1.4 Ro-ro passenger ships the keels of which were laid or which were at a similar stage of construction before XXX shall comply shall comply with requirements 9.2.5.1.2 & 9.2.5.1.3 not later than the first renewal survey on or after YYY

11.2.2 *CCTV in ro-ro spaces*

11.2.2.1 RCO presentation

The intent of this RCO is to require CCTV video cameras to be installed in ro-ro spaces as a complement to conventional fixed fire detection and fire alarm system, in order to provide fire confirmation and detailed information at the bridge in case of fire.

The option to replay the video on demand in case of a fire alarm is a key point, since at the time when the fire alarm will ring, smoke may already obscure video images.

11.2.2.2 Amendment proposal

It is proposed to include the following new requirement in SOLAS II-2/20.4:

> 20.4.4 Television surveillance
>
> On passenger ships, television surveillance shall be arranged throughout closed vehicles and ro-ro spaces as a complement to the fixed fire detection and fire alarm system. Where the fixed fire-extinguishing system required by regulation 20.6.1 is divided into sections, at least one video camera per section shall be provided. In addition, video cameras shall be installed alternately on each side of the deck and high enough to see over cargo and vehicles after loading.
>
> The videos recorded by this television system shall be available for replay at a continuously manned control station or at the safety centre for at least 6 hours and the correspondence between any one video camera and the section of the fixed fire-extinguishing system it is covering shall be clearly displayed close to the video monitor.

The proposed wording is in line with the wording of SOLAS II-1/17-1.3, requiring CCTV surveillance in ro-ro passenger ships for flooding damage prevention and control purposes.

11.2.3 *Combined heat and smoke detection*

This RCO was extensively discussed in the first part of FIRESAFE II (EMSA, 2018).The intent of this RCO is to ensure that both heat elevation and smoke would trigger fire detection. RCO assessment was carried out considering conventional combined heat and smoke detectors.

11.2.3.1 Amendment proposal

It is proposed to amend SOLAS II-2/20.4.1 as follows:

> Except as provided in paragraph 4.3.1, there shall be provided a fixed fire detection and fire alarm system complying with the requirements of the Fire Safety Systems Code, so as to provide smoke and heat detection throughout vehicle, special category and ro-ro spaces. The fixed fire detection system shall be capable of rapidly detecting the onset of fire. The ~~type of detectors and their~~ spacing of the detectors and their location shall be to the satisfaction of the Administration, taking into account the effects of ventilation and other relevant factors. […]

This wording and requirement location are in line with those used in SOLAS II-2/75.2 to require smoke detectors in the accommodation, service spaces and control stations of passenger ships.

It is to be noted that, with the proposed wording, combined heat and smoke detection would be required on both passenger and cargo ro-ro ships. In case it is decided to apply such requirement to passenger ships only, the following wording could be considered:

> Except as provided in paragraph 4.3.1, there shall be provided a fixed fire detection and fire alarm system complying with the requirements of the Fire Safety Systems Code. On passenger ships, the fixed fire detection and fire alarm system shall provide smoke and heat detection throughout vehicle, special category and ro-ro spaces; on cargo ships, the type of detectors shall be to the satisfaction of the Administration. The fixed fire detection system shall be capable of rapidly detecting the onset of fire. The ~~type of detectors and their~~ spacing of the detectors and their location shall be to the satisfaction of the Administration, taking into account the effects of ventilation and other relevant factors. […]

11.2.3.2 Relevant interpretations & consequential amendments

Two key interpretations are associated with SOLAS II-2/20.4.1: IACS UI SC73 and an interpretation included in IMO MSC/Circ.1120.

11.2.3.2.1 IACS UI SC73: Fire protection of weather decks

IACS UI SC73 states:

> The requirements for a fixed fire extinguishing system, fire detection, foam applicators and portable extinguishers need not apply to weather decks used for the carriage of vehicle with fuel in their tanks.

This interpretation would remain valid and relevant with the proposed amendment.

11.2.3.2.2 MSC.1/Circ.1120: Arrangements for disconnecting detector sections during loading and unloading

With respect to SOLAS II-2/20.4.1, IMO MSC/Circ.1120 clarifies that smoke detectors may be temporarily disconnected for e.g. loading/unloading sequences. The following amendment is proposed in order to clarify that heat detectors should not be disconnected under such circumstances. Indeed, one of the identified gains of having combined heat and smoke detection is to improve detection during loading/unloading sequences.

> The smoke detector sections in vehicle, special category, and ro-ro spaces may be provided with an arrangement, (e.g. a timer) for disconnecting detector sections during loading and unloading of vehicles to avoid "false" alarms. The time of disconnection should be adapted to the time of loading/unloading. The central unit should indicate whether the detector sections are disconnected or not.
>
> However, manual call points and heat detectors should not be capable of being disconnected by the arrangements referred to above.

11.2.3.2.3 FSS Code Ch.9 §2.1.1

FSS Code Ch 9 §2.1.1 allows for temporary disconnection of the fire detection and fire alarm system. Similar to above, the following amendment is proposed in order to clarify that only smoke detectors may be disconnected:

> 2.1.1 Any required fixed fire detection and fire alarm system with manually operated call points shall be capable of immediate operation at all times (this does not require a backup control panel). Notwithstanding this, particular spaces may be disconnected, for example, workshops during hot work and smoke detectors in ro-ro spaces during on and off-loading. The means for disconnecting the detectors shall be designed to automatically restore the system to normal surveillance after a predetermined time that is appropriate for the operation in question. The space shall be manned or provided with a fire patrol when detectors required by regulation are disconnected.
>
> Detectors in all other spaces shall remain operational. In ro-ro spaces, heat detectors shall remain operational during on and off-loading.

11.2.4 *Alarm system design and integration*

This RCO was extensively discussed in the first part of FIRESAFE II (EMSA, 2018).The purpose of this RCO is to improve the design of the fixed fire detection and fire alarm system in order to support fire incident decision-making and ensure quick activation of the fire suppression system.

11.2.4.1 Amendment proposal

It is proposed to insert the following requirements in FSS Code Chapter 9, after existing §2.5.1.1, and the next requirements should be re-numbered accordingly:

> 2.5.1.2. [In ro-ro passenger ships,] indications shall follow a consistent alarm presentation scheme (wording, vocabulary, colour, position). Alarms shall be immediately recognisable on the bridge and shall not be compromised by noise or poor placing.
>
> 2.5.1.3. [In ro-ro passenger ships,] the interface shall provide alarm addressability, allow the crew to identify the alarm history and the most recent alarm. The system shall provide the means to suppress alarms while making sure that alarms with ongoing trigger conditions are still clearly visible.

Note: The wording [In ro-ro passenger ships] in inserted into brackets because the present study is focused on ro-ro passenger ships. However, the above requirements are simple, non-expensive safety measures and it seems relevant to apply them for all newbuildings.

11.2.5 *Signage and markings for effective wayfinding and localisation*

This RCO was extensively discussed in the first part of FIRESAFE II (EMSA, 2018).

11.2.5.1 Amendment proposal

It is proposed to add the following requirement in SOLAS II-2/20.6:

> 6.1.6. In passenger ships, closed vehicles and ro-ro spaces and special category spaces, where fixed pressure water-spraying systems are fitted shall be provided with suitable signage and marking on deck and on the vertical boundaries allowing easy identification of the sections of the fixed fire-extinguishing system. Signage and markings shall be adapted to typical patterns of crew movement and shall not be obstructed by cargo or fixed installations. Section number signs shall be of photoluminescent material tested in accordance with the Fire Safety System Code. The section numbering indicated inside the space shall be same as section valve identification and section ID at the safety centre or continuously manned control station.

It was deemed relevant to include such requirement directly in SOLAS rather than in the MSC Circulars and Resolutions covering the fixed fire extinguishing systems for ease of reference, because such marking is likely to be provided by yards and not by system designers.

The proposed wording for photoluminescent signage is in line with that found in SOLAS II-2/13.3.2.5.1 for photoluminescent signs for safety signage.

11.2.6 *Fire monitors on weather deck*

This RCO was extensively discussed in the second part of FIRESAFE II (EMSA, 2018). The purpose of this RCO is to require water monitors on weather decks intended for the carriage of vehicles in order to extinguish or contain a fire starting on this weather deck and in order to cool down adjacent boundaries to limit structural damage.

The following features are outlined:

- The fire monitors on weather deck and drencher / fixed water-based fire extinguishing system for open or closed ro-ro spaces may be fed by the same pump and piping system; and
- Remote control from a safe position.

11.2.6.1 Amendment proposal

It is proposed to add the following requirement in SOLAS II-2/20.6, after the existing regulation II-2/20.6.1, and to renumber the following regulations accordingly:

6.2 Water monitors on weather decks

6.2.1 On passenger ships, water monitors shall be provided on the weather decks intended for the carriage of vehicles. The arrangement, length and height of throw of the water monitors shall be sufficient to reach 90% of:

.1 The area intended for the storage of vehicles on the weather deck; and

.2 The area, including superstructure boundaries, located within [8m] measured horizontally from the area intended for vehicle storage.

6.2.2 The combined capacity of all water monitors shall be such as to provide an average coverage of 2L/min per square meter of protected area.

6.2.3 It shall be possible to remotely operate the fire monitors from a safe position in case of a fire on the weather deck.

6.2.4 Where the ship's required fire pumps are used to feed the water monitors:

.1 It shall be possible to segregate the ship's fire main from the water monitors by means of a valve in order to operate both systems separately or simultaneously

.2 The capacity of the pumps shall be sufficient to serve both systems simultaneously

6.2.5 Where the pump dedicated to the fixed pressure water spraying system required by regulation 20.6.1.2 is used to feed the water monitors, it shall be possible to segregate both systems by means of a valve and both systems need not be able to operate simultaneously.

6.2.6 Suitable scupper or freeing ports are to be provided to ensure efficient drainage of water accumulating on deck surfaces when the fire monitors are in operation. Discharge valves for scuppers shall be kept open while the ship is at sea.

Note 1: SOLAS II-2/10.7.3 requires mobile fire monitors (that can be plugged on fire hydrants) on container ships. However, the intent here is to require fixed water monitor, therefore the proposed wording is different.

Note 2: The proposed capacity requirement is in line with the total capacity considered in the second part of FIRESAFE II:

	Cargo RoPax	Standard RoPax	Ferry RoPax
B [m]	20.25	25.5	25
L [m]	171.05	186.5	203.3
$L_{weather\ deck}$ [m] (rough estimate)	81	73	32
Nb of fire monitors (1000L/min each)	3	4	2
Capacity (rough estimate)	1000 x 3 / (81*20.25) = 1.8 L/min/m^2	1000 x 4 / (73*25.5) = 2.1 L/min/m^2	1000 x 2 / (32*25) = 2.5 L/min/m^2

It is to be noted that this 2L/min/m^2 is significantly below the capacity required for drencher systems (3.5L/min/m^2 or 5L/min/m^2) which is justified by the fact that:

- A fire a on weather deck does not behave in the same way as a fire in an enclosed space; and
- The fire monitors will concentrate on a local fire area, not flood the whole weather deck at once.

Note 3: The 8m criterion is proposed by coherence with the criterion proposed for LSAs, see 11.2.7. This value could be discussed and challenged.

Note 4: Only 90% coverage is required, in line with the assumptions considered for the study. Indeed, shading due to e.g. exhaust chimneys can happen and covering the shaded areas would require additional monitors. This is not deemed necessary as global cooling is the main intent of this RCO.

11.2.6.2 Further development

It may be relevant to identify or develop an approval standard for fire monitors.

11.2.7 *Distance between LSAs and openings*

11.2.7.1 RCO presentation

The purpose of this RCO is to prevent LSAs from being exposed to and possibly damaged by a fire in a vehicle space. One RCO ensuring safe evacuation on RoPax ships was identified and defined as a design with:

- A [13 m] safety distance between LSA embarkation stations and weather deck/ro-ro space aft openings;
- An [8 m] safety distance between stowed LSAs (including survival craft, not embarked onboard) and weather deck/ro-ro space aft openings; and
- No LSAs or embarkation station within the full vertical range 6 m forward and aft of a side opening larger than [0.01] m^2.

11.2.7.2 Amendment proposal

It is proposed to delete SOLAS regulation II-2/20.3.1.5 (which is only applicable to closed vehicle spaces, ro-ro spaces and special category spaces) and insert a new paragraph II-2/20.4 as follows – following paragraphs to be renumbered accordingly:

4 Permanent openings

4.1 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 spaces.

4.2 It is considered that stowage area and embarkation stations for survival craft are not endangered by a fire in the cargo space when:

.1 Survival craft is stowed:

.1.1 More than 6 m, measured horizontally, away from any opening to a vehicle or ro-ro space

.1.2 More than [8 m], measured horizontally, away from any weather deck area intended for the storage of vehicles

.2 Survival craft embarkation stations and muster stations are located:

.1.1 More than 6 m, measured horizontally, away from any opening to a vehicle or ro-ro space

.1.2 More than [13 m], measured horizontally, away from any weather deck area intended for the storage of vehicles

.3 Marine evacuation systems and lifeboats shall be in such position that they can be deployed or launched:

.1.1 More than 6 m, measured horizontally, away from any opening to a vehicle or ro-ro space

.1.2 More than [8 m], measured horizontally, away from any weather deck area intended for the storage of vehicles

Note 1: The 8 m and 13 m criterion here is proposed as an additional output of the study. This value would benefit from being further discussed.

12 BIBLIOGRAPHY

EMSA. (2016). *Study investigating cost effective measures for reducing the risk from fires on ro-ro passenger ships (FIRESAFE).* Lisbon: European Maritime Safety Agency.

EMSA. (2018). *Second study investigating cost effective measures for reducing the risk from fires on ro-ro passenger ships (FIRESAFE II) - Combined Assessment.* Lisbon: European Maritime Safety Agency.

EMSA. (2018). *Second study investigating cost effective measures for reducing the risk from fires on ro-ro passenger ships (FIRESAFE II) - Containment and Evacuation.* Lisbon: European Maritime Safety Agency.

EMSA. (2018). *Second study investigating cost effective measures for reducing the risk from fires on ro-ro passenger ships (FIRESAFE II) - Detection and Decision.* Lisbon: European Maritime Safety Agency.

HM Treasury. (2018). *The Green Book - Central Government Guidance on Appraisal and Evaluation.* London.

IMO. (2007). *MSC 83/INF.8 - FSA - Container vessels - Details of the Formal Safety Assessment.* London: International Maritime Organization.

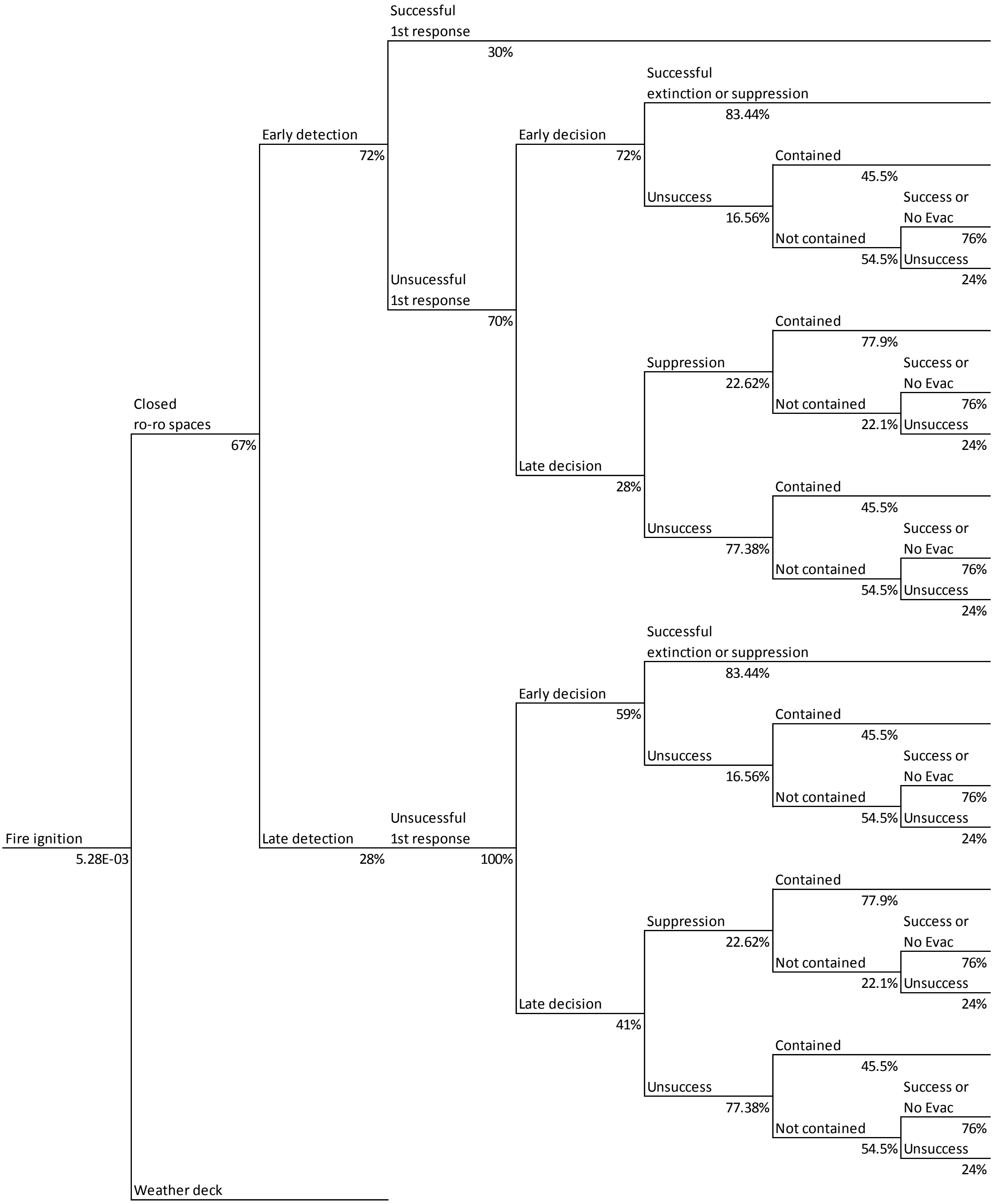
IMO. (2016). *III 3/4/5 - Lessons learned and safety issues identified from the analysis of marine safety investigation reports – Use of accident data.* London: International Maritime Organization (Submitted by Cruise Lines International Association (CLIA) and International Association of Classification Societies (IACS)).

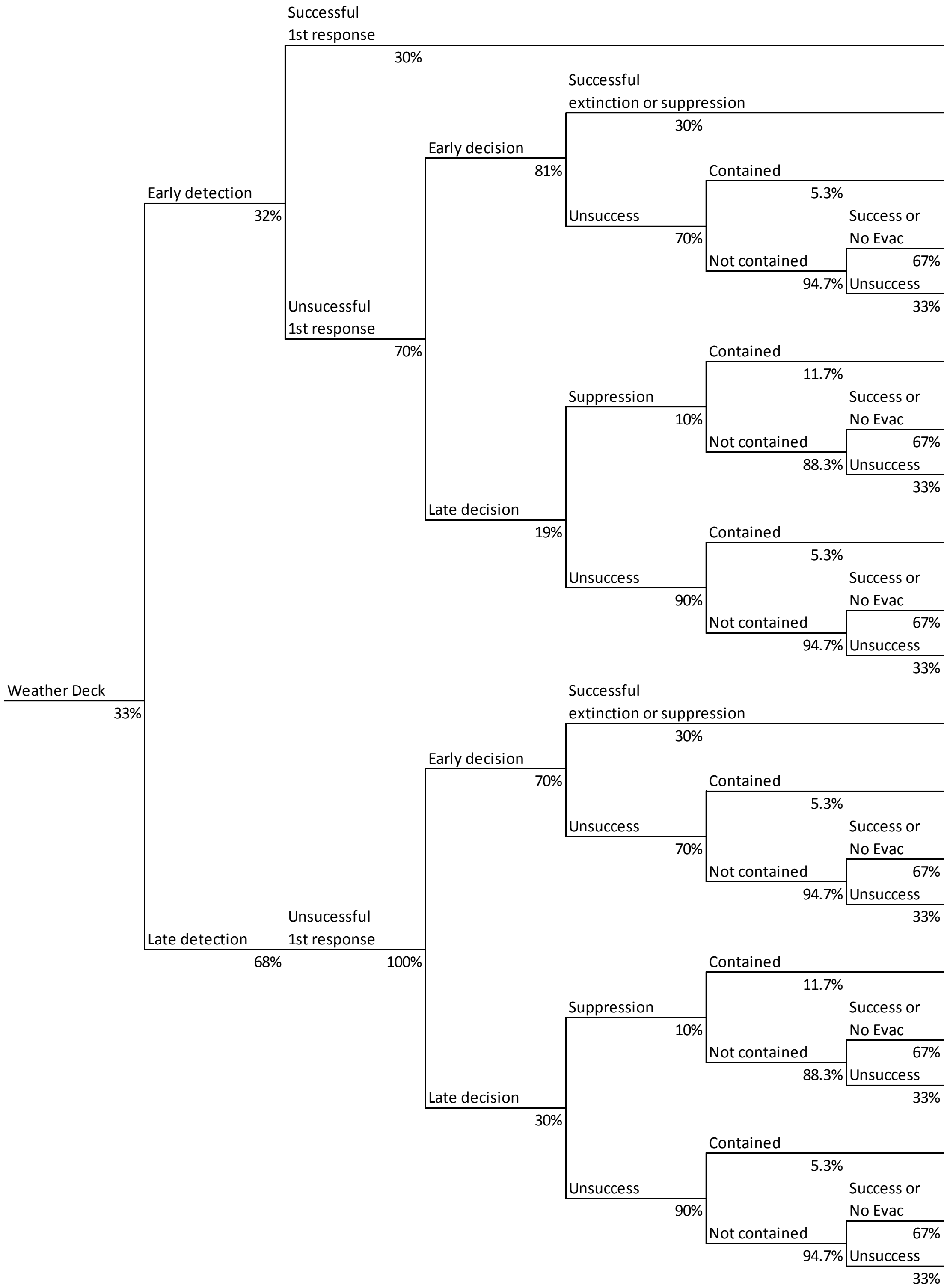
IMO. (2018). *MSC-MEPC.2/Circ.12/Rev.2 - Revised Guidelines for Formal Safety Assessment (FSA) for Use in the IMO Rule-Making Process.* London: International Maritime Organization.

Vanem, E., & Skjong, R. (2004). Fire and Evacuation Risk Assessment for Passenger Ships. *Proceedings of the 10th International conference on Fire Science and Engineering, Interflam 2004.*

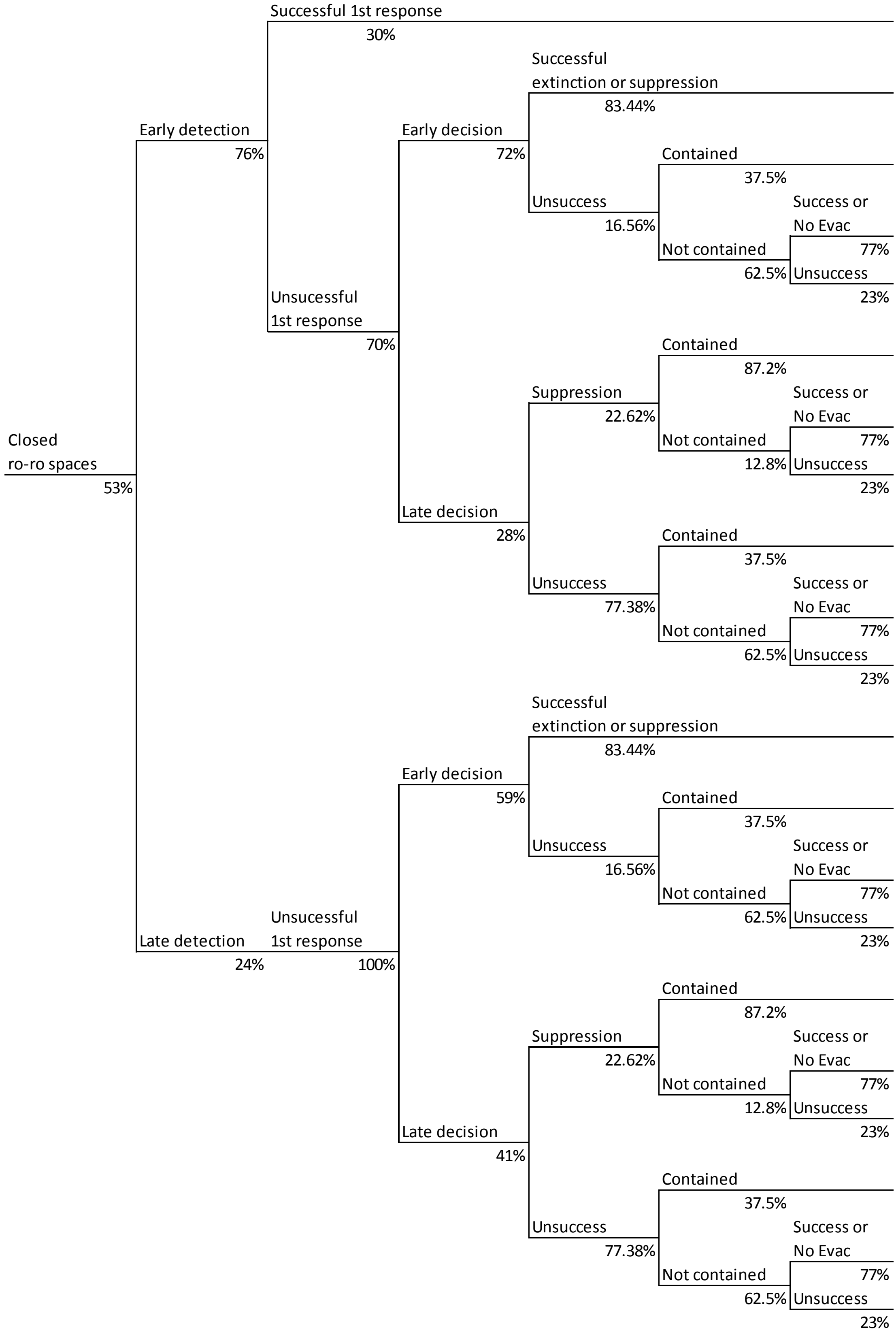
A1 ANNEXES:

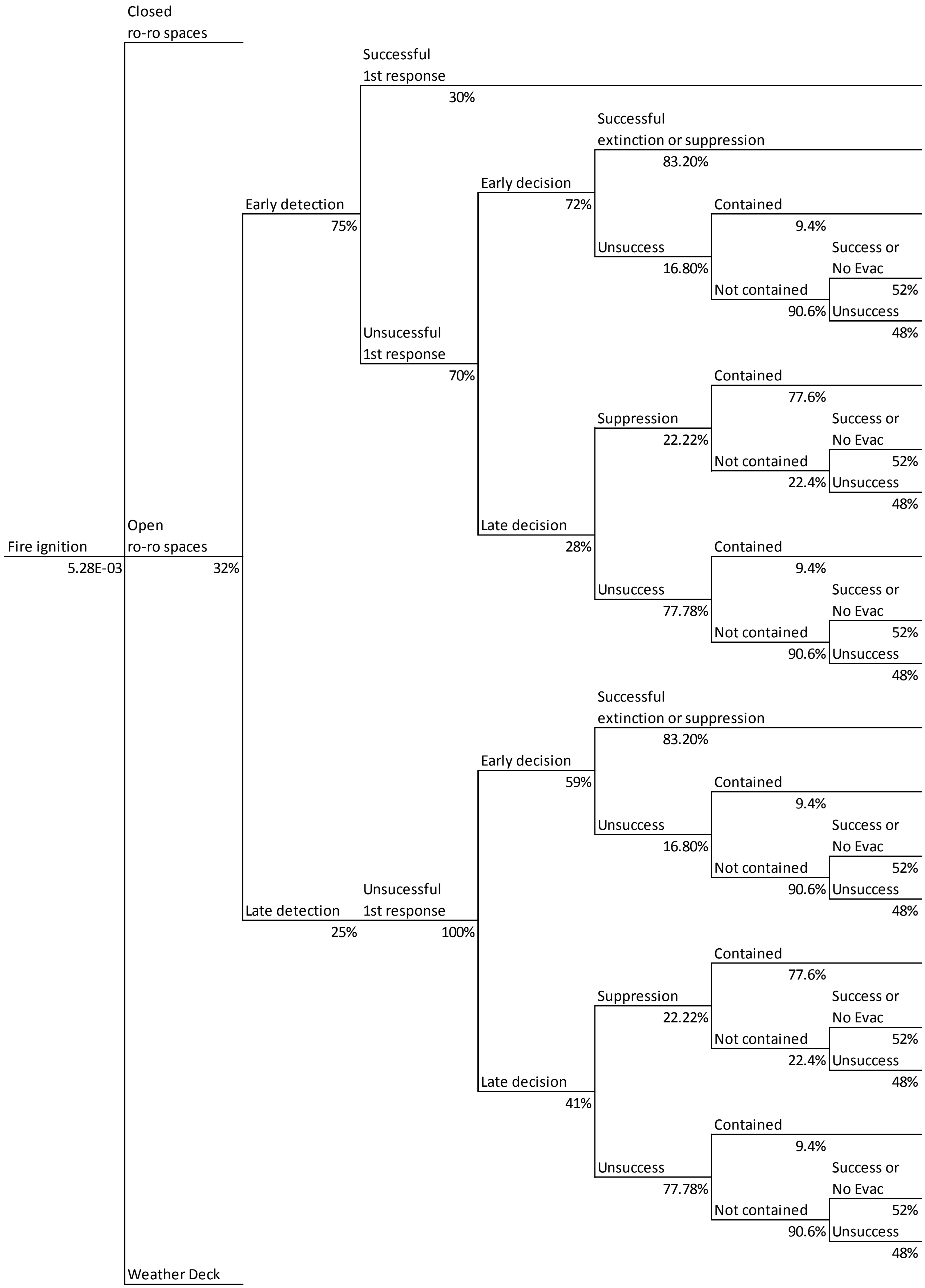
A1.1 Updated Main fire risk model (*Cargo RoPax* – Newbuildings)

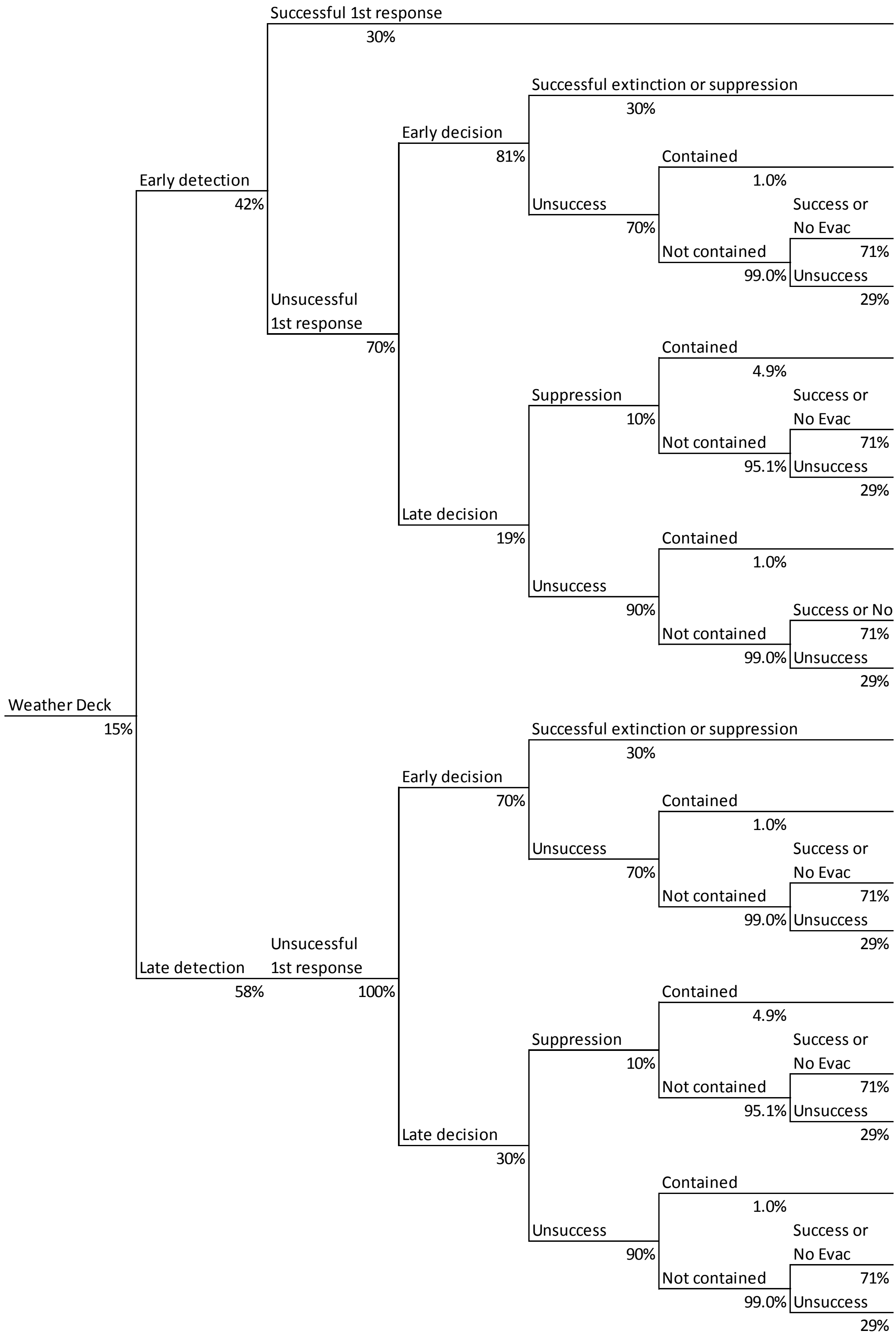



Weather Deck
33%
Early detection
32%
Successful
1st response
30%
Unsucessful
1st response
70%
Early decision
81%
Successful
extinction or suppression
30%
Unsuccess
70%
Contained
5.3%
Not contained
94.7%
Success or
No Evac
67%
Unsuccess
33%
Late decision
19%
Suppression
10%
Contained
11.7%
Not contained
88.3%
Success or
No Evac
67%
Unsuccess
33%
Unsuccess
90%
Contained
5.3%
Not contained
94.7%
Success or
No Evac
67%
Unsuccess
33%
Late detection
68%
Unsucessful
1st response
100%
Early decision
70%
Successful
extinction or suppression
30%
Unsuccess
70%
Contained
5.3%
Not contained
94.7%
Success or
No Evac
67%
Unsuccess
33%
Late decision
30%
Suppression
10%
Contained
11.7%
Not contained
88.3%
Success or
No Evac
67%
Unsuccess
33%
Unsuccess
90%
Contained
5.3%
Not contained
94.7%
Success or
No Evac
67%
Unsuccess
33%

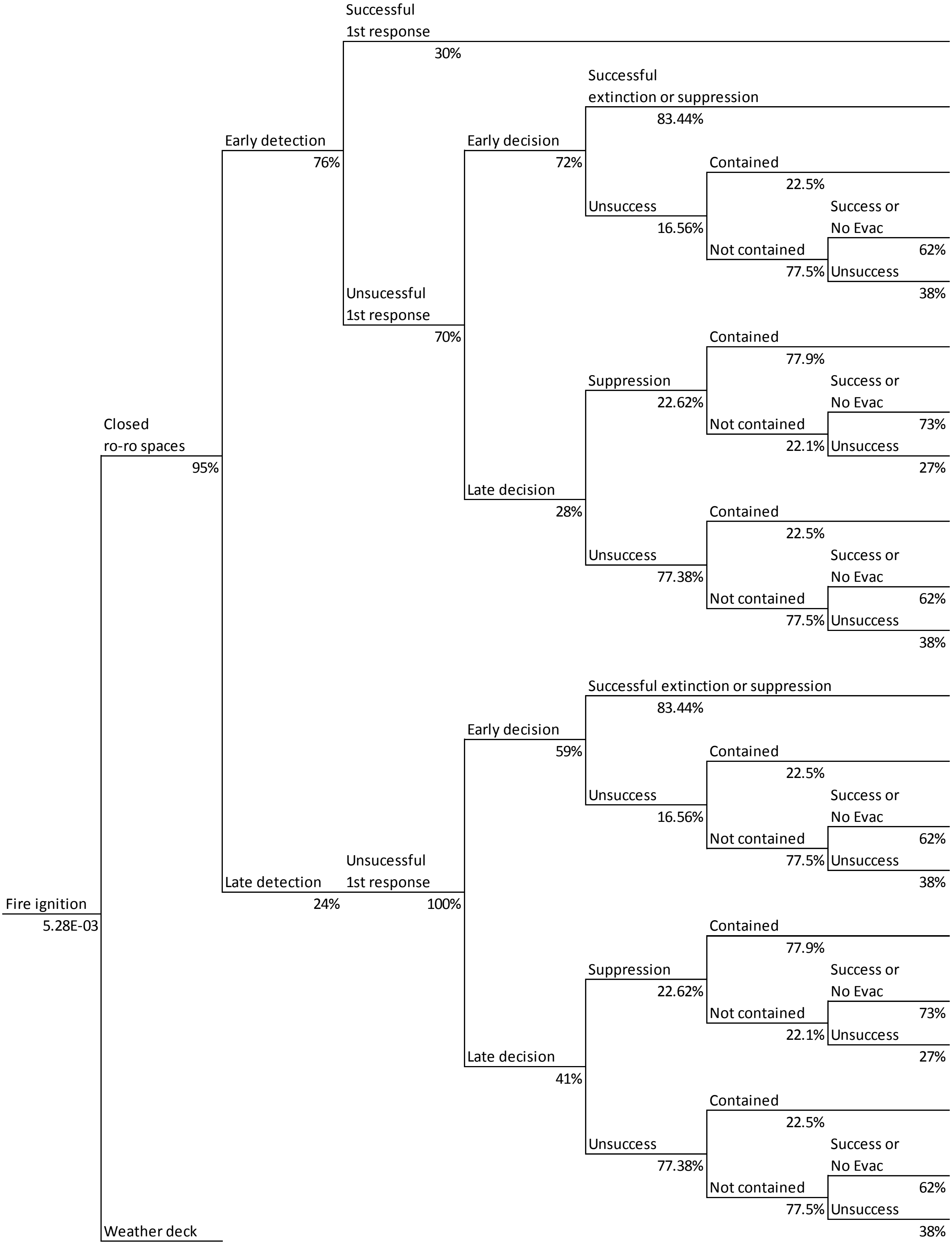
A1.2 Updated Main fire risk model (*Standard RoPax* – Newbuildings)

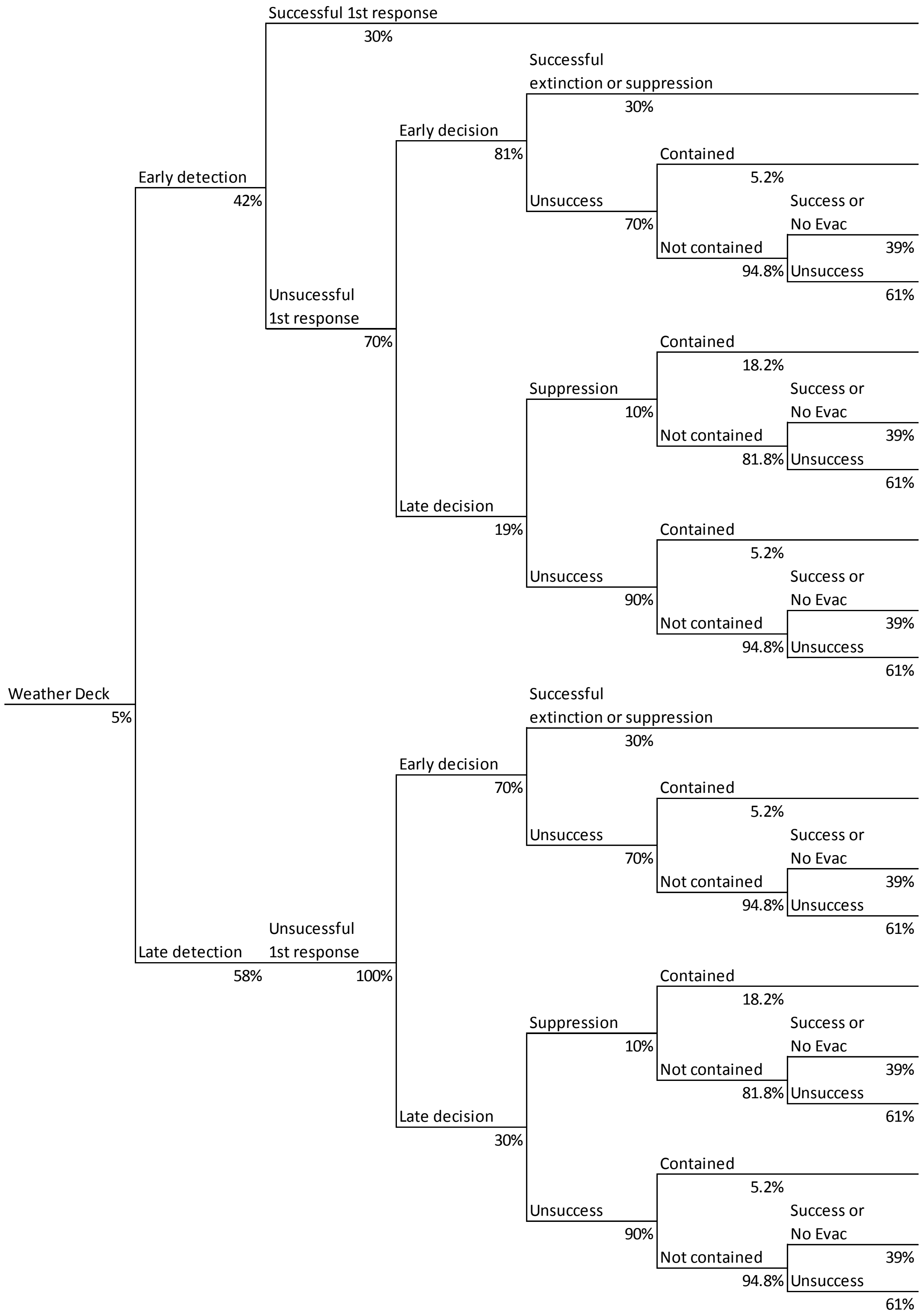



Closed
ro-ro spaces
Successful
1st response
30%
Successful
extinction or suppression
83.20%
Early decision
72%
Early detection
75%
Contained
9.4%
Unsuccess
16.80%
Success or
No Evac
Not contained
90.6%
52%
Unsuccess
48%
Unsuccessful
1st response
70%
Contained
77.6%
Suppression
22.22%
Success or
No Evac
Not contained
22.4%
52%
Unsuccess
48%
Fire ignition
5.28E-03
Open
ro-ro spaces
32%
Late decision
28%
Contained
9.4%
Unsuccess
77.78%
Success or
No Evac
Not contained
90.6%
52%
Unsuccess
48%
Successful
extinction or suppression
83.20%
Early decision
59%
Contained
9.4%
Unsuccess
16.80%
Success or
No Evac
Not contained
90.6%
52%
Unsuccess
48%
Late detection
25%
Unsuccessful
1st response
100%
Contained
77.6%
Suppression
22.22%
Success or
No Evac
Not contained
22.4%
52%
Unsuccess
48%
Late decision
41%
Contained
9.4%
Unsuccess
77.78%
Success or
No Evac
Not contained
90.6%
52%
Unsuccess
48%
Weather Deck


Weather Deck
15%
Early detection
42%
Successful 1st response
30%
Unsucessful
1st response
70%
Early decision
81%
Successful extinction or suppression
30%
Unsuccess
70%
Contained
1.0%
Not contained
99.0%
Success or
No Evac
71%
Unsuccess
29%
Late decision
19%
Suppression
10%
Contained
4.9%
Not contained
95.1%
Success or
No Evac
71%
Unsuccess
29%
Unsuccess
90%
Contained
1.0%
Not contained
99.0%
Success or No
71%
Unsuccess
29%
Late detection
58%
Unsuccessful
1st response
100%
Early decision
70%
Successful extinction or suppression
30%
Unsuccess
70%
Contained
1.0%
Not contained
99.0%
Success or
No Evac
71%
Unsuccess
29%
Late decision
30%
Suppression
10%
Contained
4.9%
Not contained
95.1%
Success or
No Evac
71%
Unsuccess
29%
Unsuccess
90%
Contained
1.0%
Not contained
99.0%
Success or
No Evac
71%
Unsuccess
29%

A1.3 Updated Main fire risk model (*Ferry RoPax* – Newbuildings)




Successful 1st response
30%
Successful
extinction or suppression
30%
Early decision
81%
Contained
5.2%
Early detection
42%
Unsuccess
70%
Success or
No Evac
Not contained
94.8%
39%
Unsuccess
61%
Unsuccessful
1st response
70%
Contained
18.2%
Suppression
10%
Success or
No Evac
Not contained
81.8%
39%
Unsuccess
61%
Late decision
19%
Contained
5.2%
Unsuccess
90%
Success or
No Evac
Not contained
94.8%
39%
Unsuccess
61%
Weather Deck
5%
Successful
extinction or suppression
30%
Early decision
70%
Contained
5.2%
Unsuccess
70%
Success or
No Evac
Not contained
94.8%
39%
Unsuccess
61%
Unsuccessful
1st response
100%
Late detection
58%
Contained
18.2%
Suppression
10%
Success or
No Evac
Not contained
81.8%
39%
Unsuccess
61%
Late decision
30%
Contained
5.2%
Unsuccess
90%
Success or
No Evac
Not contained
94.8%
39%
Unsuccess
61%

A2 LIST OF ABBREVIATIONS

AB:	Able seaman
CCTV:	Closed-Circuit Television
ECR:	Engine Control Room
EMSA:	European Maritime Safety Agency
EU:	European Union
FSA:	Formal Safety Assessment
FSS:	International Code for Fire Safety Systems
FTP:	International Code for Application of Fire Test Procedures
GCAF:	Gross Cost of Averting a Fatality
GT:	Gross Tonnage
HazId:	Hazard Identification
IACS:	International Association of Classification Societies
IMO:	International Maritime Organization
IR:	Infrared
LSA:	Life-Saving Appliances
MEPC:	Marine Environment Protection Committee
MSC:	Maritime Safety Committee
MVZ:	Main Vertical Zone
NCAF:	Net Cost of Averting a Fatality
NPV:	Net Present Value
PLC:	Potential Loss of Cargo
PLL:	Potential Loss of Life
PLS:	Potential Loss of Ship
PS:	Portside
RCM:	Risk Control Measure
RCO:	Risk Control Option
SB:	Starboard
SOLAS:	Safety of Life at Sea
UI:	Unified Interpretation
UR:	Unified Recommendation

A3 INTERDEPENDENCY MATRIX

		El1	El2	El3	El4	El5	El6	Det1	Det2	Det3	Dec1	Dec2	Dec3	Su1	Su3	Su4	Su5	Su6	Su7	Cont1	Cont2
El1	Robust connection boxes		Strong	Weak	Weak	Strong	Strong	No	No	No	No	No	No	No	No	No	No	No	No	No	No
El2	Only ship cables	Weak		No	Weak	Weak	Strong	No	No	No	No	No	No	No	No	No	No	No	No	No	No
El3	IR camera	No	Weak		No	No	Weak	No	No	No	No	No	No	No	No	No	No	No	No	No	No
El4	Training for awareness	Weak	Strong	Weak		Strong	Strong	No	No	Weak	No	No	No	No	No	No	No	Weak	No	No	No
El5	Only crew connections	Strong	Strong	No	Weak		Strong	No	No	No	No	No	No	No	No	No	No	No	No	No	No
El6	Cable reeling drums	Strong	Strong	No	Weak	Weak		No	No	No	No	No	No	No	No	No	No	No	No	No	No
Det1	Combined heat & smoke	No	No	No	No	No	No		No	No	Strong	Strong	Weak	Weak	Strong	Weak	Weak	Weak	Weak	Weak	Weak
Det2	Ban / closure of side (PS & SB) openings (open ro-ro spaces)	No	No	No	No	No	No	Strong		No	Strong	No	No	Weak		Weak	Weak	Weak	Weak	Strong	Strong
Det3	Increased frequency of fire patrols	No	No	No	No	No	No	No	No		No	Weak	Weak	No	No	No	No	Strong	Weak	No	No
Dec1	Alarm system design & integration (smoke)	No	No	No	No	No	No	Strong	No	No		Strong	No	Weak	No	Weak	Weak	No	Weak	No	Weak
Dec2	Improved markings for wayfinding and localisation	No	No	No	No	No	No	Weak	No	Weak	Weak		Weak	Weak	Weak	No	No	Strong	Weak	No	Weak
Dec3	Preconditions for Early Activation of Drencher System	No	No	No	No	No	No	Weak	Weak	Weak	Weak	Strong		Weak	Weak	Weak	Weak	Weak	Weak	Weak	Strong
Su1	Remote control	No	No	No	No	No	No	No	No	No	Weak	Weak	Weak		No	Weak	No	Weak		No	No
Su3	Rolling shutters (PS & SB side) (Open ro-ro spaces)	No	No	No	No	No	No	No		No	No	No	Weak	Weak		Weak	Weak	Weak	Weak	Strong	
Su4	Efficient activation routines	No	No	No	No	No	No	No	No	No	No	No	Weak	Strong	Weak		No	Weak	Weak	No	No
Su5	Fresh water activation/flushing	No	No	No	No	No	No	No	No	No	Weak	No	Weak	No	No	No		Weak	No	No	Weak
Su6	CCTV	No	No	No	No	No	No	No	No	Weak	No	Strong	No	Weak	Weak	Weak	Weak			No	No
Su7	CCTV + Remote control	No	No	No	No	No	No	No	No	No	No	Strong	Weak		Weak	Strong	No			No	No
Cont1	Ban/closure of side & end openings (closed and open ro-ro spaces)	No	No	No	No	No	No	Strong	Strong	No	Strong	No	No	Weak	Strong	Weak	Weak	Weak	Weak		Strong
Cont2	Fire monitors on weather deck	No	No	No	No	No	No	No	Strong	No	No	No	Strong	No		No	No	No	No	Strong	

A4 SUMMARY OF THE COSTS

Table 18: Investment, Annual and Lifetime Costs of the Electrical RCOs

Electrical		Newbuildings			Existing ships		
RCO #	**Description**	**Cargo RoPax**	**Standard RoPax**	**Ferry RoPax**	**Cargo RoPax**	**Standard RoPax**	**Ferry RoPax**
El1 Robust connection boxes	Investment	8 400 €	22 400 €	22 400 €	8 400 €	28 000 €	28 000 €
	Annual	500 €	500 €	500 €	500 €	500 €	500 €
	Present Value	**19 116 €**	**33 116 €**	**33 116 €**	**15 506 €**	**35 106 €**	**35 106 €**
El2 Only ship cables	Investment	6 000 €	16 000 €	16 000 €	6 000 €	16 000 €	16 000 €
	Annual	3 200 €	3 200 €	3 200 €	3 200 €	3 200 €	3 200 €
	Present Value	**74 579 €**	**84 579 €**	**84 579 €**	**51 480 €**	**61 480 €**	**61 480 €**
El3 IR camera	Investment	2 000 €	2 000 €	2 000 €	2 000 €	2 000 €	2 000 €
	Annual	1 000 €	1 000 €	1 000 €	1 000 €	1 000 €	1 000 €
	Present Value	**23 431 €**	**23 431 €**	**23 431 €**	**16 212 €**	**16 212 €**	**16 212 €**
El4 Training for awareness	Investment	4 000 €	4 000 €	4 000 €	4 000 €	4 000 €	4 000 €
	Annual	- €	- €	- €	- €	- €	- €
	Present Value	**4 000 €**	**4 000 €**	**4 000 €**	**4 000 €**	**4 000 €**	**4 000 €**
El5 Only crew connections	Investment	2 000 €	2 000 €	2 000 €	2 000 €	2 000 €	2 000 €
	Annual	- €	- €	- €	- €	- €	- €
	Present Value	**2 000 €**	**2 000 €**	**2 000 €**	**2 000 €**	**2 000 €**	**2 000 €**
El6 Cable reeling drums	Investment	90 000 €	240 000 €	240 000 €	90 000 €	240 000 €	240 000 €
	Annual	6 000 €	16 000 €	16 000 €	6 000 €	16 000 €	16 000 €
	Present Value	**218 586 €**	**582 896 €**	**582 896 €**	**175 274 €**	**467 398 €**	**467 398 €**

Table 19: Investment, Annual and Lifetime Costs of the Detection RCOs

Detection			Newbuildings		Existing ships		
RCO #	**Description**	**Cargo RoPax**	**Standard RoPax**	**Ferry RoPax**	**Cargo RoPax**	**Standard RoPax**	**Ferry RoPax**
Det1 Combined heat & smoke detection	Investment	17 500 €	17 500 €	17 500 €	145 000 €	155 000 €	53 000 €
	Annual	- €	- €	- €	- €	- €	- €
	Present Value	**17 500 €**	**17 500 €**	**17 500 €**	**145 000 €**	**155 000 €**	**53 000 €**
Det2 Ban / closure of side (PS & SB) openings (open ro-ro spaces)	Investment	N/A	510 000 €	N/A	N/A	660 000 €	N/A
	Annual	N/A	120 000 €	N/A	N/A	120 000 €	N/A
	Present Value	**N/A**	**3 081 722 €**	**N/A**	**N/A**	**2 365 488 €**	**N/A**
Det3 Increased frequency of fire patrols	Investment	- €	- €	- €	- €	- €	- €
	Annual	60 000 €	34 000 €	60 000 €	60 000 €	34 000 €	60 000 €
	Present Value	**1 285 861 €**	**728 655 €**	**1 285 861 €**	**852 744 €**	**483 222 €**	**852 744 €**

Table 20: Investment, Annual and Lifetime Costs of the Decision RCOs

Decision			Newbuildings		Existing ships		
RCO #	**Description**	**Cargo RoPax**	**Standard RoPax**	**Ferry RoPax**	**Cargo RoPax**	**Standard RoPax**	**Ferry RoPax**
Dec1 Alarm System Design & Integration	Investment	20 000 €	20 000 €	20 000 €	145 000 €	155 000 €	53 000 €
	Annual	- €	- €	- €	- €	- €	- €
	Present Value	**20 000 €**	**20 000 €**	**20 000 €**	**145 000 €**	**155 000 €**	**53 000 €**
Dec2 Improved markings for wayfinding and localisation	Investment	2 850 €	3 300 €	3 300 €	2 850 €	3 300 €	3 300 €
	Annual	- €	- €	- €	- €	- €	- €
	Present Value	**2 850 €**	**3 300 €**	**3 300 €**	**2 850 €**	**3 300 €**	**3 300 €**
Dec3 Preconditions for Early Activation of Drencher System	Investment	- €	- €	- €	- €	- €	- €
	Annual	10 000 €	10 000 €	10 000 €	10 000 €	10 000 €	10 000 €
	Present Value	**214 310 €**	**214 310 €**	**214 310 €**	**142 124 €**	**142 124 €**	**142 124 €**

Table 21: Investment, Annual and Lifetime Costs of the Suppression RCOs

Suppression		Newbuildings			Existing ships		
RCO #	**Description**	**Cargo RoPax**	**Standard RoPax**	**Ferry RoPax**	**Cargo RoPax**	**Standard RoPax**	**Ferry RoPax**
Su1 Remote control	Investment	80 000 €	80 000 €	80 000 €	100 000 €	100 000 €	100 000 €
	Annual	1 000 €	1 000 €	1 000 €	1 000 €	1 000 €	1 000 €
	Present Value	**101 431 €**	**101 431 €**	**101 431 €**	**114 212 €**	**114 212 €**	**114 212 €**
Su3 Rolling shutters	Investment	N/A	840 000 €	N/A	N/A	1 260 000 €	N/A
	Annual	N/A	14 000 €	N/A	N/A	14 000 €	N/A
	Present Value	**N/A**	**1 140 034 €**	**N/A**	**N/A**	**1 458 974 €**	**N/A**
Su4 Efficient activation routines	Investment	200 €	200 €	200 €	200 €	200 €	200 €
	Annual	- €	- €	- €	- €	- €	- €
	Present Value	**200 €**	**200 €**	**200 €**	**200 €**	**200 €**	**200 €**
Su5 Fresh water activation/flushing	Investment	7 000 €	7 000 €	7 000 €	14 000 €	14 000 €	14 000 €
	Annual	- €	- €	- €	- €	- €	- €
	Present Value	**7 000 €**	**7 000 €**	**7 000 €**	**14 000 €**	**14 000 €**	**14 000 €**
Su6 CCTV	Investment	40 000 €	40 000 €	40 000 €	50 000 €	50 000 €	50 000 €
	Annual	1 000 €	1 000 €	1 000 €	1 000 €	1 000 €	1 000 €
	Present Value	**61 431 €**	**61 431 €**	**61 431 €**	**64 212 €**	**64 212 €**	**64 212 €**
Su7 CCTV + Remote control	Investment	120 000 €	120 000 €	120 000 €	150 000 €	150 000 €	150 000 €
	Annual	2 000 €	2 000 €	2 000 €	2 000 €	2 000 €	2 000 €
	Present Value	**162 862 €**	**162 862 €**	**162 862 €**	**178 425 €**	**178 425 €**	**178 425 €**

Containment		Newbuildings			Existing ships		
RCO #	Description	Cargo RoPax	Standard RoPax	Ferry RoPax	Cargo RoPax	Standard RoPax	Ferry RoPax
Cont1 Ban/closure of side & end openings (closed and open ro-ro spaces)	Investment	480 000 €	1 002 000 €	804 000 €	515 000 €	1 187 000 €	905 000 €
	Annual	10 000 €	120 000 €	25 000 €	10 000 €	120 000 €	1 780 000 €
	Present Value	**694 310 €**	**3 573 722 €**	**1 339 775 €**	**657 124 €**	**2 892 488 €**	**26 203 078 €**
Cont2 Fire monitors on weather deck	Investment	99 330 €	112 035 €	77 385 €	129 000 €	145 500 €	100 500 €
	Annual	- €	- €	- €	- €	- €	- €
	Present Value	**99 330 €**	**112 035 €**	**77 385 €**	**129 000 €**	**145 500 €**	**100 500 €**

Evacuation		Newbuildings			Existing ships		
RCO #	Description	Cargo RoPax	Standard RoPax	Ferry RoPax	Cargo RoPax	Standard RoPax	Ferry RoPax
Evac1a Safe distance / Closing all significant openings	Investment	N/A	1 002 000 €	804 000 €	N/A	1 187 000 €	905 000 €
	Annual	N/A	120 000 €	25 000 €	N/A	120 000 €	1 780 000 €
	Present Value	**N/A**	**3 573 722 €**	**1 339 775 €**	**N/A**	**2 892 488 €**	**26 203 078 €**
Evac1b Safe distance / Closing all side openings	Investment	N/A	500 000 €	N/A	N/A	660 000 €	N/A
	Annual	N/A	120 000 €	N/A	N/A	120 000 €	N/A
	Present Value	**N/A**	**3 071 722 €**	**N/A**	**N/A**	**2 365 488 €**	**N/A**
Evac1c Safe distance / Closing openings near LSAs	Investment	N/A	- €	N/A	N/A	30 000 €	N/A
	Annual	N/A	- €	N/A	N/A	- €	N/A
	Present Value	**N/A**	**- €**	**N/A**	**N/A**	**30 000 €**	**N/A**