



Horizon 2020

Project acronym: **LASH FIRE**

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

Grant Agreement No: **814975**

Coordinator: **RISE Research Institutes of Sweden**



Deliverable D04.6

Cost-effectiveness assessment report

February 2023

Dissemination level: **Public**

Abstract

The Formal Safety Assessment carried out in LASH FIRE requires the cost-effectiveness assessment of a selection of technical and operational solutions developed by the partners of the project. The objective is to compare the effectiveness to reduce the fire risk of ro-ro spaces and the costs associated with the implementation of selected Risk Control Options (RCOs).

For this purpose, the marginal costs for each Risk Control Option were estimated in terms of life cycle costs at present value. The performances of each Risk Control Option were assessed by the Development & Demonstration Work Packages and then used to feed the risk model in order to estimate the risk reduction in terms of fatalities, cargo losses and ship losses. Finally, the cost-effectiveness indices were computed and analyzed.

As a results, 16 Risk Control Options were selected, defined and assessed:

1. **Ro-ro passenger ships - Newbuildings:** 13 RCOs were found cost-effective in terms of life safety, saving the cargo and ship;
2. **Ro-ro passenger ships - Existing ships:** 8 RCOs were found cost-effective in terms of life safety, saving the cargo and ship and 3 RCOs in saving the cargo and ship;
3. **Ro-ro cargo ships - Newbuildings:** No RCO was found cost-effective in terms of life safety but 4 RCOs were found cost-effective in saving the cargo and ship;
4. **Ro-ro cargo ships - Existing ships:** No RCO was found cost-effective in terms of life safety but 2 RCOs were found cost-effective in saving the cargo and ship;
5. **Vehicle carriers - Newbuildings:** No RCO was found cost-effective in terms of life safety but 4 RCOs were found cost-effective in saving the cargo and ship; and
6. **Vehicle carriers - Existing ships:** No RCO was found cost-effective in terms of life safety but 1 RCO was found cost-effective in saving the cargo and ship.

These results are interim and will be ascertained by the sensitivity and uncertainty analyses that will be conducted as a next step in the project and presented in deliverable D04.7.



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

The information contained in this deliverable reflects only the view(s) of the author(s). The Agency (CINEA) is not responsible for any use that may be made of the information it contains.

The information contained in this report is subject to change without notice and should not be construed as a commitment by any members of the LASH FIRE consortium. In the event of any software or algorithms being described in this report, the LASH FIRE consortium assumes no responsibility for the use or inability to use any of its software or algorithms. The information is provided without any warranty of any kind and the LASH FIRE consortium expressly disclaims all implied warranties, including but not limited to the implied warranties of merchantability and fitness for a particular use.

© COPYRIGHT 2019 The LASH FIRE Consortium

This document may not be copied, reproduced, or modified in whole or in part for any purpose without written permission from the LASH FIRE consortium. In addition, to such written permission to copy, acknowledgement of the authors of the document and all applicable portions of the copyright notice must be clearly referenced. All rights reserved.

Document data

Document Title:	D04.6 – Cost-effectiveness assessment report		
Work Package:	WP04 – Formal safety assessment		
Related Task(s):	T04.6, T04.7		
Dissemination level:	Public		
Deliverable type:	R, Report		
Lead beneficiary:	8 – BUREAU VERITAS		
Responsible author:	Eric De Carvalho		
Co-authors:	Léon Lewandowski		
Date of delivery:	2023-02-28		
References:	IR04.23, D03.5, D04.4, D04.5, D04.7, D04.9, D05.7, D05.8		
Approved by	Jon Steinlein on 2023-01-26	Stina Andersson on 2023-01-25	Maria Hjohlman on 2023-02-07

Involved partners

No.	Short name	Full name of Partner	Name and contact info of persons involved
1	RISE	Research Institutes of Sweden	Stina Andersson – stina.andersson@ri.se Roshni Pramanik – roshni.pramanik@ri.se Staffan Bram – staffan.bram@ri.se Vasudev Ramachandra – vasudev.ramachandra@ri.se Magnus Arvidson – magnus.arvidson@ri.se Anna Olofsson – anna.olofsson@ri.se
3	FRN	Rise Fire Research AS	Davood Zeinali – davood.zeinali@risefr.no
4	FLOW	FLOW Ship Design DOO za Projektiranje, Konzalting I Inzenjering u Brodogradnji	Vito Radolovic – vito.radolovic@flowship.eu
8	BV	Bureau Veritas Marine & Offshore Registre International De Classification De Navires Et De Plateformes Offshore	Eric De Carvalho – eric.de-carvalho@bureauveritas.com Léon Lewandowski – leon.lewandowski@bureauveritas.com
15	SAS	Sociedad de Salvamento y Seguridad Maritima	Jaime Bleye Vicario – jaimebv@centrojoventianos.es
19	NSR	NTNU Samfunnsforskning AS	Lucia Liste Munoz – lucia.liste@samforsk.no Torgeir K. Haavik – torgeir.haavik@samforsk.no

Document history

Version	Date	Prepared by	Description
01	2022-01-04	Léon Lewandowski	Draft of structure, circulated to reviewers
02	2023-01-06	Eric De Carvalho	Draft of final report, circulated to reviewers
03	2023-02-24	Eric De Carvalho	Final report
04	2023-02-28	Eric De Carvalho	Final report

Content

1	Executive summary	5
2	List of symbols and abbreviations	7
3	Introduction.....	9
4	Identification of Risk Control Measures	10
5	Selection of relevant Risk Control Measures	14
5.1	Preliminary risk reduction	14
5.2	Preliminary ship integration feasibility	16
5.3	Preliminary cost.....	16
5.4	Preliminary regulatory compatibility.....	17
5.5	Level of support from maritime stakeholders.....	17
5.6	Other considerations from D&D WPs	18
6	Risk Control Options.....	19
6.1	RCOs selection and definition workshop	19
6.2	Selected RCOs.....	20
6.3	Technical description of selected RCOs.....	21
6.4	Quantification of RCOs effectiveness	43
6.5	Impact of RCOs on the safety levels	75
7	Cost-Effectiveness Assessment	80
7.1	Cost-effectiveness assessment background.....	80
7.2	Estimation of the costs	83
7.3	GCAF and NCAF	84
7.4	Comparison with previous study.....	88
8	Conclusion	90
9	References.....	93
10	Indexes	95
10.1	Index of tables	95
10.2	Index of figures.....	96
11	ANNEXES.....	97
11.1	ANNEX A: Detailed list of the 16 selected RCOs.....	97
11.2	ANNEX B: Breakdown of marginal cost of each RCO	98
11.3	ANNEX C: Estimation of risk reduction by the implementation of RCOs	102

1 Executive summary

1.1 Problem definition

The LASH FIRE project aims to develop solutions to enhance fire safety in ro-ro spaces by the development of innovative technologies as well as by the modification of operations and applications. An evaluation of each solution developed in the project will be carried out, in line with the IMO Formal Safety Assessment (FSA) procedures [1]. This implies the cost-effectiveness assessment of a selection of solutions.

The cost-effectiveness assessment constitutes the step 4 of a FSA. It compares the effectiveness to reduce the risk and the costs associated with the implementation of selected Risk Control Options. The effectiveness should reply to the question “how much better would it be?” and the cost should reply to the question “how much will it cost?”. It is an important step that will drive the development of recommendations for decision-making (step 5 of FSA).

1.2 Method

The Risk Control Options of LASH FIRE were selected among the different solutions developed, validated and demonstrated by the Development and Demonstration Work Packages (D&D WPs or WP06-11).

On one side, the performances of each Risk Control Option were assessed by the D&D WPs and then used to feed the risk model developed by the Work Package 4 (WP04) (refer to deliverable D04.4 “Holistic risk model” [2] and deliverable D04.5 “Development of holistic risk model report” [3]). Consequently, the risk reduction in terms of fatalities, cargo losses and ship losses was estimated for each Risk Control Option.

On the other side, the marginal costs for each Risk Control Option were estimated in terms of life cycle costs at present value by the Work Package 5 (WP05) (refer to deliverable D05.8 “Ship integration cost and environmental assessment” [4]). The marginal costs include investment, operating, maintenance, training, inspection, etc.

Finally, the cost-effectiveness indices Gross and Net Cost of Averting a Fatality (GCAF and NCAF) were computed and analyzed. The sensitivity and uncertainty analyses will be provided in the deliverable D04.7 “Cost-effectiveness assessment report: Uncertainty and sensitivity analysis report” [5].

1.3 Results and achievements

16 Risk Control Options were selected and defined. Their marginal costs at present value were estimated and reported in Table 13 and Table 14. Their risk reduction in terms of fatalities, cargo losses and ship losses was estimated and reported in Figure 16 to Figure 21.

Table 15 to Table 20 provides the resulting cost-effectiveness indices GCAF and GCAF indices for each RCO, including their ranking. Table 23 and Table 24 summarize the cost-effective RCOs. These results are interim and will be ascertained by the sensitivity and uncertainty analyses that will be conducted as a next step in the project. This will be reported in deliverable D04.7 [5].

1.4 Contribution to LASH FIRE objectives

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

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

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

Cost-effectiveness assessment of at least 15 regulatory proposals, based on developed operational and technical solutions, in line with FSA procedure.

1.5 Exploitation

The results of the cost-effectiveness assessment will be used to identify the best candidates for recommendations for decision-making (action 4-C).

This deliverable can be used by external parties at different levels:

- The deliverable provides an overview of the different Risk Control Options to be implemented in order to enhance fire safety in ro-ro spaces, their main benefits in terms of fire safety and their side effects; and
- The deliverable provides an objective comparison of the different Risk Control Options based on their potential reduction of risks and cost-effectiveness.

2 List of symbols and abbreviations

AB	Able seaman
APV	Alternatively Powered Vehicle
CAF	Compressed Air Foam
CCTV	Closed-Circuit Television
CNG	Compressed Natural Gas
CO ₂	Carbon dioxide
CRS	Close Ro-ro Space
D&D	Development and Demonstration
DFC	Digital Fire Central
DG	Dangerous Good
DTS	Distributed Temperature Sensing
EMSA	European Maritime Safety Agency
EU	European Union
EV	Electric Vehicle
FP	Fire Protection
FSA	Formal Safety Assessment
FSS	International code for Fire Safety Systems (IMO)
FTP	International code for application of Fire Test Procedures (IMO)
GA	General Arrangement
GCAF	Gross Cost of Averting a Fatality
GDP	Gross Domestic Product
HF	Hydrogen fluoride
HSE	Health, Safety and Environment
IMDG	International Maritime Dangerous Goods (IMDG) code (IMO)
IMO	International Maritime Organization
IR	InfraRed
LNG	Liquefied Natural Gas
LSA	Life-Saving Appliance
MAAG	Maritime Authorities Advisory group
MOAG	Maritime Operators Advisory Group
MOC	Manually Operated Call Point
MSC	IMO Maritime Safety Committee
NCAF	Net Cost of Averting a Fatality
NFPA	National Fire Protection Association (US)
NFIRS	National Fire Incident Reporting System (US)
OECD	Organization for Economic Co-operation and Development
OOW	Officer Of the Watch
ORS	Open Ro-ro Space
OS	Ordinary Seaman
PLC	Programmable Logic Controller
PLC	Potential Loss of Cargo
PLL	Potential Loss of Life
PLS	Potential Loss of Ship
PPE	Personal Protective Equipment
RCM	Risk Control Measure

RCO	Risk Control Option
Ro-Pax	Ro-ro passenger ships
Ro-Ro Cargo	Ro-ro cargo ships
SMS	Safety Management System
SOLAS	International convention for the Safety Of Life At Sea (IMO)
SSE	IMO sub-committee on Ship Systems and Equipment
STCW	International convention on Standards of Training, Certification and Watchkeeping for seafarers (IMO)
TBC	To Be Confirmed
TRL	Technology Readiness Level
UHF	Ultra High Frequency
UI	User Interface
VC	Vehicle Carriers
VHF	Very High Frequency
WD	Weather Deck
WP	Work Package
WP03	Work package on cooperation and communication
WP04	Work package on Formal Safety Assessment
WP05	Work package on ship integration

3 Introduction

Main author of the chapter: Eric De Carvalho, BV

Started in 2019, the LASH FIRE project funded by the European Union's Horizon 2020 research and innovation programme aims at providing a technical basis for future revisions of regulations by assessing risk reduction and economic properties of design and operational solutions for all types of ro-ro ships and all types of ro-ro spaces. This objective is founded on the cost-effectiveness assessment of a selection of solutions developed by the partners of the LASH FIRE project.

The cost-effectiveness assessment constitutes the step 4 of a Formal Safety Assessment (FSA), as described in the IMO FSA guidelines [1]. It compares the effectiveness to reduce the risk and the costs associated with the implementation of selected Risk Control Options (RCOs). The effectiveness should reply to the question "how much better would it be?" and the cost should reply to the question "how much will it cost?". It is an important step that will drive the development of recommendations for decision-making (step 5 of FSA).

The RCOs of LASH FIRE were selected among the different solutions developed, validated and demonstrated by the Development and Demonstration Work Packages (D&D WPs or WP06-11). On one side, the risk model developed by Work Package 4 (WP04) (refer to deliverable D04.4 "Holistic risk model" [2] and deliverable D04.5 "Development of holistic risk model report" [3]) was used to estimate the risk reduction in terms of fatalities, cargo losses and ship losses for each RCO. On the other side, the marginal costs for each RCO were estimated in terms of life cycle costs at present value by the Work Package 5 (WP05) (refer to deliverable D05.8 "Ship integration cost and environmental assessment" [4]). The marginal costs include investment, operating, maintenance, training, inspection, etc.

This document summarizes the cost-effectiveness assessment. Chapter 4 recapitulates the Risk Control Measures (RCMs) initially proposed by the D&D WPs, as the starting point of the cost-effectiveness assessment. Chapter 5 details the methodology developed and used to select the RCOs among the RCMs. Chapter 6 describes the selected RCOs, details their effectiveness and impact on the risk model. Chapter 7 provides the results of the cost-effectiveness assessment.

Sensitivity and uncertainty analyses of the results will be provided in the deliverable D04.7 "Cost-effectiveness assessment report: Uncertainty and sensitivity analysis report" [5].

4 Identification of Risk Control Measures

Main author of the chapter: Léon Lewandowski, BV

Table 1 (taken from the deliverable D04.9 “Preliminary impact of solutions and related testing and demonstrations plan” [6]) summarizes the 44 RCMs initially proposed by the D&D WPs, before the selection and definition of the RCOs that took place during the workshop on the 7-8th of June 2022. More details about those RCMs can be found in D04.9. This list of RCMs was the starting point of the preparatory work for the cost-effectiveness assessment.

Table 1. Summary of the 44 RCMs proposed by the D&D WPs.

WP	Action	ID	Title of solution	Ship types ⁽¹⁾	Ro-ro spaces types ⁽²⁾	NB, Ex ⁽³⁾	TRL	Attribute(s) Category A ⁽⁴⁾	Attribute(s) Category B ⁽⁴⁾
06	6-A	Op1	Improved fire patrol procedures and minimum assisting equipment for a more effective screening of fire hazards	Ro-Pax, Ro-Ro	CRS, ORS, WD	NB + Ex	6, 7	Preventive, Mitigating	Engineering, Procedural
		Op2	Manual screening of cargo at port before the loading operations	Ro-Pax, Ro-Ro	CRS, ORS, WD	NB + Ex	6, 7	Preventive	Engineering, Procedural
	6-B	Op3	Improvement of current signage and markings standards/conditions to support effective wayfinding and localization	Ro-Pax, Ro-Ro, VC	CRS, ORS, WD	NB + Ex	6, 7	Mitigating	Inherent
		Op4	Guidelines for the standardization and formalization of manual fire confirmation and localization	Ro-Pax, Ro-Ro, VC	CRS, ORS, WD	NB + Ex	6, 7	Mitigating	Engineering, Procedural
	6-C	Op5	First response guidelines and new equipment to put out the fire in the initial stage	Ro-Pax, Ro-Ro, VC	CRS, ORS, WD	NB + Ex	5, 6	Mitigating	Engineering, Procedural
		Op6	Technology for localization of first responders through digital information processed via network	Ro-Pax, Ro-Ro, VC	CRS, ORS, WD	NB + Ex	4, 5, 6, 7	Mitigating	Engineering
	6-D	Op7	Training, new equipment and procedures to suppress fires in Alternatively Powered Vehicles with special focus on Li-ion batteries fires	Ro-Pax, Ro-Ro, VC	CRS, ORS, WD	NB + Ex	5, 6	Mitigating	Engineering, Procedural

WP	Action	ID	Title of solution	Ship types ⁽¹⁾	Ro-ro spaces types ⁽²⁾	NB, Ex ⁽³⁾	TRL	Attribute(s) Category A ⁽⁴⁾	Attribute(s) Category B ⁽⁴⁾
07	7-A	Des1	User friendly alarm system interface design guidelines	Ro-Pax, Ro-Ro, VC	CRS, ORS, WD	NB + Ex		Mitigating	Engineering, Inherent
		Des2	Alarm system interface prototype	Ro-Pax, Ro-Ro, VC	CRS, ORS, WD	NB + Ex	5	Mitigating	Engineering, Inherent
	7-B	Des3	Procedures and design for efficient extinguishment system activation	Ro-Pax, Ro-Ro, VC	CRS, ORS, (WD)	NB + Ex	6	Mitigating	Procedural
		Des4	Training module for activation of extinguishment systems	Ro-Pax, Ro-Ro, VC	CRS, ORS	NB + Ex	5	Mitigating	Procedural
	7-C	Des5	Integrated solutions for fire resource management, combining relevant sources of information, including drone and camera monitoring system	Ro-Pax, Ro-Ro, VC	CRS, ORS, WD	NB + Ex	6	Mitigating	Engineering, Inherent
		Des6	Guidelines for organizing the response in case of a fire emergency	Ro-Pax, Ro-Ro, VC	CRS, ORS, WD	NB + Ex	6	Mitigating	Procedural
08	8-A	Pre1a	Cargo scanning and identification and tracking system by the means of a called Vehicle Hot Spot Detector system	Ro-Pax, Ro-Ro, VC	CRS, ORS, WD	NB + Ex	5	Preventive	Engineering
		Pre1b	Automatic screening and management of cargo fire hazards by means of Automated Guided Vehicles	Ro-Pax, Ro-Ro, VC	CRS, ORS, WD	NB + Ex	5	Preventive, Mitigating	Engineering
		Pre2	Stowage planning tool with optimization algorithm for cargo distribution	Ro-Pax, Ro-Ro, VC	CRS, ORS, WD	NB + Ex	5	Preventive, Mitigating	Engineering, Inherent
	8-B	Pre3	Develop guidelines for safe electrical power connections in ro-ro spaces for reefer units	Ro-Pax, Ro-Ro	CRS, ORS, WD	NB + Ex	6, 7	Preventive	Engineering
		Pre4	Develop guidelines for safe electrical power connections in ro-ro spaces for charging of electric vehicles	Ro-Pax	CRS, ORS, WD	NB + Ex	6, 7	Preventive	Engineering
	8-C	Pre5	Proposal for requirements of surface materials in ro-ro spaces, with reference to suitable test method and material property performance criteria	Ro-Pax, Ro-Ro, VC	CRS, ORS, WD	NB + Ex	6, 7	Mitigating	Engineering, Inherent

WP	Action	ID	Title of solution	Ship types ⁽¹⁾	Ro-ro spaces types ⁽²⁾	NB, Ex ⁽³⁾	TRL	Attribute(s) Category A ⁽⁴⁾	Attribute(s) Category B ⁽⁴⁾
09	9-A	Det1	Flame wavelength detectors	Ro-Pax, Ro-Ro, (VC)	WD, (CRS), (ORS)	NB + Ex	7	Mitigating	Engineering
		Det8	Thermal imaging (infrared) cameras	Ro-Pax, Ro-Ro, (VC)	WD, (CRS), (ORS)	NB + Ex	7	Mitigating	Engineering
		Det2	Deck mounted linear heat detection by fibre optic cables	Ro-Pax, Ro-Ro, VC	CRS, ORS, WD	NB + Ex	6	Mitigating	Engineering
	9-B	Det3	Video detection	Ro-Pax, Ro-Ro, VC	CRS	NB + Ex	7	Mitigating	Engineering
		Det4	Adaptive detection threshold settings	Ro-Pax, Ro-Ro, VC	CRS, ORS, WD	NB + Ex	6	Mitigating	Engineering
		Det7	Fibre optic linear heat detection	Ro-Pax, Ro-Ro, VC	CRS, ORS	NB + Ex	7	Mitigating	Engineering
	9-C	Det5	Video detection	Ro-Pax, Ro-Ro, VC	CRS	NB + Ex	7	Mitigating	Engineering
		Det6	Thermal imaging (infrared) cameras	Ro-Pax, Ro-Ro, VC	CRS, ORS, WD	NB + Ex	7	Mitigating	Engineering
10	10-A	Ext1a	Dry pipe sprinkler system for ro-ro spaces on vehicle carriers	VC	CRS	NB + Ex	5	Mitigating	Engineering
		Ext1b	Automatic deluge water spray for ro-ro spaces system on vehicle carriers	VC	CRS	NB + Ex	5	Mitigating	Engineering
	10-B	Ext3	Autonomous fire monitor (water only) system for the protection of weather decks	Ro-Pax, Ro-Ro	WD	NB + Ex	6	Mitigating	Engineering
		Ext4	Remotely-controlled Compressed Air Foam fire monitor system for the protection of weather deck	Ro-Pax, Ro-Ro	WD	NB + Ex	6	Mitigating	Engineering
	10-C	Ext5	Development of a relevant fire test standard for alternative fixed water-based fire-fighting systems intended for ro-ro spaces and special category spaces	Ro-Pax, Ro-Ro	CRS, ORS	NB	6	Mitigating	Engineering
11	11-A	Cont1b1	A-30 fire integrity	Ro-Pax, Ro-Ro, VC	CRS, ORS	NB	9	Mitigating	Engineering, Inherent
		Cont1b2	Extinguishing system simultaneously activated above and below sub-dividing deck	Ro-Pax, Ro-Ro, VC	CRS, ORS	NB	9	Mitigating	Engineering
		Cont3a	Solid curtain, horizontal mounting, fully rolled down	Ro-Pax, Ro-Ro	CRS, ORS	NB	5	Mitigating	Engineering

WP	Action	ID	Title of solution	Ship types ⁽¹⁾	Ro-ro spaces types ⁽²⁾	NB, Ex ⁽³⁾	TRL	Attribute(s) Category A ⁽⁴⁾	Attribute(s) Category B ⁽⁴⁾
		Cont3b	Solid curtain, vertical mounting, fully rolled down	Ro-Pax, Ro-Ro	CRS, ORS	NB	5	Mitigating	Engineering
		Cont3c	Solid curtain, vertical mounting, partly rolled down	Ro-Pax, Ro-Ro	CRS, ORS	NB	5	Mitigating	Engineering
		Cont3d	Solid stripped curtain, vertical mounting, fully/partly rolled down	Ro-Pax, Ro-Ro	CRS, ORS	NB	5	Mitigating	Engineering
	11-B	Cont5	Alternative disembarkation path through “dedicated side door”	Ro-Pax, Ro-Ro, VC?	CRS, ORS, WD	NB	5	Mitigating	Engineering
	11-C	Cont9	Ship manoeuvring/operation to limit the effect of fire at least in critical areas	Ro-Pax, Ro-Ro, VC	CRS, ORS, WD	NB + Ex	5	Mitigating	Procedural
		Cont10	Safety distances between side and end openings and critical areas	Ro-Pax, Ro-Ro	ORS	NB + Ex	5	Mitigating	Inherent
	11-D	Cont11	Guidance on calculation of side openings in ro-ro spaces	Ro-Pax, Ro-Ro	CRS, ORS	NB	5	Mitigating	Inherent
		Cont12	Configuration of side openings in ro-ro spaces	Ro-Pax, Ro-Ro	CRS, ORS	NB	5	Mitigating	Inherent
		Cont13	Tactical guidelines for manual interventions	Ro-Pax, Ro-Ro	CRS	NB + Ex	5	Mitigating	Procedural?
		Cont14	SOLAS requirement of reversible fans	Ro-Pax, Ro-Ro	CRS	NB	5	Mitigating	Engineering, Procedural
⁽¹⁾ Ro-Pax = Ro-ro passenger ships, Ro-Ro = Ro-ro cargo ships, VC = Vehicle carriers.									
⁽²⁾ CRS = Closed ro-ro spaces, ORS = Open ro-ro spaces, WD = Weather decks.									
⁽³⁾ NB = Newbuildings, Ex = Existing ships.									
⁽⁴⁾ Attributes as defined in MSC-MEPC.2/Circ.12/Rev.2 [1].									

5 Selection of relevant Risk Control Measures

Main author of the chapter: Léon Lewandowski, BV

This section details the tools and methods used to select and define RCOs out of RCMs.

5.1 Preliminary risk reduction

Work Package in charge of this method: WP04

One of the tools to discriminate the different RCMs was to compare their respective risk reduction, based on the inputs collect in the part A of Internal Report IR04.23 “Template for risk reduction estimation”. For each RCM, D&D WPs leaders, with the help of WP04, selected the nodes of the risk model impacted by each of their RCMs.

Then, based on the median of risk reductions applied in the FIRESAFE II study, a risk reduction of 25% was applied to each of these nodes when they were decreasing the risk, whereas a risk augmentation of 35% was applied when the RCMs were increasing the risk. RCMs were then classed according to their relative risk reduction, for each type of ship. It has been decided not to create a generic and arbitrary criterion to split the RCMs into the different categories, but rather to take into account the different groups naturally emerging.

The results displayed in this work should not be considered as definitive computation of the risk reduction for all the RCMs, but rather as a preliminary analysis, able to give a global tendency of an RCM’s risk reduction, based on generic values. The quantitative and more precise risk reduction analysis used for upcoming decision-making shall be carried out during the next phase of the project.

Thus, even though for most of the RCMs, the risk reduction without cost cannot be used to disregard/push forward an RCM, this indicator can be used to rank the different RCMs and to decide between two RCMs.

All these results are summarized in Figure 1 to Figure 3. Table 2 summarizes the colours used for this categorization.

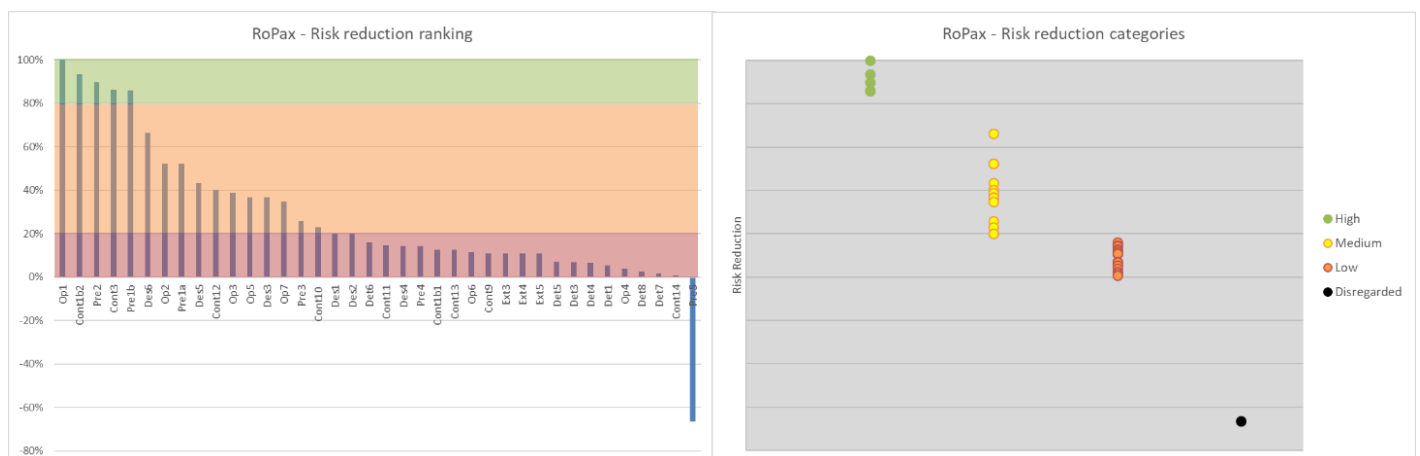


Figure 1. Ranking of all the RCMs by risk reduction for ro-ro passenger ships.

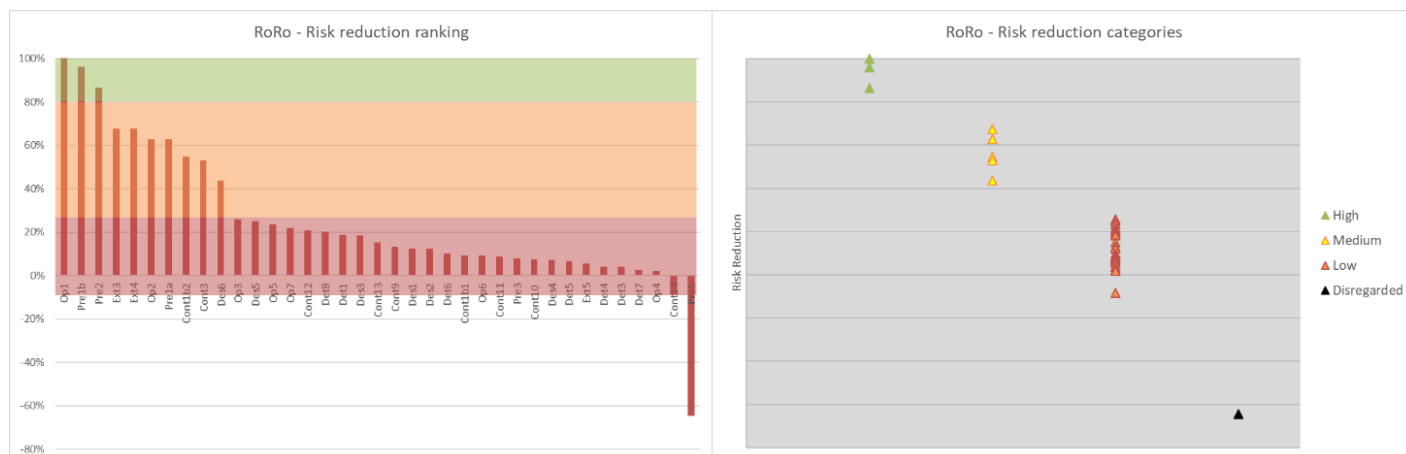


Figure 2. Ranking of all the RCMs by risk reduction for ro-ro cargo ships.

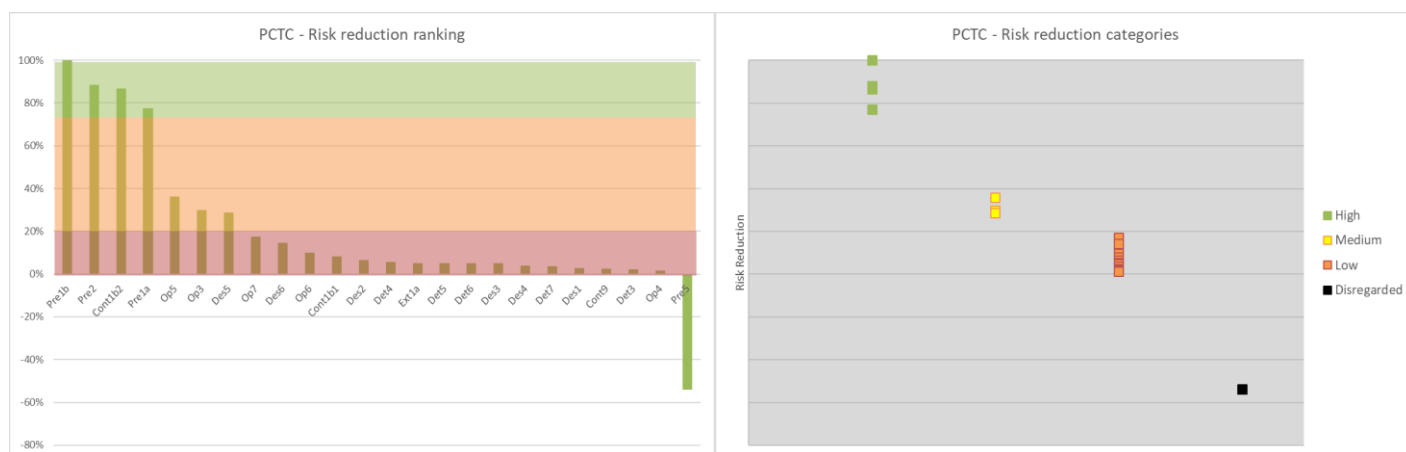


Figure 3. Ranking of all the RCMs by risk reduction for vehicle carriers.

Table 2. Colour code used to split RCMs in different categories, based on their risk reduction.

Colour code	Meaning
High	High risk reduction
Medium	Medium risk reduction
Low	Low risk reduction
Increase	Increase of the fire risk
N/A	Not applicable or not assessed






5.2 Preliminary ship integration feasibility

Work Package in charge of this method: WP05

The objective of this second tool is to indicate, for each of the RCMs, how easily it would be to integrate it, for instance, physically on board a ship for engineering solutions or in the onboard routines for procedural solutions, etc. This indicator will be of paramount importance in the selection of RCMs as potential RCOs and will also identify any showstopper (i.e. “Not integrable” in Table 3).

The different levels of integration feasibility are presented in Table 3.

Table 3. Colour code used to split RCMs in different categories, based on their integration feasibility.

Colour code		Meaning
	High	Easily integrable onboard
	Medium	Moderately integrable onboard
	Low	Hardly integrable onboard
	Not integrable	Not integrable onboard
	N/A	Not applicable or not assessed

More details and results from the ship integration assessment can be found in the deliverable D05.7 “Ship integration evaluation” [7].






5.3 Preliminary cost

Work Package in charge of this method: WP05

Although, for most of the RCMs, the cost without risk reduction cannot be used to disregard/push forward an RCM, it can be a useful indicator in the two extreme cases. RCMs with very high marginal costs have another argument against them to be disregarded, whereas RCMs with very low costs can be considered as “low-hanging fruits”, and thus be pushed forward without spending resources while computing their cost-effectiveness.

The different levels of cost assessment are presented in Table 4.

Table 4. Colour code used to split RCMs in different categories, based on their preliminary cost.

Colour code		Meaning
	Low	Low preliminary cost
	Medium	Medium preliminary cost
	High	High preliminary cost
	Not assessed	Cost of the RCM could not be assessed (at this stage of the project)
	N/A	Not applicable or not assessed

More details and results about the cost assessment can be found in the deliverable D05.8 “Ship integration cost and environmental assessment” [4].



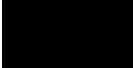


5.4 Preliminary regulatory compatibility

Work Package in charge of this method: WP03

In order to anticipate the fifth step of the FSA study (“Recommendation for decision-making”), all RCMs have been screened with regards to the existing IMO regulations. Indeed, it would be hard for an RCM requiring to change the philosophy of the regulation itself to be developed and adopted as new amendments. This indicator will also identify any showstopper (i.e. “Change of philosophy” in Table 5).

The different categories of regulatory compatibilities were defined as presented in Table 5.

Table 5. Colour code used to split RCMs in different categories, based on their regulatory compatibility.

Colour code		Meaning
	Easily integrable	Requirement already exists in the IMO regulations, LASH FIRE proposes more details or specifications. Requirement already in discussion at IMO. Few lines to be changed in the existing regulations
	Integrable (*)	New requirement, new system, new operation. New paragraphs or section in the existing regulations
	Change of philosophy	Change of philosophy of the existing regulations
	No opinion	Too specific to be regulated. Not verifiable. Not enough maturity/development to conclude
	N/A	Not applicable or not assessed
*The objective of the asterisk is to notify the D&D WPs that additional regulatory considerations may be raised during IMO assessment of the regulation modification proposal.		

More details and results about the preliminary regulatory compatibility can be found in the deliverable D03.5 “First proposal on updated rules and regulations on fire safety” [8].

5.5 Level of support from maritime stakeholders





Work Package in charge of this method: WP03

To anticipate uptake from decision-makers, representatives of maritime stakeholders were part of the selection process. The two LASH FIRE’s advisory groups (MAAG and MOAG) were invited to participate in the selection process to represent the maritime stakeholders.

The programme of MAAG/MOAG solution workshops was completed with Workshop #8 on 11 May 2022. The objective of this programme of MAAG/MOAG workshops was to give visibility and familiarity, as well as receive feedback, of the progress and development of the emerging solutions in the various D&D Work Packages. A final Workshop on 01 June 2022 was held in order engage the MAAG/MOAG members as part of the selection process and to collect their level of support for each RCM. This indicator will be of paramount importance in the selection of RCMs as potential RCOs.

The different categories of level of support granted to each RCM by the maritime stakeholders are summarized in Table 6.

Table 6. Colour code used to split RCMs in different categories, based on the inputs from maritime stakeholders.

Colour code		Meaning
	High	High level of support for the solution to be taken forward
	Medium	Medium level of support for the solution to be taken forward
	Low	Low level of support for the solution to be taken forward
	N/A	Not applicable or not assessed

More details about the results of the MAAG/MOAG workshops can be found in the deliverable D03.5 “First proposal on updated rules and regulations on fire safety” [8].

5.6 Other considerations from D&D WPs

Work Package in charge of this method: D&D WPs

Any other considerations, such as Technology Readiness Level (if the RCM is mature enough to be assessed and then integrated into the IMO regulations), accuracy/validity in the different assessments (including validation and demonstration), level of uncertainties of the data, schedule, etc., that can support the selection of RCMs were also taken into account.

6 Risk Control Options

Main author of the chapter: Eric De Carvalho, BV

This section details the selection and definition of RCOs for the cost-effectiveness assessment.

6.1 RCOs selection and definition workshop

The selection of the RCOs from the 44 RCMs took place during the RCOs Selection and Definition Workshop, prepared and facilitated by WP04. It took place early June 2022 and was attended by more than 30 people, including:

- All the WP leaders and D&D action leaders: representatives of the development of the RCMs;
- Ship operators (Stena, DFDS and Wallenius), SEA Europe and Interferry: representatives of the maritime stakeholders; and
- Risk engineers from WP04: facilitator and responsible for the FSA methodology.

The objectives of the RCOs workshop were to select at least fifteen RCOs, provide a general description and define the applicability of the RCOs in order to start the quantitative assessment of the RCOs.

The different steps of the RCOs workshop are presented in the Figure 4 and detailed in the next sections.

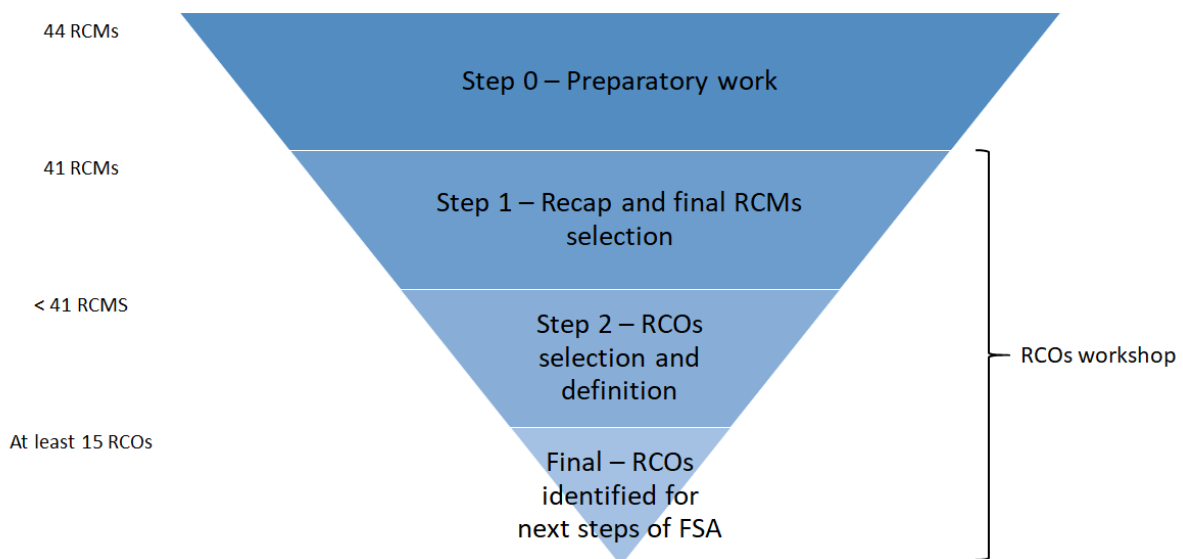


Figure 4. Steps of the methodology.

Step 0 is the preparatory work for the RCOs workshop described in section 5. At the end of step 0, 41 RCMs among the original 44 were selected by D&D WPs for the RCOs workshop.

6.1.1 Step 1 – Recap and RCMs selection for the next steps of workshop

The 41 RCMs preliminarily selected by the D&D WPs were screened one by one. Their preliminary assessments (ship integration, cost, regulatory compatibility, risk reduction and level of support from MAAG & MOAG), compiled into an excel file (see Figure 5), were discussed. Potential showstopper(s) for FSA and low-hanging fruits were identified.

At the end of step 1, 31 RCMs were identified as potential RCOs.

ID	Action	Status?	ID	Title of Risk Control Measure (RCM)	Ro-Pax				Ro-Ro			
					Preliminary ship integration feasibility	Preliminary cost	Preliminary regulatory compatibility	Preliminary risk reduction	Preliminary ship integration feasibility	Preliminary cost	Preliminary regulatory compatibility	Preliminary risk reduction
WP06	Effective Manual Operations											
(6-A)	Manual screening of cargo fire hazards and effective fire patrols	Active	Op1	Improved fire patrol procedures and minimum assisting equipment for a more effective screening of fire hazards	High	Low	Easily integrable	High	High	Low	Integrable	High
		Active	Op2	Manual screening of cargo at port before the loading operations	Medium	Medium	Integrable	Medium	Medium	Medium	Integrable	Medium
(6-B)	Quick manual fire confirmation and localization	Active	Op3	Improvement of current signage and markings standards/conditions to support effective wayfinding and	High	Low	Easily integrable	Medium	High	Low	Integrable	Low
		Active	Op4	Guidelines for the standardization and formalization of manual fire confirmation and localization	High	Low	Integrable	Low	High	Low	Integrable	Low

Figure 5. Detail from the excel file used to select the RCOs.

6.1.2 Step 2 – RCOs selection and definition

The 31 RCMs were ranked in terms of TRL, level of support from MAAG & MOAG, ship integration and preliminary cost-effectiveness. The RCMs with the best rankings were selected to progress as RCOs. The RCOs and their final applicability (i.e. ro-ro ship type, ro-ro space type and new vs. existing ships) were defined, and combinations of RCMs were performed, when needed. At the end of step 2, 16 RCOs were selected and defined for the quantitative cost-effectiveness assessment.

6.2 Selected RCOs

This RCOs workshop allowed to select 16 RCOs out of the 41 RCMs. All selected RCOs are listed in Table 7.

Table 7. List of the 16 selected RCOs.

ID	RCM(s) of origin	Title of Risk Control Option (RCO)
RCO1	Op1, Op4	Improved fire patrol. Improved fire confirmation & localization
RCO2	Op3	Improved signage and markings for effective wayfinding and localization
RCO3	Op5	Developed efficient first response
RCO4	Op7	Developed manual firefighting for Alternatively Powered Vehicles
RCO5	Des2	Alarm system interface prototype
RCO6	Des3	Process for development of procedures and design for efficient activation of extinguishing system
RCO7	Des4	Training module for efficient activation of extinguishing system
RCO8	Pre3	Safe electrical connection for reefers
RCO9	Pre4, Pre3	Safe electrical connection of reefers and electric vehicles (EVs)
RCO10	Det1, Det8	Fire detection on weather decks
RCO11	Det7	Alternative fire detection in closed ro-ro spaces & open ro-ro spaces
RCO12	Det5, Det6, Det8	Visual system for fire confirmation and localization
RCO13	Ext1a	Dry-pipe sprinkler system for vehicle carriers
RCO14	Ext3a	Fixed remotely-controlled fire monitor system using water for weather decks
RCO15	Ext3	Fixed autonomous fire monitor system using water for weather decks
RCO16	Cont13, Cont14	Guideline for fire ventilation in closed ro-ro space

A more detailed list of RCOs (including their fields of application in terms of ship type, ro-ro space type, etc.) is given in Table 25, in ANNEX A: Detailed list of the 16 selected RCOs.

6.3 Technical description of selected RCOs

This section details the technical aspects of each RCO, based on their descriptions given by the D&D WPs.

6.3.1 Technical description of RCO1: Improved fire patrol. Improved fire confirmation & localization

Main author of the chapter: Jaime Bleye, SAS

6.3.1.1 *Technical description*

RCO1 is establishing the role, task and conditions for the fire patrol member and the runner.

The fire patrol member is the crew member (normally AB or OS) that oversees following periodic safety routes through defined key locations on board with the aim of ensuring that there are no issues on board from the security/safety side. He or she will be in permanent communication with the OOW, so that any undesired events/incidents can be notified as soon as possible.

The runner is the crew member (normally AB or OS) sent to the point of fire detection with the task of confirming or disconfirming the existence of a fire.

In an average fire chain of events, fire patrol member and runner will be merged in the same person. Therefore, RCO1 is considering both conditions at the same task:

- Company and/or ship specific procedures shall include the route to be followed by the fire patrol member, frequency, key locations to be inspected and training for a crew member to become fire patrol member.
- The runner shall be an experienced fire patrol member familiarized with the whole layout of the ship and related activities.
- The runner shall wear equipment that allows to keep his/her both hands free and ready to act if firefighting first response is needed.
- Communication equipment with sufficient range covering the whole key point locations. Not less than the 85% of the cargo deck area shall have radio coverage with full cargo.
- Ships with English as working language shall standardize language and terminology used by adopting the use of IMO Standard Marine Communication Phrases (resolution A.918(22)).
- Manual fire confirmation and localization activities shall be trained in realistic fire drills. The performance of manual fire confirmation and localization related drills activities shall be assessed and discussed in drill debriefs. Potential challenges and concerns related to the task shall be discussed in HSE meetings.

Important: RCO1 only considers the fire patrol for ro-ro passenger ships and ro-ro cargo ships, not for vehicle carriers. RCO1 for vehicles carriers only consist of improved fire confirmation and localization.

6.3.1.2 *Impact on safety*

The response to a fire alarm must be as fast as possible, to ensure efficient first response and tackle the fire at the initial stage. The suggested improvements will arguably reduce the time used by the runner to manually confirm and localize fire onboard which help the firefighting team to direct their work as accurately as possible from the start and increase the chance to successfully fight a fire.

Quick manual confirmation and localization is a key factor to limit the effects of the fire development on people, on structure and related systems, cargo and sea environment.

6.3.1.3 *Side effects*

No particular side effects were identified in the implementation of RCO1.

6.3.2 Technical description of RCO2: Improved signage and markings for effective wayfinding and localization

Main author of the chapter: Lucia Liste, NSR

6.3.2.1 Technical description

In order to support a quicker manual fire confirmation and localization, the guidelines propose to improve the current signage and marking standards/conditions by adopting the following requirements for ships:

- Signage and marking of drencher zones and deck number should be consistent with information displayed in the ship's fire management system interface.
- All printed information sources on board must have consistent drencher zone and deck references, aligned with signage and alarm system.
- Ambiguous deck names should be avoided, as well as mixing reference to deck numbers with reference to names, such as "lower hold".
- Signs and marks shall be easily identifiable and interpretable.
- Drencher zones and decks should be marked in such a way that fire patrol always, in fully loaded deck condition, should be able to visually confirm location from any position along the patrol route, allowing for movement of maximum +/-3 m along path.
- CCTV system should allow for instant identification of which drencher zones are visible from each camera.

The following shall be considered:

- Size: Markings and signs shall have a minimum size of 500 x 500 mm for deck numbers and drencher zones. Frame numbers should correspond with the width of the frame.
- Colour: The use of red or a combination of red/white is recommended.
- Font: The use of Bold Sans Serif for signage is recommended since it is one of the most readable fonts for signage.
- Material:
 - The use of both painted and prefabricated signs and markings are permitted
 - Requirement: Section number signs shall be of photoluminescent material complying with ISO 15370:2021 Ships and marine technology - Low-location lighting (LLL) on passenger ships - Arrangement.
- Maintenance:
 - Signage and markings shall be resistant to wear and tear.
 - Signage and markings shall be included in maintenance schemes.
- Location: Placing shall be decided by performing an in-situ analysis based on typical patterns of crew movement and real use cases. The following shall be considered:
 - Sign and markings shall not be obstructed by cargo or fixed installations and shall be visible through video monitoring systems.
 - Signs and markings shall be always visible: crew member shall be able, by means of signage and boundary marking only, to determine the exact location in the ship by walking +/- 3 meters along walking route.
 - Deck and vertical boundaries shall be marked to easily identify the sections of the fixed fire-extinguishing system in closed vehicle, ro-ro spaces and special category spaces with water-spraying systems.

6.3.2.2 *Impact on safety*

This solution will address previously identified challenges and thus contribute arguably to a more effective wayfinding and localization onboard by:

- Improving consistency and eliminating common mismatches between naming/framing of vertical zones in the cargo space and the information gathered at the bridge.
- Deploying easily readable position descriptions (drencher zones, frame markings, decks, etc.).

The response to a fire alarm must be as fast as possible, to ensure efficient first response and tackle the fire at the initial stage. The suggested improvements will arguably reduce the time used by the runner to manually confirm and localize fire onboard which help the firefighting team to direct their work as accurately as possible from the start and increase the chance to successfully fight a fire.

6.3.2.3 *Side effects*

Different side effects can be identified:

- Crew members will need to get familiar with the new signage and marking system onboard and the new locations.
- Crew members may continue referring to old signage and marking, which may lead to misunderstandings.
- New signage and marking locations will result in increasing maintenance needs since the paint will need to be renewed often on the floor of the cargo deck.

6.3.3 *Technical description of RCO3: Developed efficient first response*

Main author of the chapter: Jaime Bleye, SAS

6.3.3.1 *Technical description*

A first response to firefighting is a concept directly linked to the early detection and reflects that the fire is detected at its early stage. A quick and safe firefighting action may be provided independently the fire scenario considered.

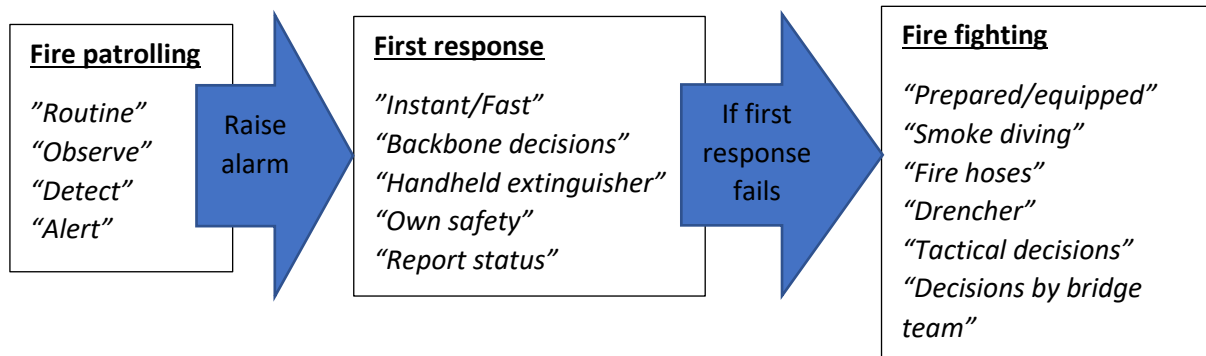
However, the concept and role of first response is not widely understood and not often included in the shipping operators' procedures. It is a fact that early detection, early confirmation and efficient first response are key factors to avoid fire escalation. When looking into some major marine fire events, there are different causes for a first response failure:

- Late detection. Fire too large and developed to be extinguished with first response equipment.
- No training/preparedness for first response (lack of confidence, unable to act as first responder).
- Time slot available after detection but no suitable firefighting method at hand.
- Cargo spacing is too tight. Accessibility problems or not possible to reach the base of the fire with the handheld portable firefighting media (most likely dry chemical powder).

The current equipment available on board for a first response according to SOLAS Chapter II-2 does not face new challenges with potential fires on APV. APV's fire produce toxic gasses emission like HF and the designated first responders should be prepared for protection.

Today, there is no defined function between First response and Manual firefighting in neither rules nor reality. Introducing such would be of great contribution but must be made with care not to cause confusion. To add to the complexity, it may well be that the same person, while present on location,

will during the timeline move from acting as fire patrol/runner to acting in first response into (preparing for) firefighting.



Depending on ambition level (general or designated) for a first responder, the location of fire stations with access to relevant lighter equipment could be relevant.

RCO3 "Developed efficient first response" aims to:

- Calibrate the role in the most efficient way. Any crew member may act as first responder by raising the alarm regardless of mental preparedness, firefighting skills and equipment but there are most skilled personnel with access to restricted cargo spaces that should be trained as **designated first responders**.
- Awareness on raising the alarm as the first action to be taken. Different ways of raising the alarm are:
 - Via portable radio (UHF or VHF);
 - Through a manually operated call point;
 - Via internal telephone;
 - By shouting 3 times "FIRE, FIRE, FIRE" ensuring that another crew member has received the message that has to be transmitted to the OOW.
- Develop electronic or other learning material than can be shared across the ro-ro industry.
- Investigate method/equipment to extend the usability of fire extinguisher to less accessible fire seats such as high places on top of cabins, reefer units.
- Develop special instructions for APV. Special focus on identifying type of vehicle, detection of risk indicators, safe approach, thermal runaway confirmation.
- Develop standard communication terminology protocol to secure prompt understanding.
- Set the outer layer clothing (Figure 6), when approaching a plausible fire, wear long sleeve jacket/shirt and long trousers in a material that is not easily combustible. Typically, coverall material is good, but fleece and polyester are not recommended. Clothing shall be clean, not stained with oily content or similar that increase combustibility. A set of thin material protective long sleeve gloves and safety footwear should also be worn when approaching a fire. Idea is to cover bare skin as much as possible. A radio for communication should always be carried. One complexity is the difference in conditions indoor/outdoor especially in bad weather and wintertime. Appointed crew member need be ready for first response action at all locations onboard. Other complexity is that in practice a fire patrol outfit may vary depending on the tasks to be performed before or after patrol round, be it mooring operations in wintertime or bridge outlook duties or something in between. Correct gear is immensely important to give first responder courage and confidence to act.



Figure 6. Typical first response outfit on board Stena Flavia.

- Develop specific training focusing on:
 - Mental preparedness;
 - Awareness on the first action when discovering a fire is raising the alarm;
 - Physical preparedness (a fire extinguisher weighs about 9 kg);
 - Use of portable heat camera;
 - Familiarity with vessel, access ways and limitations, keys, radio shadows, marking of drencher zones;
 - Familiarity with, in each location, available firefighting extinguishers and locally stored PPE;
 - Skilled to use different types of extinguishers;
 - Awareness of how other functions in safety organization work;
 - Communication skills, technology and terminology with standard phrases;
 - Self-protection, what to avoid and what is safe;
 - Skills in different cargo types and its hazard;
 - Basic DG, IMDG knowledge and firefighting options;
 - Basic vehicle and cargo knowledge, main switch locations and specific hazards;
 - Electric power system awareness for reefers or charging of electric cars;
 - Awareness of experiences from other vessels and colleagues (lessons learnt);
 - The transition period of new crew member until up and running, extra preparedness/overlap from other members of the watch.

6.3.3.2 Impact on safety

The main goal of RCO3 by developing the designated first responder's role, task, equipment and training is reducing the *Required Time for Safe First Response*; this is, the time needed to detect the fire and start first response actions in a safe manner during the early stage of the fire, allowing time for an efficient decision in case the fire chain of events need to be followed.

6.3.3.3 Side effects

According to RCO3, one main task of a designated first responder will be raising the alarm when discovering a fire or a potential fire, no matter the fire or smoke plume size.

By triggering the wrong manually operated call point, the real situation of the fire can be misinterpreted affecting the correct detection and thus having an impact on the fire management decision making process.

6.3.4 Technical description of RCO4: Developed manual firefighting for Alternatively Powered Vehicles

Main author of the chapter: Jaime Bleye, SAS

6.3.4.1 *Technical description*

Manual firefighting are firefighting actions to be carried out by the fire squad on board in accordance to Muster List. This means the deployment of fire hoses and donning of full PPE.

Conditions for manual firefighting may be considered as follows:

- If it is the only firefighting alternative when previous attempts were not successful (first response with a handheld device or fixed fire-extinguishing systems).
- For life saving.
- As backup of spaces protected with fixed fire-extinguishing systems, when the system has not been effective or in addition for fixed fire-extinguishing systems.
- As stable post-firefighting like cooling down, inspection or monitoring.

RCO4 is proposing the following **procedures** in case an APV fire on board:

- Try to perform a quick **first response** operation before the fire has affected the fuel (with a hand-held fire extinguisher). Stay out of the smoke plume and do so safely if possible. Most likely there is no battery fire and no risk for pressure vessel explosion at this stage. Detection or scan IR / gas detection / smell indication. Activation of the MOCP manually operated call points.
- If the initial fire cannot be extinguished by a first response, a **fixed fire-extinguishing system** (drencher) should be activated. For many reasons, the drencher system should be activated in an early stage of a fire. This means that manual firefighting needs to be coordinated for a drencher operation before approaching a fire location.
- If first response and fixed system are not effective, try to extinguish or suppress the fire further away from the vehicle in case the fire can still be extinguished from a distance or behind a protection.
- If extinguishment is not possible, as a defensive tactic, try to focus only on preventing the spread of fire and protecting adjacent vehicles and ship equipment. Hose system with water curtain or handheld cooling nozzle able to prevent fire propagation from a distance.
- With an **offensive tactic**, initially, the AFV fire can be extinguished as a standard vehicle fire. Traction battery will take long time to become involved and gas tanks are designed with a margin of safety in case of a fire. If possible, cool the energy storage (including traction battery and gas tanks).
- As soon as compressed gas tanks are being cooled or not affected by any fire, they regain a margin of safety against a pressure vessel explosion. In case of EV jet flames, allow the battery and jet flames to burn out, cool the surrounding and prevent fire spreading (defensive tactic). In case of gas jet flames, do not extinguish the jet flame but try to extinguish the fire, cool nearby vehicles/gas tanks and continue with the offensive tactics.
- If none of these methods are effective, **evacuation** shall be considered.

RCO4 is proposing the use of the following **equipment** in case of an APV fire on board:

- **Fire suits** compliant with EN 469:2020 X2 Y2 Z2, worn in combination with a hood second layer, will protect well from all vehicle fire gases including those of Li-Ion batteries such as hydrogen fluoride.
- **Smaller hoses.** Typical fire hoses that can be found on board are composed of 3 layers, are 20 m long and 45 mm thick. It is important to consider the heaviness and stiffness of different hose sizes for the manual firefighting tactics. 25 mm thick hoses are easier to operate and offer less drag to the firefighting operational proceeding of crew members, but smaller hoses produce a larger water pressure drop that needs to be considered.
- **Fog nails** connected to the fire hose. Fog nails will create small droplets, which absorb lot of heat. And fog nails are proven to be very effective inside the vehicle, preventing oxygen supply.
- **Boundary and direct cooling devices** to be used as a proactive measure, if suspicion or indication of thermal runaway or as a post fire measure. It can also be used as additional water source for firefighting. Working pressure between 8-10 bar. Max. pressure 15 bar. Total length 2 m. It creates a shield between and underneath the vehicles.
- **Special vehicle fire blanket.** To be used to contain and suppress a car fire covering the whole vehicle. Two firefighters are needed to handle the blanket covering and sliding the device over the roof. As battery fires can suffer re-ignition, fire blankets are an excellent prevention application to avoid re-ignitions. They can also partially content the emission of toxic gases from the fire.

RCO4 is proposing **training** on APV fires as the current IMO-STCW training courses do not include any specific training module. APV fires should be included also into the periodic drills on board.

6.3.4.2 *Impact on safety*

Fires in densely packed vehicles can spread quickly regardless of fuel storage. Early detection and a fast and efficient response are critical to limit the damages of fire.

Vehicle fires are hazardous and if the first response attempt fails the fixed fire-extinguishing system should be activated quickly. If the drencher fails, a manual firefighting operation is required.

Manual firefighting tactics and methods of how to suppress the fire from a distance need to be considered due to the risk of explosion and toxic gases.

APV fires can be tackled but they are difficult to identify and difficult to reach. It is very important to avoid propagations.

Fire spread between vehicles is of great importance when considering firefighting operations in ro-ro spaces. This concerns how severe a fire can become, whether it has to be extinguished, when it needs to be extinguished to prevent spread and how it can make the firefighting operation more difficult and hazardous.

6.3.4.3 *Side effects*

Manual firefighting operations are risky operations for the life of firefighting team members. According to STCW A-VI/3, the crew members will receive compulsory firefighting hands-on training, but they are not professional firefighters and the level of realism of on-board drills is generally low.

There are other side effects on the health of the manual firefighters raised from the emission of toxic gases produced in the vehicle fires.

Finally, run-off water from manual firefighting operations will be drained to sea from scuppers producing an environmental impact due to the presence of contaminants.

6.3.5 Technical description of RCO5: Alarm system interface prototype

Main author of the chapter: Staffan Bram, RISE

6.3.5.1 *Technical description*

The current prototype of the fire alarm system has been designed to support situation awareness and to offload the user's mental load. The interface has been calibrated for user ergonomics, e.g. with regard to symbols, colours and luminance. The UI consists of four main areas: General Arrangement (GA), timeline, emergency controls and map details:

General Arrangement (GA):

- Representations of detectors & fire appliances;
- Clearly indicated detector status, together with temperature, smoke and oxygen trends;
- Visual representation of heat and smoke spread;
- Oxygen level data;
- Cargo information; and
- Rudimentary interface for external surveillance drone deployment & control.

Timeline:

- A visualization of the alarm and event history with a timeline scrubber & functionality for making notes.

Emergency Controls:

- Integrated emergency controls, such as fire alarm, fire doors, dampers, fire pumps, evacuation ventilation, ventilation & drenchers.

Map details:

- Filtering functionality to show/hide information on the GA (e.g. fire appliances, cargo).

The following functionality was previously meant for inclusion but was scrapped:

- User-friendly interface for temporary deactivation of detectors;
- Situation-dependent decision support for common actions; and
- Pre-alerts.

6.3.5.2 *Impact on safety*

The aim of the digital fire centre is to provide immediate, precise and accessible information that supports the localization and monitoring of a fire, and that provides the information necessary to support firefighting, especially activation of drenchers. The main effects on safety are:

- Integration of multiple information sources, from elements of current fire centrals, in one user interface, aiming both to reduce mental workload, to speed up decision-making and to facilitate communication between fire command and on-scene personnel.
- Graphical, intuitive representation providing a good overview of fire safety information & assets, aimed at improving recognition and reducing workload. This also supports effective communication between bridge and fire scene personnel.
- Quick and easy access to emergency controls (e.g. fire alarm, drencher activation etc.).
- Support for reviewing the event history, thus aiding in the interpretation of fire development.

6.3.5.3 Side effects

A few possible adverse effects of this solution are:

Reduced competence

- Weakened ability to utilize traditional fire safety systems due to more infrequent use, which could have negative effects should the Digital Fire Central (DFC) go out of commission.

Touch screen¹ interaction

- Potential problems with precision in touch screen interaction, e.g. due to heavy seas.
- Risk of contaminating the screen with dirty or greasy hands, possibly obscuring information.
- Risk of accidental clicks e.g. leading to erroneous activation of functionality or confusion around information displayed.

Collaboration

- The DFC mainly caters for use by one individual who will be able to perform actions that are normally distributed over several officers and crewmembers. This kind of centralization could lead to less joint sense making and reduced shared situation awareness.
- The consequences of multi-user inputs have not fully been researched in the current iteration of the DFC.

6.3.6 Technical description of RCO6: Process for development of procedures and design for efficient activation of extinguishing system

Main author of the chapter: Torgeir K. Haavik, NSR

6.3.6.1 Technical description

Fixed fire extinguishing system activation (drencher and CO₂) often takes long time, typically 20 minutes or more, from fire detection until extinguishing system is activated. This allows fires to escalate and spread before extinguishment starts. Reasons for late activation can be found both in the way the extinguishing systems and activation mechanisms are designed, and in how the operational routines for activation are designed and practiced.

LASH FIRE studies of procedures for drencher and CO₂ system activation have documented a number of practices related issues where efficiency can be improved, uncertainties can be lowered and time spent can be reduced.

RCO6 addresses among others the following challenges (themes) associated with today's (diverse) activation processes:

- Confirmation of fire;
- Optimize location from where drenchers are activated;
- Clarity in responsibility for drencher activation;
- Correct drencher zone identification;
- Relocation to CO₂ room;
- Dangerous goods management;
- Optimization of operating instructions for extinguishing system;
- Optimized combination of manual/electric/automatic solutions for operating fire-related equipment (e.g. fire dampers);
- Improved radio communication – form; and

¹ The DFC use a pressure based touch screen.

- Optimized communication content and feedback loops related to extinguishment activation.

RCO6 is a process solution – a process for *Reflection, evaluation and change*. The RCO is adopted in connection with ordinary fire drills where activation of fixed fire extinguishing systems are involved. As an extension of the standard drill, the RCO provides a structured approach for converting tacit knowledge into explicit knowledge, and for identifying procedure and design candidates for change, in order to increase efficiency in the activation process (Figure 7). Elements included in this structure are:

- Pre-brief before drill (1/2h) – priming participants to make note of both “autopilot actions” and improvised actions during the drill;
- De-brief after drill (1h) – structured discussion first of noted points, thereafter of a number of prepared, leading questions, to identify improvement potentials relating to the adequacy of procedures and design; and
- Concluding decisions regarding changes needed in procedures and design.

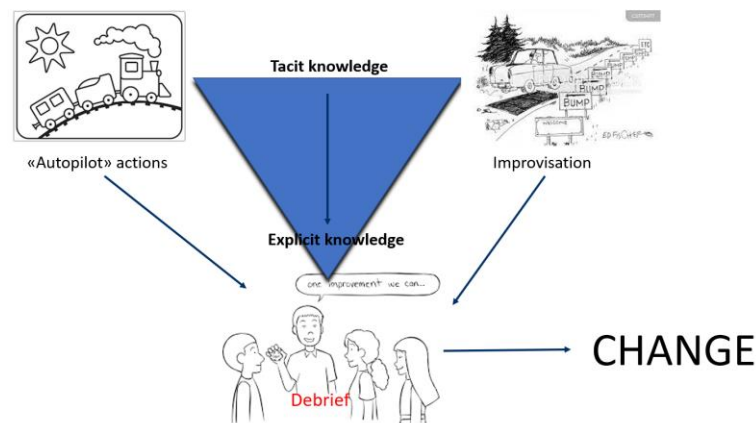


Figure 7. Elements of reflection, evaluation and change process.

6.3.6.2 Impact on safety

RCO6 constitutes a generic work process for addressing of an array of themes that all contribute towards faster activation of extinguishing systems, with reduced risk of human error, given that the ship operator and its crew are willing to invest the necessary resources for implementing the measures in full.

The RCO will facilitate identification and improvement of suboptimal practices and design aspects relating to extinguishing systems activation. In addition, the RCO will facilitate identification of good practices and design solutions of which there is little explicit awareness, and that hence run the risk of being thrown out with the bath water in case of organizational or technical changes. Hence, the RCO builds on both classical risk-oriented safety approaches and on resilience perspectives.

The RCO supports continuous learning and does so through making explicit the tacit knowledge existing among the crew members, making it available for scrutiny, adaptation and sharing, in line with central principles of resilience engineering [9].

6.3.6.3 Side effects

No obvious side effects or adverse effects on safety are foreseen. One potential problem that may occur, however, is lack of motivation to continue using the RCO if results from early adoption are not followed up by management. The RCO facilitates identification of necessary changes in procedures and design from the perspective of the crew. Some of these changes would have to be acknowledged

and invested in by company management, and if they are not willing to invest the necessary resources the result from adopting the RCO would be a strengthened awareness of a potential for safety improvement that will not take place. This side effect is, however, related to dissatisfaction and demotivation, and not reduced safety.

6.3.7 Technical description of RCO7: Training module for efficient activation of extinguishing system

Main author of the chapter: Jaime Bleye Vicario, SAS

6.3.7.1 Technical description

RCO7 “Training module for efficient activation of extinguishing system” recommends the inclusion of training on the manual activation of the fire extinguishing systems, considering that such training is not included on the Table A-VI/3 of the STCW Course “*Advanced firefighting*”. Model course- 2.03.

SOLAS Chapter II regulation 19.3.2 requires at least one fire drill on board every month. The shipping company Safety Management System (SMS) will specify clear instructions and guidelines about how fire drills shall be safely and efficiently carried out. However, in reality and due to the daily operative on board the real activation of the firefighting systems is not part of the compulsory fire drills. Chief officers periodically test the drencher system, as it is common to detect clogging on the sprinklers. However, there is no way to test the CO₂ system, that represents a real danger to life is not handled carefully.

According to MSC.1/Circular. 1430 “*Revised Guidelines for the Design and Approval of Fixed Water-Based Fire-Fighting Systems for Ro-Ro Spaces and Special Category Spaces*” – (31 May 2012), the manual activation of the deluge (or so-called drencher) systems is allowed and every crew member should be aware of the procedure. But reality shows that the recommendation is not fully implemented throughout the shipping industry.

According to Chapter 5 “*Fixed gas fire-extinguishing systems*” of the International Code for Fire Safety Systems (FSS Code) Point 2.2.2. set that “*Controls of the Carbon Dioxide Systems shall be located inside a release box clearly identified for the particular space. The box containing the control is to be locked and a key to the box shall be in a break-glass-type enclosure conspicuously located adjacent to the box*” Reality shows that crew members don’t have access to the CO₂ control room which is considered as a protected space with locked access. They are not familiar with activation and the efficacy of the CO₂ as firefighting agent.

Therefore, RCO7 has detected the need of training on activation of the extinguishing system and is proposing such activity as a recommendation for risk reduction besides the compulsory requirements stated on the IMO STCW Code. The target group for this training are captains, deck and engine officers, AB or personnel with access to cargo spaces and engine control room. Training should be refreshed every 5 years in a land certified maritime safety training centre.

6.3.7.2 Impact on safety

Hands-on training will ensure that crew members are compliant and competent managing high-risk systems in a safe environment without interrupting on the daily operative.

Training shall empower all relevant personnel to act in the case of fire and be varied to reflect different possible situations at the time of a fire alarm, while making sure that crew actions are supported by sufficient competence and mandate.

Sharing subject matter expertise on the activation of fire systems will help to build and sustain a safe workplace, protect the cargo on board and the sea environment.

Training that includes communicative practices and that covers realistic communication between the bridge and personnel on the activation system room will reduce the risk of communication failure.

Quick activation of the fire activation systems is considered as one of the main keys to successful fire management, allowing to prevent loss of life and damage the ship and cargo.

6.3.7.3 *Side effects*

Drencher activation can be associated with negative side effects that can both delay fire extinguishment and create operational hazards. The primary challenge is to handle the large quantities of water on deck created by the drenchers that may cause stability issues for the ship.

CO₂ is an asphyxiant gas that can provoke serious damage to people or even death in larger concentrations in volume. Activation of CO₂ will require intense communication and information between Captain and the person who physically activates the system. Activation of CO₂ will require perfect coordination because it is a “one-shoot” system, meaning that once the bottles are triggered, the process cannot be stopped.

Crew members may feel hesitated about the activation by fear of making the wrong decision without the correct permission. This RCO consists of the inclusion of training for efficient activation of extinguishing systems (both drencher and CO₂) to ensure that the crew has the knowledge for quick and efficient action without fear to fail in the process.

6.3.8 *Technical description of RCO8: Safe electrical connection for reefers*

Main author of the chapter: Vasudev Ramachandra, RISE

6.3.8.1 *Technical description*

Most of the loads that demand and consume power in the ro-ro spaces are cargo and are mainly reefer units. From the ship owner’s perspective, these loads are seen as a “black box” as they have no control over the build, maintenance or the condition.

In lieu of this, it is proposed that from the ship’s power circuit, each outlet is equipped with a main breaker, several sensors in parallel and communication devices which monitor and gather data for automated analysis using computer algorithms to detect anomalies. This will give the ship the current state of each phase in the socket, with higher resolution than what is considered standard today. This solution will also be open to implementation of communication architecture like reefer containers have today.

To effectively understand the behaviour of a given load, the following parameters will have to be measured at a certain frequency which will, as a result, define the sensitivity of the system:

- Power, current, voltage and phase difference; and
- Insulation.

6.3.8.2 *Impact on safety*

RCO8 is primarily aimed at detection of electrical faults before the faults have developed into fires making its impact very significant. The RCO benefits can be summarized as follows:

- Addresses reefer unit safety which has been a cause for major concern so far;
- Non-intrusive solution and hence does not involve modifying any reefer unit;
- Constantly monitors the electrical behaviour of the reefers to capture anomalies;
- Combines different measurements to predict possible failure and/or fires;
- Allows remote disconnection of individual reefer units at any time; and
- Centrally displays warnings and notifications.

6.3.8.3 *Side effects*

With automation of detection of electrical faults, one side effect will be possible spam alerts or warnings that do not warrant any action. This can be dealt with by fine tuning the system over its usage and by collecting more data. It can also be reduced by appropriate training for crew members.

6.3.9 Technical description of RCO9: Safe electrical connection of reefers and electric vehicles (EVs)

Main author of the chapter: Vasudev Ramachandra, RISE

6.3.9.1 *Technical description*

Monitoring of chargers and EVs are to be done by measuring important electrical and thermal parameters. Unlike in the case of reefer connections where only the reefer unit was a “black box” with only one connection to the electrical output of the ro-ro ships, there are two “black boxes” in case of the EV charging infrastructure: the EVs and the chargers. This corresponds to two connections that can be monitored: between the EV and the charger, and between the charger and the ship’s supply.

It is mandated for EV chargers to be connected to grounded electrical networks rather than floating or ungrounded systems and hence the need to monitor and emphasize on the first insulation fault is eliminated. More popular residual current circuit breaker solutions can be utilized to disconnect the systems if there happens to be a fault.

Except for the insulation measurement, other parameters like power, voltage, currents and temperatures are to be measured like the reefer solution (RCO8) except that the measurements shall be at two junctions and not one. This dual measurement shall also allow a comparison of the behaviours on either side of the charger unit which may give more details about the origin of the fault.

As a smart and a robust system, the proposed solution is to predict possible fires or extreme electrical conditions using artificial intelligence. With the knowledge of ideal behaviour of electrical parameters of the load, both reefers and EVs, the constantly monitored data can be used as a comparison and a model can be built and trained to study the differences. These differences, depending on the time frames, magnitudes and other aspects, can be used to predict the future states of the parameters and hence can be used as a method to predict fires.

RCO9 includes RCO8, i.e. safe electrical connection of reefers.

6.3.9.2 *Impact on safety*

In addition to the benefits of RCO8, the impact of RCO9 is estimated to be as follows:

- Additional layer of monitoring of EVs apart from the charger unit;
- Non-intrusive solution and hence does not involve modifying any EV or charger unit;
- Constantly monitors the electrical behaviour of the charger and EV charging to capture anomalies;
- Combines different measurements to predict possible failure and/or fires;
- Allows remote disconnection of individual EVs at any time; and
- Centrally displays warnings and notifications.

6.3.9.3 *Side effects*

RCO9 have the same side effects than RCO8 (refer to section 6.3.8.3).

6.3.10 Technical description of RCO10: Fire detection on weather decks

Main author of the chapter: Davood Zeinali, FRN

6.3.10.1 Technical description

Given that there is currently no requirement for fire detection systems on weather decks, it is expected that the addition of detectors will have a significant potential for risk reduction regarding the consequences of fires breaking out on weather decks. This is in line with the recent draft amendments to SOLAS chapter II-2 of the International Maritime Organization (IMO) which have required a fire detection system for any new ships built after January 1, 2026. Accordingly, several detection solutions that can cover large areas from a distance are evaluated as part of LASH FIRE action 9-A for weather decks. These solutions are based on infrared (IR) light that can be transferred from the fire to the detector through the air. The evaluated detectors within this category are flame wavelength detectors and thermal imaging cameras.

The detection systems based on flame detectors and thermal imaging (infrared) cameras comprise of a few detector units as shown in Figure 8, and a cable connecting each detector back to the ship's fire control panel for receiving and processing the alarm signals provided by the detectors. The detection capability of these detectors depends mainly on their sensitivity settings. For instance, a 0.3 m × 0.3 m heptane pool fire may be detected by a flame detector at 15 m in nearly 1 s with low sensitivity settings, whereas the same fire may be detected from 60 m in nearly 3 s with high sensitivity settings, albeit more nuisance alarms may be triggered with the latter settings. Correspondingly, the sensitivity settings may be fixed according to the application, desired detection time, and acceptable frequency of nuisance alarms. In addition to provide fire alarms, these detection systems can identify the location of the fire and can provide this information in terms of X/Y/Z coordinates that are useful for fire suppression using autonomous systems.

Both flame detectors and thermal imaging cameras were installed on board the operational ship Hollandia Seaways in March 2022 to evaluate the systems during operational conditions for an entire year.



Figure 8. Example flame detector (left) and thermal imaging camera (right).

6.3.10.2 Impact on safety

As current regulations do not require automatic detection for weather decks, the addition of a detection system based on flame detectors or thermal cameras is expected to decrease the probabilities of having no active fire detection on the weather decks.

The superstructures of the weather deck can be used for the installations to provide remote detection coverage for a large area using a single device. Correspondingly, one or more detectors may be used to cover the entire weather deck. However, the downside of this solution is that the detectors need to see the area of fire development, otherwise they will not be able to detect the fire. In this case, thermal imaging cameras have one benefit compared to the other optical devices, namely, they do not require open flames for detecting fires as they could also detect any heated

surfaces (for example roof of a container when there is a fire inside), and this could help detect the fire development more efficiently.

The detection system may have to be deactivated during situations such as times of loading/unloading operations at the harbour. For example, the high temperature of truck mufflers may easily trigger an alarm depending on the temperature threshold used by the detection system. Accordingly, the availability of the system will depend on whether the sensitivity settings are adaptable to these operations. One option is that the system is designed to provide only pre-warnings during such operations. Another option is that the system allows reducing the sensitivity settings manually with a timer that will automatically revert to the normal settings after a predefined amount of time.

6.3.10.3 Side effects

If the proposed detection system installation on the weather decks produces frequent nuisance alarms in certain situations (e.g. during loading operations), there is a probability that the system is muted or deactivated during those situations. As a result, there is a probability that the system is forgotten on the muted or deactivated state, leading to a false sense of security and possibly even missing some raised alarms, especially for existing ships where the addition of the system is a new change.

6.3.11 Technical description of RCO11: Alternative fire detection in closed ro-ro spaces & open ro-ro spaces

Main author of the chapter: Davood Zeinali, FRN

6.3.11.1 Technical description

The system of fibre optic linear heat detection comprises mainly of a fibre optic cable, while all the electronics and signal processing are done in the central unit, where the laser pulses are generated, transmitted to the fibre optic cable, and the reflections are analyzed and processed for alarm evaluations. This means that the required maintenance of the system can be done centrally. Moreover, in case the fibre optic cable is damaged, the system can identify the location of the damage. The sensing cable can also be connected as a loop and connected to the central unit at both ends to provide redundancy against one cable breach per loop.

The sensor cable needs to be fixed on the ceiling along the deckhead of the ro-ro space (see Figure 9), whereby continuous temperature recordings are made along the cable. As the longitudinal and transversal girders on the deckhead create many compartments along the ceiling, the ideal configuration for fire detection is achieved when the cable goes through all the compartments.



Figure 9. Example ceiling installation of a linear heat detection cable (isolated from a pipe using a spacer).

6.3.11.2 Impact on safety

Today open and closed ro-ro spaces are in most cases protected by point detectors. These require transport of smoke and heat to the different detectors which can give a delayed response time when affected by for example wind diluting the smoke or moving it in different directions away from detectors. In a closed ro-ro space, the delay can be caused by ventilation, beams or other obstructions hindering the smoke and/or heat transport to the detector. Another problem in open ro-ro spaces is the open environment which reduces the ability of point detectors for fire detection. Normal point detectors have a small coverage area requiring many detectors to be installed to cover the complete area.

The fibre optic linear heat detection proposed for open and closed ro-ro spaces are cables mounted in deckhead, which will give a better coverage than traditional point heat detectors. The system is robust to dirt, dust, radiation and other harsh environmental circumstances affecting the detectors.

6.3.11.3 Side effects

Although the visual information provided by the linear system is rather intuitive and user-friendly, the crew need a short introduction to the working principle of the system and the placing of the cables on the different decks to get familiar with the system. Accordingly, if any crewmembers have not received such an introduction to the system before, they may be unable to obtain the necessary information from the system efficiently during an emergency.

6.3.12 Technical description of RCO12: Visual system for fire confirmation and localization

Main author of the chapter: Davood Zeinali, FRN

6.3.12.1 Technical description

Visual systems of fire confirmation and localization based on CCTV cameras of video fire detection and infrared cameras of thermal imaging fire detection comprise of a few detector units as shown in Figure 10, and a cable connecting each detector back to the ship's fire control panel for receiving and

processing the alarm signals provided by the detectors. The cameras rely on optical technology and thus require a free line of sight to the flame or smoke.

The visual information quality from cameras depends mainly on their lens resolution and view angle but also distance from targets. The visual ability of cameras follows the square law between distance and area of detection: as long as the distance is high compared to the characteristic length of the object to be detected, visibility at twice the distance requires nearly four times the area, as illustrated in Figure 11.

Thermal cameras have the benefit of being able to highlight high temperature regions more easily, such that there is clear contrast between hot and cold areas, especially in the case of heated surfaces in the absence of open flames where ordinary video analytics will not be able to identify the hazard at all.

In addition to assisting with manual confirmation and localization of fires, the detection systems based on video analytics and thermal imaging can provide the location of the fire in terms of X/Y/Z coordinates which can be used by automatic fire suppression systems to activate autonomously (refer to RCO15).

Both flame detectors and thermal imaging cameras were installed on board the operational ship Hollandia Seaways in March 2022 to evaluate the systems during operational conditions for an entire year.



Figure 10. Example CCTV camera (left) and thermal imaging camera (right).

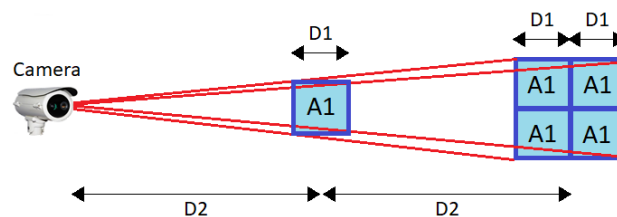


Figure 11. Square law between distance and area of detection (applicable when $D2 \gg D1$): if an object that has an area of $A1$ is detectable at the distance of $D1$, detection at a distance of $2 \times D1$ requires nearly an area of $4 \times A1$.

6.3.12.2 Impact on safety

The superstructures on the weather deck can be used for the installations to provide remote detection coverage for a large area using a single device. Correspondingly, one or more detectors may be used to monitor the entire deck adequately (i.e. in closed and open ro-ro spaces). However, the downside of this solution is that the detectors need to see the area of fire development, otherwise they will not be able to detect the fire. In this case, thermal imaging cameras have one benefit compared to the other optical devices, namely, they do not require open flames for detecting fires as they could also detect any heated surfaces (for example roof of a container when there is a fire inside), and this could help detect the fire development more efficiently.

The detection system based on thermal imaging may have to be deactivated during situations such as times of loading/unloading operations at the harbour. For example, the high temperature of truck mufflers may easily trigger an alarm depending on the temperature threshold used by the detection system. Accordingly, the availability of the system will depend on whether the sensitivity settings are adaptable to these operations. One option is that the system is designed to provide only pre-warnings during such operations. Another option is that the system allows reducing the sensitivity settings manually with a timer that will automatically revert to the normal settings after a predefined amount of time.

The detection systems based on video analytics may also be deactivated if they trigger frequent false alarms, e.g. when the light conditions change or routine washdowns are performed that will cover the lens with droplets. Accordingly, video fire detection is only recommended for use in closed ro-ro spaces where the lighting conditions are more fixed. Some new/hybrid video fire detection systems working based on other principles or combinations with heat detection may be better suited for weather decks and open ro-ro spaces where light conditions are more variable, although this is not confirmed yet.

6.3.12.3 Side effects

The efficiency of visual fire localization using cameras depends on the simplicity of the addressing system for all the installed cameras. In cases where there are too many cameras involved or when the addressing system is complex such that the crew may have difficulty pinpointing the fire location correctly, the system may be inefficient in terms of time to obtain the required information. Similarly, it is possible in such situations that the fire location is misinterpreted, causing the crew to focus on the wrong place, possibly leading to delays in the implementation of first response measures or failure in the activation of the fire suppression system in the correct location.

6.3.13 Technical description of RCO13: Dry-pipe sprinkler system for vehicle carriers

Main author of the chapter: Magnus Arvidson, RISE

6.3.13.1 Technical description

One automatic water-based fire protection system solution was selected for further evaluation, a dry pipe sprinkler system (RCO13). The system should be used as a supplement to the fixed installed CO₂ system used in ro-ro cargo spaces on vehicle carriers. The overall approach is that early and automatic activation will allow time to properly discharge the fixed installed CO₂ system. As the fire is controlled by the water-based fire protection system, fire damage will be smaller, and the fire may (also this has not been proven) be more easily extinguished by the CO₂ system.

A dry pipe sprinkler system uses automatic sprinklers that are attached to a piping system containing air or nitrogen under pressure. When one or more sprinklers (installed at the ceiling of the protected space) operates by the heat from the fire, the pressure drop opens a dry pipe valve, and water flows into the piping system and out the opened sprinklers. The opening of the valve generates an electrical signal that starts the sprinkler pump. There is typically a delay time in the order of 45 s to 60 s from the activation of the first sprinkler(s) to the discharge of water. The system needs to be hydraulically designed for a certain area of operation; the maximum area over which the sprinklers are expected to operate in a fire. This area contains about twelve to fifteen sprinklers according to the design and installation guidelines developed in the project (refer to deliverable D10.1 "Description of the development of local application fire-extinguishing systems and selected solutions" [10]).

The system requires a water pump that is connected to the freshwater tank(s) of the ship and would be supplied by the main power supply. Dry pipe valves are located either outside the protected space or inside separate cabinets inside the protected space. As water is discharged inside the protected spaces, means for water drainage are required. It is anticipated that the scuppers of the drainage system are designed to prevent clogging by debris and that the drainage system pump (if required) starts at the same time as the water-based fire protection system is started.

6.3.13.2 Impact on safety

The main benefit of a dry pipe system is that the system activates automatically and thereby early in the event of a fire. The discharge of water will control a fire, i.e. prevent it from involving multiple vehicles, prevent it from spreading to adjacent spaces and limit structural damage. In addition, water is readily available, inexpensive and there are no negative environmental aspects (although contaminated water during an actual fire may be a concern). The fire control performance was investigated in a series of large-scale tests and the performance was proven to be sufficient (refer to D10.1 [10]).

6.3.13.3 Side effects

From a safety aspect, the main concern of using water is that it may endanger the stability of the ship, unless water is properly drained from the space. This requires the drainage system to be properly designed and that the scuppers are not blocked by debris carried by the water from the sprinkler system. There is guidance from IMO on the design of firefighting water drainage, refer to MSC.1/Circ.1320 [11]. It is assumed that those guidelines are implemented. In spaces above the bulkhead deck, scuppers shall be fitted so as to ensure that firefighting water is rapidly discharged directly overboard. In the spaces below the bulkhead deck, pumping and drainage facilities shall be provided designed to remove no less than 125% of the combined capacity of both the sprinkler system pump and the required number of fire hose nozzles. The drainage system valves shall be operable from outside the protected space at a position in the vicinity of the extinguishing system controls. Means shall be provided to prevent the blockage of drainage arrangements, for example by a screen or grating installed over each drain, raised above the deck or installed at an angle to prevent large objects from blocking the drain. If the sprinkler system is activated, a close check must be made on the over side discharge and the angle of list of the ship. If a listing of the vessel occurs, consideration should be given to stopping the sprinkler system until the ship is brought upright.

It is judged that the system can be installed without or with minimal influence on the cargo capacity in the terms of space. However, the system will add weight to the total weight of the ship, which will influence the cargo capacity in terms of payload and/or the fuel consumption of the ship.

There is also an installation cost and a cost for maintenance and service associated with the system.

Further, it should be recognized that a dry pipe system is an automatic system, thereby fulfilling the objective in LASH FIRE, but there are no means to activate the system manually. It is only possible to manually stop the outflow of water, either by closure of the dry pipe section valve or the main system valve, alternatively by stopping the water pump.

6.3.14 Technical description of RCO14: Fixed remotely-controlled fire monitor system using water for weather decks & RCO15: Fixed autonomous fire monitor system using water for weather decks

Main author of the chapter: Magnus Arvidson, RISE

6.3.14.1 *Technical description*

Two different fire monitor systems concepts for the protection of weather decks were selected for the continued evaluation:

- RCO14: Fixed remotely-controlled fire monitor system using water for weather decks.
- RCO15: Fixed autonomous fire monitor system using water for weather decks.

Both systems require a water pump that is connected to the freshwater tank(s) of the ship and would be supplied by the main power supply. A seawater connection is anticipated to provide a continuous supply of water in case a long discharge duration time is needed.

Remote-controlled fire monitors are controlled by an operator positioned at a safe location and not at the actual fire monitor, for example using a joystick connected by a cable to the monitor's programmable logic controller (PLC). An **autonomous fire monitor system** as used herein is a system comprising a fire detection system, fire monitors and electronic hardware and software enabling the system to detect the presence and position of a fire and autonomously and dynamically guide the one or more monitors to achieve fire suppression, without any human intervention. However, it should be emphasized that an autonomous monitor system can also be remote-controlled by a human operator at any time, regardless of whether it has detected a fire or has autonomously initiated suppression of a fire.

A low installation cost of a system is essential. Therefore, the system concept is based on small sized 2" fire monitors, lightweight DN125 (5") or DN150 (6") pipes, and small dimensions valves and actuators, keeping material and installation costs to a minimum.

Fire monitors should be elevated and installed either on the superstructure of the ship or on dedicated stands such that any point of the weather deck can be reached by at least two streams of water. Discharge of water from two different positions/angles will to some extent reduce the influence by wind conditions on the performance of the system.

6.3.14.2 *Impact on safety*

Fire monitors, whether remote-controlled or autonomous, are widely known to be a highly effective means of controlling or suppressing fires. It is expected that equipping weather decks with a fire monitor system will provide a significant risk reduction potential. It is assumed that a) the fire is detected either manually or by a fire detection system, and suppression that commenced at an early stage; and b) that the fire monitor system complies with the Guidelines for the Design, Installation and Approval of Fixed Water-Based Monitor Systems for the Protection of Ro-Ro Weather Decks developed in WP10-B.

The remote control feature will allow safe control of a fire monitor, from a position that is not exposed to heat and smoke.

6.3.14.3 *Side effects*

From a safety aspect, the main concern of using water is that it may endanger the stability of the ship, unless water is properly drained from the deck. This requires that the drainage system be properly designed and that the scuppers are not blocked by debris carried by the water from the fire monitors. There is guidance from IMO on the design of firefighting water drainage, refer to

MSC.1/Circ.1320 [11]. As the weather deck is positioned above the bulkhead deck, scuppers or side openings shall be fitted so as to ensure that firefighting water is rapidly discharged directly overboard.

6.3.15 Technical description of RCO16: Guideline for fire ventilation in closed ro-ro space

Main author of the chapter: Stina Andersson & Anna Olofsson, RISE

6.3.15.1 Technical description

RCO16 is a *Guideline for fire ventilation in closed ro-ro spaces* that is developed to improve the current situation on board regarding how to handle the mechanical ventilation during a fire inside a closed ro-ro space.

The guideline will be based on the results from the computer simulations, the model scale tests and the study visits with including interviews and survey that has been conducted in WP11 in LASH FIRE.

Rather than providing direct instructions, the guideline is intended to increase crew members understanding of the risks and effects of mechanical ventilation and to constitute a knowledge asset to be used before and during firefighting. The guideline, as a first version, has a focus on the early phase of the fire scenario.

A fire is a dynamic situation and ro-ro passenger crew members that have been interviewed state that if there are some guidance it would be easier to operate. A fire is an emergency and everything that has to do with distress should be short texts, so that it is simple to understand when there are many stressors present. The guideline is expected to give the crew an understanding of why they do something, making it possible to practice and thereby improve the understanding of various firefighting situations.

To make the guideline easy to understand and adapt for crews, the intention is to offer it in the form of a “quick guide” which is planned to be 2 pages maximum. The main scope of the quick guide is to explain risks and opportunities of using mechanical ventilation during a fire inside a closed ro-ro space. Below is an example of the scope and content of the quick guide. As this is work in progress, the headings mentioned are tentative:

- Understanding risks and opportunities with mechanical ventilation.
- What to consider when using mechanical ventilation:
 - Size of fire;
 - Proximity to supply/exhaust fan; and
 - Adjacent cargo.
- Equipment, such as reversible fans.

This RCO is applicable for both newbuildings and for existing ships. The focus is on ro-ro passenger ships, but it is applicable to ro-ro cargo ships as well. The RCO is only considered for closed ro-ro spaces since this is where the requirement of mechanical ventilation currently exists. The requirements are for everyday purpose, not intended for fire scenarios.

6.3.15.2 Impact on safety

Mechanical ventilation can be a helping tool during firefighting. Interviews with ro-ro passenger crew showed that the crew would welcome a guideline which helps to understand how to handle the mechanical ventilation.

Impact on safety that was mentioned by the crew was the following:

- To improve the environment for the firefighters to operate:

- Which can help them find fire source and extinguish in right place; and
 - Increase visibility.
- Prevent spread of smoke to staircases and other parts of the ship.
- Reduce smoke, which is toxic and might lead to fatalities when exposed.

The proposed quick guide aims at facilitating firefighting operations in case of a fire in ro-ro space onboard. Based on the work in Action 11-D that will be implemented in the guideline, the main impact on safety would be to facilitate manual interventions (i.e. extinguishment) in closed ro-ro space, by:

- Increase crew members understanding of the risks and effects of mechanical ventilation (effect on visibility, temperatures, etc.); and
- Constitute a knowledge asset to be used before and during firefighting.

Indirect, this RCO may lead to mitigation of heat spread to adjacent spaces by reducing the temperature in the ro-ro space and prevent accumulation of hot gases.

6.3.15.3 Side effects

Using mechanical ventilation during a fire requires continuous monitoring. Overall, the usage of mechanical fire ventilation is an active tool, that needs to be adjusted to the fire scenario. A guideline can possibly create an over confidence in the ventilation system and thereby decrease the perception about the need to continuously monitor the ventilation.

If ventilation is used improperly, it might increase the size of the fire, making it more severe. It might also increase the risk of fire spread to the surrounding cargo.

6.4 Quantification of RCOs effectiveness

This section describes how effective each RCO is, i.e. their reliability, their impact on the risk model, etc. The risk reduction values of each RCO were provided by the D&D WPs based, as far as possible, on the results of their validation and demonstration work. The values were then reviewed and challenged by WP04 before their implementation in the risk model.

6.4.1 Effectiveness of RCO1: Improved fire patrol. Improved fire confirmation & localization

Main author of the chapter: Jaime Bleye Vicario, SAS

The evaluation method for the calculation of the percentage of risk reduction after the implementation of RCO1 is based on the results of several ship visits, internal LASH FIRE documents, research, interviews and onboard testing.

The impact on the risk model for RCO1 is:

- **Ignition** (only applicable to ro-ro passenger and cargo ships):

Ship equipment \ Electrical: Electrical failures are seen as the main ignition risk on board. By implementing efficient fire patrol procedures, it is expected to have a risk reduction of 9%.

Ship equipment \ Other than electrical: Fire origin can be unknown. It can even be intentionally provoked. By implementing efficient fire patrol procedures, it is expected to have a risk reduction of 6%.

Ship cargo \ Conventional vehicle \ Electrical: Many fires are caused by electrical failures; these are overheated components or cables that may produce smouldering fires (no flame). Some of them produce too little smoke or soot to be detected by automatic means (smoke detectors). If the fire patrol pass through the cargo space and manually detect either by smell or with the help of an IR camera, it is expected to produce a risk reduction on this node of 9%.

Ship cargo \ Conventional vehicle \ Other than electrical: Spontaneous fires on conventional vehicles are rare to occur. It can be provoked because of a low flash point fuel leak. The only way to detect such incidents is by visual confirmation. It is expected that a fire patrol focusing on the ship cargo rather than on other locations on board can reduce the probability of this node by 6%.

Ship cargo \ APV \ EV \ Electrical \ Connection: Connection of the car battery to an onboard charging system may contribute to overcharge provoking a thermal runaway despite the inner safety measures of the battery management system. Increased safety awareness of fire patrols by monitoring the condition of the battery may contribute to reduce the risk by 9%.

Ship cargo \ APV \ EV \ Electrical \ Other (electrical cause): Technical ignition sources for vehicles are most likely from electrical malfunction. By implementing efficient fire patrol procedures, it is expected to have a risk reduction of 6%.

Ship cargo \ APV \ EV \ Other than electrical: EV fire might not be related to the traction battery but related to mechanical issues. By implementing efficient fire patrol procedures, it is expected to have a risk reduction of 4%.

Ship cargo \ APV \ Other APV \ Electrical: Manual detection of boil-off gases is tricky activity (even if the fire patrol member is equipped with a gas-detector sniffer). In any case, by implementing efficient fire patrol procedures, it is expected to have a risk reduction in this node of 6%.

Ship cargo \ APV \ Other APV \ Other than electrical: Vehicles using other energies than gasoline or diesel will be referred to as APV. i.e. vehicles that include other liquid fuels like ethanol, LNG, LPG,

compressed gas like CNG, hydrogen fuel cells. Safety solutions to protect the fuel or energy storage from fires are similar within the different groups and their failure nodes are also similar. By implementing efficient fire patrol procedures, it is expected to have a risk reduction in this node of 4%.

Ship cargo \ Cargo unit \ T°C-controlled cargo unit \ Electrical \ Connection: Crew should make the connection with own cables. Fire patrol will monitor and check connections after departure. It is expected to have an impact on risk reduction of 14%.

Ship cargo \ Cargo unit \ T°C-controlled cargo unit \ Electrical \ Other (electrical cause): Reefer units are generally not allowed to operate on their own diesel generator power supply (excepting weather deck and in some cases in ro-ro open spaces) and should be connected to the ship's grid. Reviewing the belts and mechanical parts of the system, fire patrols can reduce the risk by 12%.

Ship cargo \ Cargo unit \ T°C-controlled cargo unit \ Other than electrical: Shipping operators cannot control the conditions that reefer units are loading. Therefore, it is expected that by increasing the awareness and vigilance of these units by the fire patrol can reduce the risk of failure by 12%.

Ship cargo \ Cargo unit \ Other cargo unit \ Electrical: There are new electrical devices on the market like electric bicycles, hoverboards or similar that can be loaded on board. Some of them are poor quality with limited safety functions. By implementing efficient fire patrol procedures and check the accommodation block by the fire patrol it is expected to have a risk reduction of 14%.

Ship cargo \ Cargo unit \ Other cargo unit \ Other than electrical: Ro-ro ships are carrying Dangerous Goods complying with IMDG Code. DG can generate self-reactions and provoke fires. Even though accessibility is a problem for an efficient fire patrol inspection, it is expected that by implementing efficient fire patrol procedures, risk reduction in this node will be of 12%.

Other origin \ Electrical: By implementing efficient fire patrol procedures, it is expected to have a risk reduction in this node of 9%.

Other origin \ Other than electrical: By implementing efficient fire patrol procedures, it is expected to have a risk reduction in this node of 6%.

- **Late detection** (only applicable to ro-ro passenger and cargo ships):

Late/no manual detection \ Fire patrol failure \ Not present \ Required but not present: Another task or priority of the fire patrol member can result in the fire patrol not being present while he/she would be required. Some systems like the check point reader can guarantee that fire patrol is physically present at the location reducing the risk of absence by 45%.

Late/no manual detection \ Fire patrol failure \ Quality failure \ Accessibility problems: Accessibility problems caused by tight parked cargo can produce important failures in manual detection. By including IR cameras, smouldering fires can be detected from a distance (10-15 meters) reducing the detection failures by 55%.

Late/no manual detection \ Fire patrol failure \ Quality failure \ Lack of training / experience: By establishing the requirements and experience of a crew member (AB or OS) before becoming member of the fire patrol. Risk reduction of this node will about 55%.

Late/no manual detection \ Fire patrol failure \ Quality failure \ Lack of equipment: SOLAS Chapter II-2 only states the use of a two-way radio apparatus for the fire patrol member. By defining a more comprehensive gear and equipment, the risk reduction on this node will be reduced by 25%.

Late/no manual detection \ Fire patrol failure \ Quality failure \ Low motivation: Low motivation due to high workload and repetitive task is seen as the main barrier for an effective fire patrol route. By identifying this problem and establishing correct rest periods among the ro-ro fleet, the risk of late response due to this cause can be reduced by 60%.

- **Failure of first response** (only applicable to ro-ro passenger and cargo ships):

Failure by first responder \ Accessibility problems: Accessibility within ro-ro spaces between cargo is very limited. Sometimes less than 15 cm making the first response very difficult. Fire patrol procedures will not improve accessibility, but the use of IR cameras can detect risk from an efficient procedure is expected to reduce the risk in this node by 25%.

Failure by first responder \ Tactical failure: First response will be performed by the first crew member that discovers the fire in the initial stage. This way, fire patrol or runner is directly linked with the first response. An efficient procedure is expected to reduce the risk in this node by 33%.

- **Late decision:**

Late confirmation \ Late manual confirmation \ Late arrival at detector point \ Late deployment of runner: By training the role of the runner and acquiring a better understanding of the task, the time for an efficient manual confirmation can be reduced by 55%.

Late confirmation \ Late manual confirmation \ Late arrival at detector point \ Long travel time to detection point: By training the best route from the bridge to possible detection points, the time for an efficient manual confirmation can be reduced by 30%.

Late confirmation \ Late manual confirmation \ Late localization \ Inadequate strategy: By establishing written clear instructions of the role of the runner, the risk of this node can be reduced by 25%.

Late confirmation \ Late manual confirmation \ Late localization \ Inadequate equipment: By establishing the right gear and equipment (UHF radio with hands free press to talk bottoms and IR camera), the risk of late confirmation in this node can be reduced by 15%.

Late confirmation \ Late manual confirmation \ Failure of communication: By identifying shade points of communication on board and establishing slave antennas for correct communication, the risk of late communication can be reduced by 75%.

Late assessment \ Information is not made readily: Better trained runners and clear communication protocols can reduce the risk of late assessment by lack of information in 15%.

6.4.2 Effectiveness of RCO2: Improved signage and markings for effective wayfinding and localization

Main author of the chapter: Lucia Liste, NSR

Little data typically exists to guide the quantification of RCOs targeted at the human operator and human operative capabilities. Instead, a joint qualitative assessment of the RCO has been performed by experts within LASH FIRE. The expert judgement was based on results and knowledge gathered by means of: collaboration with LASH FIRE partners, interview data (relevant stakeholders and industries), remote trial on Stena Jutlandica in May 2021; observation and state of the art study

(including investigation reports). Lastly, RCO2 has been applied to a reference case, Stena Baltica, in April 2022.

The impact on the risk model is:

- **Late decision:**

Late alarm interpretation \ Delayed acknowledgment \ Delayed alarm handling \ Time lost on information integration: Consistency between signage and markings and information in the bridge represent an important resource for wayfinding and localization in case of fire in closed ro-ro spaces, this RCO was assessed to represent a 40% reduction of probability for the “time lost on information integration” node in closed ro-ro spaces following early detection and 33% following late detection. Yet, 33% in case of open ro-ro spaces, due to signage and marking in open ro-ro spaces is simpler and there is less probabilities for consistency mismatches.

Late confirmation \ Late technical confirmation: Lack of consistency between signage and markings and information in the bridge and not easily readable and interpretable signage and marking can represent an obstacle for technical localization and confirmation in case of fire in closed and open ro-ro spaces, this RCO was assessed to represent a 33% reduction of probability for the “late technical confirmation” node in closed and open ro-ro spaces following early detection. Following late detection, more factors play a role in the technical confirmation such as human errors and fire damages on the electrical systems of the ship, thus, this RCO was assessed to represent a 10% reduction of probability for the “late technical confirmation” node in closed and open ro-ro spaces.

Late confirmation \ Late manual confirmation \ Late arrival at detector point \ Long travel time to detection point: Consistency between signage and markings and information in the bridge and readable and identifiable signage and markings can reduce misunderstandings and errors when identifying and traveling to detection point. Yet, other factors such as physical condition of the runner or familiarity with the ship can also have an effect on it. This RCO was assessed to represent a 40% reduction of probability for the “long travel time to detection point” node in closed ro-ro spaces following early detection and 33% following late detection. Yet, 33% in case of open ro-ro spaces, due to signage and marking in open ro-ro spaces is simpler and there is less probabilities for consistency mismatches.

Late confirmation \ Late manual confirmation \ Late localization \ Difficult environment: Signage and markings represent an important resource for wayfinding and localization in case of fire in closed and open ro-ro spaces, but seeing that manual confirmation is also affected by the cargo deck environment (tight passages, smoke, etc.), this RCO was assessed to represent a 33% reduction of probability for the “difficult environment” node.

Late confirmation \ Late manual confirmation \ Late localization \ Inadequate strategy: The signage and markings onboard and its consistency with information in the bridge may contribute to some extent to an inadequate strategy. Other factors such as lack of familiarity with the ship or stress among others can also play a role. This RCO was assessed to represent a 25% reduction of the probability for “inadequate strategy”, for close and open ro-ro spaces, and 10% for weather decks.

Late confirmation \ Late manual confirmation \ Failure of communication: Improved signage and markings and lack of mismatches were also believed to contribute to bridge/deck communications in the way of shared vocabulary and common ground, among other factors such as poor English level, radio coverage challenges, etc. Therefore, this RCO can reduce the probability of “failure of communication” by 25% for close and open ro-ro spaces, and 10% for weather decks.

Late implementation: Many factors contribute to a late implementation, being signage and markings mismatches and bad marking and signage standards onboard one of them. Therefore, this RCO is assessed to reduce the probability of “late implementation” by 10% in all types of ro-ro spaces (close, open ro-ro spaces and weather decks).

- **Failure of 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.

6.4.3 Effectiveness of RCO3: Developed efficient first response

Main author of the chapter: Jaime Bleye, SAS

Many factors may affect the performance of an efficient first response, such as:

- Experience and level of confidence. Not all crewmembers have the right profile to deal with an emergency situation, as some are more proactive and stress-tolerant than others;
- Awareness on clear written instructions. The working culture on the vessel such as decision making, trust, openness, blame culture etc. will influence the outcome;
- Physical barriers that can obstruct reaching the site of the fire, like accessibility between vehicles, visibility, movement (rolling/pitching) of the ship due to bad weather;
- Failure during the communication with the OOW; and
- Disposal of firefighting equipment.

The evaluation method for the calculation of the percentage of risk reduction after the implementation of RCO3 is based on the results and experiences collected after performing a specific “efficient first response” training module at Jovellanos Maritime Safety Training Centre Home - Centro Jovellanos. Target trainee’s group were crew members from Stena lines. Date: October 2022.

The impact on the risk model is:

- **Late detection:**

Late/no manual detection \ Fire patrol failure \ Quality failure \ Lack of training / experience: Fire patrol might not detect a fire. Therefore, no first response will be performed. By stating the role of the designated people who might act as first responders gaining awareness on the task, the risk can be reduced by 30%.

- **Failure of first response failure:**

Failure by first responder \ Accessibility problems: Accessibility within ro-ro spaces between cargo is very limited. Sometimes less than 15 cm making the first response very difficult. An efficient procedure is expected to reduce the risk of failure due to accessibility problems by 25%.

Failure by first responder \ Tactical failure: First response will be performed by the first crew member that discover the fire in the initial stage. An efficient and well-defined procedure is expected to reduce the risk in this node by 33%.

- **Late decision:**

Late confirmation \ Late manual confirmation \ Late localization \ Inadequate strategy: By establishing written clear instructions of the role of the designated first responder, the risk of this node can be reduced by 25%.

Late confirmation \ Late manual confirmation \ Failure of communication: By identifying shade points of communication on board and incorporating the raise of the alarm when discovering a fire into the fire drill , the risk of late communication can be reduced by 75%.

6.4.4 Effectiveness of RCO4: Developed manual firefighting for Alternatively Powered Vehicles

Main author of the chapter: Jaime Bleye, SAS

Many factors may affect the performance of a manual firefighting operation, such as:

- Experience and level of confidence. Not all crewmembers have the right profile to deal with an emergency situation, as some are more proactive and stress-tolerant than others;
- Awareness on clear written instructions. The working culture on the vessel such as decision making, trust, openness, blame culture etc. will influence on the outcome;
- Physical barriers that can obstruct reaching the site of the fire, like accessibility between vehicles, visibility, movement (rolling/pitching) of the ship due to bad weather;
- Failure during the communication with the OOW and with other team members; and
- Disposal and efficiency of firefighting equipment.

The evaluation method for the calculation of the percentage of risk reduction is based on the results and the debriefing sessions among firefighting experts after performing the “Large-scale test on APVs fires” at Jovellanos Maritime Safety Training Centre (SASEMAR, Spain) during the 29th and 30th March 2022.

The impact on the percentage is calculated regarding any type of APVs (electric, hybrid, gas driven, etc.) but most of the techniques and equipment are applicable to traditional internal combustion engines vehicles as well. RCO4 is not applicable to other type of high-risk cargo like trucks or reefers, due to the height of these units requiring a different approach. For that reason, the performance of RCO4 is weighted with the contribution of fires from light vehicles in order to estimate the percentage of risk reduction:

Table 8. Percentage of fires from light vehicles among all fires originating from ro-ro spaces.

	% of fires from light vehicles		
	Ro-pax	Ro-ro cargo	Vehicle carriers
Closed	38%	60%	75%
Open	38%	60%	N/A
Weather	48%	63%	N/A

The impact on the risk model is:

- **Late decision:**

In the definition of conditions of the manual firefighting, it is assumed that manual firefighting will be deployed only if there is no other chance to put out the fire by first response or fixed fire-

extinguishing systems. That is why, RCO4 is considered to have the same performance whatever late decision following early or late detection.

Late assessment \ Lack of relevant information: RCO4 is proposing to define the conditions for manual firefighting with APVs and to raise the knowledge about the risks associated with this operation. The performance on this node will be estimated to be 30% for any light vehicle fires.

Late assessment \ Insufficient experience and competence: RCO4 is proposing specific training on APVs fires, reducing the risk of low experience and competence. The performance on this node will be estimated to be 35% for any light vehicle fires.

Late implementation: Late implementation will have an impact on the fire growth development. RCO4 is proposing to include APV fire training into drills and raise the awareness of APVs. The performance on this node will be estimated to be 16% for any light vehicle fires.

- **Failure of extinguishment:**

Manual extinguishment fail \ Failure by fire-fighting group \ Tactical failure: RCO4 is proposing to select the right firefighting technique (defensive/offensive). The strategies and tactics from RCO4 are deemed applicable to a large variety of fire sizes (up to loss of containment of ro-ro spaces), and therefore the performance on this node is deemed independent of the stage of decision-making (i.e. following early or late decision). It will be estimated to be 55% for any light vehicle fires.

Manual extinguishment fail \ Equipment failure: RCO4 is proposing to use new equipment (fog nail, boundary cooling device, smaller hoses, large fire blanket) that can face the new challenges with APVs. The equipment from RCO4 is deemed mostly applicable to fire from a limited number of involved vehicles, and therefore the performance on this node is deemed higher following by early decision than late decision. It will be estimated to be 45% for any light vehicle fires followed by early decision, and 20% followed by late decision.

6.4.5 Effectiveness of RCO5: Alarm system interface prototype

Main author of the chapter: Staffan Bram, RISE

6.4.5.1 Reliability

The possible failures may be:

Computer system malfunction – A malfunction in the computer running the DFC interface or in the DFC screen. This will force the crew to resort to traditional fire safety systems (e.g. alarm panel, safety system controls).

Estimation of reliability: 80% after 5 years.

References: Vujović, Igor; Čoko, Marin; Kuzmanić, Ivica, 2020. Reliability and Availability of Ship's Computer Systems Based on Manufacturer's Data and Worksheets. "Naše more" 67(3)/2020.

In-data malfunction – A malfunction in the signal system responsible for communication between existing systems and the DFC.

Maintenance error – Errors introduced by lacking or erroneous maintenance.

Erroneous user input – The threshold is lower e.g. for safety systems activation and other interactions than for traditional safety systems, creating a higher risk of erroneous inputs. Accidental input may also be more probable in a touch interface, e.g. due to ship movement. On the other hand, the consequences of such inputs to the DFC are deemed to be mild or easily reversible.

Overconfidence in smoke/heat visualization – Smoke/heat maps give the user a false sense of accuracy in areas between detectors. Prediction curves give a false sense of security around the possibility for manual interventions.

DFC not utilized as intended – Whether the full functionality of the DFC is utilized will depend on the fire safety organization, crew competence and user willingness.

6.4.5.2 *Impact on the risk model*

Assessments of failure probability reductions are based on observations made during DFC user testing (deliverable D07.6 “Alarm system interface prototype development and testing” [12]). These tests provide no statistical grounds for probability assessment, and because of that, the figures presented below are only estimations produced through WP07 expert discussions.

The Digital Fire Panel mainly affects the following nodes, which all relate to command-level decision-making during an onboard fire:

Node	Reduction of failure probability			
	Closed ro-ro space - Early detection	Closed ro-ro space - Late detection	Open ro-ro space	Weather deck
Late alarm interpretation \ Alarm is wrongly dismissed	Medium. Both smoke/heat detection and current data available but action will be governed by local conditions (e.g. prevalence of false alarms) (33%)	More salient indication when several detectors go off (heat/smoke maps etc.) (50%)	No difference	Some benefit since manual call point is shown in the DFC (10%)
Late alarm interpretation \ Delayed acknowledgment \ Delayed alarm handling \ Time lost on information integration	High. Test participants made no interpretation errors around the location of detection (80%)	DFC benefits are larger when information volume grows (90%)	No difference	No difference
Late alarm interpretation \ Delayed acknowledgment \ Delayed alarm handling \ Information misinterpreted	High. Same argument as above, possible error is e.g. mix-up between decks (70%)	DFC benefits are larger when information volume grows (80%)	No difference	DFC provides some aid e.g. position of manual call points (10%)
Late alarm interpretation \ Delayed acknowledgment \ Travel time on bridge	The probability was reduced to zero, given that all resources necessary for fire assessment and management on the bridge are brought together in shared or adjoining interfaces	No difference	No difference	No difference
Late confirmation \ Late manual confirmation \ Failure of communication	DFC interface provides more positional references to be used in communication (33%)	No difference	No difference	No difference

Node	Reduction of failure probability			
	Closed ro-ro space - Early detection	Closed ro-ro space - Late detection	Open ro-ro space	Weather deck
Late assessment \ Lack of relevant information	High. No information has been excluded from the DFC which is regarded as relevant for assessment (90%)	Higher benefit when more detections have occurred, e.g. timeline functionality / animations become relevant (95%)	No difference	No difference
Late assessment \ Information is not made readily available	Medium. User interaction required to display relevant information (67%)	No difference	No difference	E.g. cargo information, GA still provides some help (10%)
Manual extinguishment fail \ Failure by firefighting group \ Tactical failure	33%	No difference	No difference	No difference

The RCO5 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.

6.4.6 Effectiveness of RCO6: Process for development of procedures and design for efficient activation of extinguishing system

Main author of the chapter: Torgeir K. Haavik, NSR

6.4.6.1 Reliability

The RCO does not lend itself to evaluation of probability of total failure, since the mere adoption of the RCO implies that it works. It does not necessarily work well, though. The effect of the RCO depends on the commitment to the principles of reflective practice that are at the core of the process, and the outcome of the process depends on the quality (commitment) with which it is performed, i.e. the willingness to scrutinize own practices with the ambition of changing them when necessary.

On a side note, it could be considered as a failure if needs for e.g. a design change is identified and communicated to management, and management are not willing to make the investment. The probability for this is not possible to assume on a general basis.

6.4.6.2 Impact on the risk model

The evaluation method is based on NSR and NTNU expert judgment in collaboration with user input during solution test/demonstration on board ro-ro vessels.

- **Late decision:**

Late alarm interpretation \ Delayed acknowledgment \ Delayed alarm handling \ Alarm is missed:

Failure to detect the fire alarm on the bridge relates to work processes and routines, which is

scrutinized and made subject to improvement through RCO6. As there is low frequency of not detecting alarm on bridge and this phenomenon is likely not to be enacted during solution adoption, there is reason to believe that RCO6 will contribute to not more than 10% risk reduction on all three ro-ro ship types.

Late alarm interpretation \ Delayed acknowledgment \ Delayed alarm handling \ Time lost on information integration: Information integration relates to work processes and routines, which is scrutinized and made subject to improvement through RCO6. RCO6 is expected to have an impact of 30% risk reduction on all three ro-ro ship types.

Late alarm interpretation \ Delayed acknowledgment \ Delayed alarm handling \ Information misinterpreted: Information interpretation relates to work processes and routines, but also to design of instructions posters such as activation instructions for drencher and CO₂ systems. This is scrutinized and made subject to improvement through RCO6. RCO6 is expected to have an impact of 20% risk reduction on all three ro-ro ship types.

Late alarm interpretation \ Delayed acknowledgment \ Travel time on bridge: This relates to the level of information integration in fire management systems (e.g. digital fire central), reducing the need for moving between different interfaces in order to gather information. Identified needs for technological and design related changes may result in improved information management (given that there is willingness to invest the necessary resources). RCO6 is expected to have an impact of 10% risk reduction on all three ro-ro ship types.

Late confirmation \ Late technical confirmation: Late technical confirmation relates to e.g. the presence of well-functioning CCTV, which may reduce the dependence on runners, and they travel time for confirmation and localization. A more robust CCTV system that could result from RCO6 is estimated to have an impact of 20% risk reduction on all three ro-ro ship types.

Late confirmation \ Late manual confirmation \ Failure of communication: In connection with manual confirmation, communication between e.g. the runner and the bridge might be subject to improvement through RCO6. This could relate to clarity of radio communication style, and the use of unambiguous terms for referring to locations. Improved communication resulting from RCO6 is estimated to have an impact of 10% risk reduction on all three ro-ro ship types through reduces risk of misunderstanding, and less loss of time.

Late assessment \ Lack of relevant information and Late assessment \ Information is not made readily available: This relates to similar issues as – and a combination of **Time lost on information integration, Information misinterpreted, and Travel time on bridge**, reviewed above. In addition, this item actualizes the possibility of integrating information on e.g. dangerous goods into a digital fire central – or making it more accessible by other means – which could save time in the early decision making phase. RCO6 is expected to have an impact of 20% risk reduction on all three ro-ro ship types for this node.

Late assessment \ Insufficient experience and competence: RCO6 is a learning process with the aim of producing lasting changes of practices. The magnitude of risk reduction depends on the experience and competence base before adoption of the solution and is hence difficult to predict. The best assumption would be that, as an average, RCO6 will have an impact of 30% risk reduction on all three ro-ro ship types when it comes to experience and competence.

Late implementation: History shows that ambiguously designed/written instructions material for activation of fixed extinguishing systems can result in significant delays. RCO6 explicitly addresses the

adequacy of these instruction materials. RCO6 is expected to have an impact of 40% risk reduction on all three ro-ro ship types for this node.

6.4.7 Effectiveness of RCO7: Training module for efficient activation of extinguishing system

Main author of the chapter: Jaime Bleye Vicario, SAS

The evaluation method carried out is based on expert judgement from the Maritime Safety Training Centre experience.

RCO7 is expected to have an impact on the decision-making fault tree and especially on the assessment and implementation steps.

- **Late decision:**

Information is not made available readily: There are several examples of situations where the design and interfaces or equipment have introduced delays in activation of extinguishing systems. Like insufficient or obstructed section markings provoking a kind of trial-and-error in drencher activation, illogical ship layout drawings in the system room activation. As a direct consequence, RCO7 will improve the on-board communication and procedure; there will be better feedback from the on-site (e.g. drencher valve room) to the bridge. Therefore, there will be more and better quality information available for the bridge. RCO7 is expected to have an impact of 60% on risk reduction in ro-ro passenger and ro-ro cargo ships and slightly higher impact (75%) in vehicle carriers (noting that training on activation of CO₂ systems cannot be performed on board).

Insufficient experience and competence: Fire on board is a nightmare for any seafarer, fortunately the incidence of real fires is kept very low. Precisely, that is the reason why relevant personnel will not know how to act in case of fire. Realistic training shall empower the crew on board to reflect under different situations available at the time of a real fire alarm, while making sure that their actions are supported by sufficient competence in the activation of the right extinguishing system on the right location and circumstances. Training on the activation of fixed extinguishing systems is believed to have an impact on the level and distribution of competence among the crew, thus decreasing the probability of “insufficient experience and competence” of 40% in ro-ro passenger and ro-ro cargo ships and slightly higher impact (60%) in vehicle carriers (noting that training on activation of CO₂ systems cannot be performed on board).

Late implementation: There are certain operative conditions such as during the night or bad weather that will affect the performance and the implementation of measures to respond to a fire emergency. Training that includes communicative practices covering realistic communication between the bridge and personnel on deck was believed to reduce the risk of “late implementation” by 25% in ro-ro passenger and ro-ro cargo ships and slightly higher risk reduction (45%) in vehicle carriers (noting that training on activation of CO₂ systems cannot be performed on board).

6.4.8 Effectiveness of RCO8: Safe electrical connection for reefers

Main author of the chapter: Vasudev Ramachandra, RISE

6.4.8.1 Reliability

Failure to recognize, or in some cases predict, an electrical anomaly can be considered a failure of the solution. However, the term “electrical anomaly” can be a canopy term for all electrical related faults in the reefers, in the ship side infrastructure or the connection between the two. While detection of the latter two is certainly a part of the solution, the first is harder to define and hence harder to define its reliability. This is because of the nature of certain electrical faults that might take place in the reefer units that are not connected to the refrigeration system and hence cannot be monitored

by the solution. These might include faulty wiring in the cabins of the units, retrofit/homemade components installed in the units, etc.

The failure of the system is primarily dependent on the measurement and detection of system insulation among other things. This is dependent on a threshold that is manually set, and it must be based on a trial-and-error basis. This data is not available yet but will be as soon as the test bed is set up. There are also no logs or records of these electrical parameters for reefer units on current vessels which makes estimation of reliability hard.

However, theoretically the hardware components have a long shelf life and are designed for marine use. Failures might occur during extreme conditions like a total blackout on the ship which is highly unlikely but still a possibility. As far as measurements and monitoring are concerned, they are trivial functions for the solution and an evaluation does not indicate failures under standard operating conditions. The reliability of RCO8 can be estimated as over 95% once fully tuned (tuneable parameters of the solutions are those that can only be decided after practical tests based on various operational conditions).

6.4.8.2 *Impact on the risk model*

The affected nodes are:

- **Ignition:**

Ship cargo \ Cargo unit \ T°C-controlled cargo unit \ Electrical \ Connection:

- Evaluation method – Expert judgement and demonstrator measurements (by early 2023)
- Quantitative evidence – 90%
- Limitations – Localized heating not measured or detected as increase in temperature

- **Late decision:**

Late decision to respond \ Late confirmation \ Late localization \ Inadequate strategy: In case of reefer fires due to faults of the electrical connection, RCO8 allows to better localize the fire origin.

- Evaluation method – Demonstrator measurements
- Quantitative evidence – Probability of reefer fires due to faults of the electrical connection \times 85% (performance for this node)
- Limitations – Broken hardware or malfunctions can be a problem although it is easy to identify and replace

- **Failure of extinguishment:**

Fixed system fail \ Design incapacity \ Fixed system: In case of reefer fires due to faults of the electrical connection, RCO8 allows to better localize the fire origin, reducing the risk of activating the wrong drencher zone. The risk reduction for this node is estimated as the probability of reefer fires due to faults of the electrical connection \times 85% (performance for this node).

Manual extinguishment fail \ Failure by firefighting group \ Tactical failure: In case of fires, the disconnection of electrical connections is deemed to be a good practice. RCO8 provides an additional source of information about active or inactive electrical connections and allows to remotely disconnect electrical connections, which facilitates the activities of manual firefighting. The risk reduction for this node is estimated as the probability of reefer fires due to faults of the electrical connection \times 10% (performance for this node).

6.4.9 Effectiveness of RCO9: Safe electrical connection of reefers and electric vehicles (EVs)

Main author of the chapter: Vasudev Ramachandra, RISE

6.4.9.1 Reliability

Failure to recognize, or in some cases predict, an electrical anomaly can be considered a failure of the solution. However, the term “electrical anomaly” can be a canopy term for all electrical related faults in the EVs being charged, in the ship side infrastructure or the charging unit that connects the two. Historically there are no logs or records of data for EV charging on board which makes on board measurements vital to ascertain the reliability of the solution.

By expert judgement, the following evaluation can be made. The hardware components have a long shelf life and are designed for marine use. Failures might occur during extreme conditions like a total blackout on the ship which is highly unlikely but still a possibility. As far as measurements and monitoring are concerned, they are trivial functions for the solution and an evaluation does not indicate failures under standard operating conditions. The reliability of RCO9 can be estimated as over 90% once fully tuned (tunable parameters of the solutions are those that can only be decided after practical tests based on various operational conditions).

6.4.9.2 Impact on the risk model

The affected nodes are:

- **Ignition:**

Ship cargo \ APV \ EV \ Electrical \ Connection:

- Evaluation method – Expert judgement and demonstrator measurements (by early 2023)
- Quantitative evidence – 90%
- Limitations – Localized heating not measured or detected as increase in temperature

Ship cargo \ Cargo unit \ T°C-controlled cargo unit \ Electrical \ Connection:

- Evaluation method – Expert judgement and demonstrator measurements (by early 2023)
- Quantitative evidence – 90%
- Limitations – Localized heating not measured or detected as increase in temperature

- **Late decision:**

Late decision to respond \ Late confirmation \ Late localization \ Inadequate strategy: In case of reefer and electric vehicle fires due to faults of the electrical connection, RCO9 allows to better localize the fire origin.

- Evaluation method – Demonstrator measurements
- Quantitative evidence – Probability of reefer and electric vehicle fires due to faults of the electrical connection × 85% (performance for this node)
- Limitations – Broken hardware or malfunctions can be a problem although it is easy to identify and replace

- **Failure of extinguishment:**

Fixed system fail \ Design incapacity \ Fixed system: In case of reefer and electrical vehicle fires due to faults of the electrical connection, RCO8 allows to better localize the fire origin, reducing the risk of activating the wrong drencher zone. The risk reduction for this node is estimated as the probability of reefer and electric vehicle fires due to faults of the electrical connection × 85% (performance for this node).

Manual extinguishment fail \ Failure by firefighting group \ Tactical failure: In case of fires, the disconnection of electrical connections is deemed to be a good practice. RCO8 provides an additional source of information about active or inactive electrical connection and allows to remotely disconnect electrical connections, which facilitate the activities of manual firefighting. The risk reduction for this node is estimated as the probability of reefer and electric vehicle fires due to faults of the electrical connection $\times 10\%$ (performance for this node).

6.4.10 Effectiveness of RCO10: Fire detection on weather decks

Main author of the chapter: Davood Zeinali, FRN

6.4.10.1 Reliability

Considering their technical functionality, thermal imaging cameras and flame detectors are highly reliable as indicated by their extensive applications and experimental investigations [13], [14] and [15]. The probability of a technical failure is thus very low. For thermal cameras, the probability is taken to be 0.3% as in the study of FIRESAFE II [15]. The flame detectors are expected to offer at least the same level of reliability as thermal cameras, since they work based on the same technology but with simpler equipment.

Considering external factors relating to the weather such as snow, rain and wind, the evaluations on board Hollandia Seaways since March 2022 suggest that the devices have retained their functionality. The detectors can additionally be supplied with extra built-in options for fault and window cleanliness detection, and window heater to avoid condensation and icing. Moreover, windy conditions were found favourable for flame detectors in some previous fire experiments [13] and [14].

6.4.10.2 Impact on the risk model

The impacts on the risk model are described below. It is assumed that RCO10 performs the same way on ro-ro passenger ships and ro-ro cargo ships.

- **Late detection:**

Detection systems are not required for weather decks as per the current regulations. Probabilities of failure are provided for every affected node below **System detection failure**.

System detection failure \ Internal failure \ Manual deactivation for operational purpose \ Individual detector and **System detection failure \ Internal failure \ Manual deactivation for operational purpose \ System:** The same probability of failure as provided for closed and open ro-ro spaces was provided.

System detection failure \ Internal failure \ Technical failure \ Individual detector: The probability of technical failure is very small. For thermal cameras, the probability of failure for an individual detector is taken to be 0.1% as in the study of FIRESAFE II [15]. The flame detectors are expected to offer at least the same level of reliability as thermal cameras, since they work based on the same technology but with simpler equipment.

System detection failure \ Internal failure \ Technical failure \ System: The probability of technical failure is very small. For thermal cameras, the probability of failure of the system is taken to be 0.3% as in the study of FIRESAFE II [15]. The flame detectors are expected to offer at least the same level of reliability as thermal cameras, since they work based on the same technology but with simpler equipment.

System detection failure \ Internal failure \ Contamination/damage \ Individual detector: There is a small probability of failure due to contamination or damage. For thermal cameras, the probability for individual detector failure is taken to be 1.1% as in the study of FIRESAFE II [15]. Flame detectors are expected to offer a similar level of probability of failure.

System detection failure \ Internal failure \ Contamination/damage \ System: There is a small probability of failure due to contamination or damage. For thermal cameras, the probability for system failure is taken to be 0.6% as in the study of FIRESAFE II [15]. Flame detectors are expected to offer a similar level of probability of failure.

System detection failure \ External cause \ Poor detector positioning \ Poor location: The probability of failure due to poor location is very small. For thermal cameras, the chance is taken to be 0.3% as in the study of FIRESAFE II [15]. Flame detectors are expected to offer a similar level of probability of failure.

System detection failure \ External cause \ Poor detector positioning \ Poor spacing: The probability of failure due to poor spacing is very small. For thermal cameras, the chance is taken to be 0.1% as in the study of FIRESAFE II [15]. Flame detectors are expected to offer a similar level of probability of failure.

System detection failure \ External cause \ Type of fire \ Smouldering fire (no flame): Any detection system based on heat (radiative or convective) will be too slow to respond in the case of smouldering fires. This includes flame detectors but also thermal cameras (unless the cameras can see the smouldering source when it is hot enough to be detected). The probability of failure due to fires with no flame is deemed to be equal to probability of fire with no flame (conservatively, deemed equal to probability of fires from "other cargo unit") \times [100% - 5% (efficiency of flame detectors or thermal cameras against such fires)].

System detection failure \ External cause \ Type of fire \ Too rapid fire: Thermal cameras and flame detectors can easily detect rapidly growing fires on the weather deck. In the case of open flames, detection times in the order of milliseconds are achievable using flame detectors (used for monitoring explosions and fireballs [16]). The probability of failure due to too rapid fire is estimated to 2%.

System detection failure \ External cause \ Fire position \ Inside cargo / vehicle: Flame detectors and thermal cameras cannot easily detect fires growing inside cargo vehicles, unless they have clear line of sight to flames or hot areas on the car. The probability of failure due to fires located inside cargo / vehicle is deemed to be equal to 19% (probability of fires inside cargo / vehicle [15]) \times [100% - 10% (efficiency of flame detectors or thermal cameras against such fires)] = 17.1%.

System detection failure \ External cause \ Fire position \ Cargo between fire and detector: Flame detectors and thermal cameras cannot detect fires behind cargo vehicles, unless through reflection on shiny surfaces. The probability of failure due to cargo between fire and detector is deemed to be equal to 10% (probability of having a fire hidden by a cargo; 90% coverage) \times [1 - 98% (efficiency of flame detectors or thermal cameras against such fires)] = 9.8%.

System detection failure \ External cause \ Weather conditions: Both flame detectors and thermal cameras can detect flames regardless of any cooling effects from rain or wind. However, if the flame is not visible and only a heated surface must be detected, then only thermal cameras can be used. For thermal cameras, the probability of failure due to weather conditions is taken to be 1% as in the

study of FIRESAFE II [15]. Flame detectors are expected to offer a similar level of probability of failure.

- **Late decision:**

Detection systems are not required for weather decks as per the current regulations. Probabilities of failure are provided for every affected node below **Late alarm interpretation**, **Late technical confirmation** and **Late arrival at detector point**. In general, the probability of failure for each late detection scenario is assumed to be twice that of the corresponding early detection scenario.

Late alarm interpretation \ Alarm is wrongly dismissed: Automatic alarms are more likely to be missed than manually raised alarms (which is currently how alarms are raised for weather decks). The use of flame detectors that are largely immune to false alarms can reduce the probability of the system getting muted by the crew due to nuisance alarms. The probability of failure is estimated to 1% following early detection and 0.1% following late detection.

Late alarm interpretation \ Delayed acknowledgment \ Delayed alarm handling \ Alarm is missed: The same probability of failure as provided for detection systems installed in closed and open ro-ro spaces was used. Failure of attention is considered to be independent of the systems.

Late alarm interpretation \ Delayed acknowledgment \ Delayed alarm handling \ Time lost on information integration: The current regulations still do not require an automatic fire detection system on weather decks. Therefore, the alarm information needs to be conveyed from the person raising the alarm to the other persons who need to take necessary actions by integrating the information. If an automatic detection system is installed, thermal cameras provide a visual heat map of the hot spots which is expected to make it easier to locate the fire and to convey the necessary information to the people taking actions. Flame detectors, however, cannot provide this information the same way, unless the detection system is integrated with video analytics that can highlight the flame location on video. The probability of failure is estimated to 2% following early detection and 4% following late detection.

Late alarm interpretation \ Delayed acknowledgment \ Delayed alarm handling \ Information misinterpreted: As the current regulations still do not require an automatic fire detection system on weather decks, the alarms are raised only manually. As such, alarms of weather decks are expected to be interpreted easily. If an automatic detection system is installed, thermal cameras provide a visual heat map of the hot spots which is expected to be easy to understand, and this has the potential to reduce the probability of misinterpreting a true alarm, unless the system has been deactivated due to high sensitivity and frequent false alarms in certain situations. Moreover, flame detectors only raise an alarm if they see a visible flame, and this is not expected to be misinterpreted easily. The probability of failure is estimated to 1.3% following early detection and 2.7% following late detection.

Late alarm interpretation \ Delayed acknowledgment \ Travel time on bridge: The same probability of failure as provided for detection systems installed in closed and open ro-ro spaces was used.

Late confirmation \ Late technical confirmation: The same probability of failure as provided for detection systems installed in closed and open ro-ro spaces was used.

Late confirmation \ Late manual confirmation \ Late arrival at detector point \ Late deployment of runner: The same probability of failure as provided for detection systems installed in closed and open ro-ro spaces was used.

Late confirmation \ Late manual confirmation \ Late arrival at detector point \ Long travel time to detection point: The same probability of failure as provided for detection systems installed in closed and open ro-ro spaces was used.

Late assessment \ Information is not made readily available: Thermal cameras and flame detectors on weather decks can significantly speed up the process of making the necessary information available. A risk reduction of 66% was estimated.

- **Failure of extinguishment:**

Manual extinguishment fail \ Failure by fire-fighting group \ Tactical failure: Thermal imaging detection can help identify the hot locations which need attention. Flame detectors, however, cannot provide coordinates for tactical considerations, unless the detection system is integrated with video analytics that can highlight the flame location on video. A risk reduction of 10% was estimated but only following early decision, otherwise 0% following late decision.

6.4.11 Effectiveness of RCO11: Alternative fire detection in closed ro-ro spaces & open ro-ro spaces

Main author of the chapter: Davood Zeinali, FRN

6.4.11.1 Reliability

The reliable functioning of resettable linear heat detection systems is tested against EN 54-22 [17]. The only known failure for such systems is from sensor cable damages in cases where the cable is strongly hit or pulled by moving machinery or equipment, although this is rare as sensor cables are highly durable and are installed in places further away from regular activities, i.e. on the ceiling in the ro-ro space. Moreover, only a short amount of new cable is needed to reconnect a broken part of the sensor cable, and such a repair can easily be done in half an hour. Furthermore, the linear systems continuously monitor the faults in the sensor cables and will generate a fault alarm if a break happens in the cable.

Redundancy design is another safety factor that can be achieved using a linear system, such that the system can continue its functionality even if one sensor cable is damaged completely at a certain spot. In the case of fibre optic linear heat detection systems, detection redundancy can be considered both at the level of sensor cable and at the level of acquisition system, i.e. Distributed Temperature Sensing (DTS) instrument. For the sensor cable, it is possible to have either double-ended or single-ended measurement setups. In a double-ended configuration, a DTS channel is used to make measurements from both ends of the cable. This means that light is sent alternately from both ends into the fibre optic cable. This way, the system maintains its full functionality even if the cable is damaged at any single spot. The minimum detection time with this configuration is 40 s. In a single-ended setup, a DTS instrument with two channels is used to make measurements from only one end of the cable (up to a point where the cable is undamaged). Therefore, for a fully redundant design with a single-ended setup, two DTS channels are needed to make separate measurements from either end of the cable. If these two DTS channels are provided by the same DTS instrument, the system relies on this instrument for its functionality and has a minimum detection time of 30 s. If the two DTS channels are provided by two separate DTS instruments, the minimum detection time will be 20 s and the system relies less on each given DTS instrument for its functionality. In addition, it is noteworthy that each standard sensor cable carries two fibre optic cables inside, offering “cable redundancy”, although it is normally expected that both these inner cables are likely to be damaged at the same time in cases where the cable is damaged by a strong force.

6.4.11.2 *Impact on the risk model*

In the first series of laboratory experiments, the linear detectors were able to detect all the smallest of ethanol fires, while none of the point smoke/heat/gas detectors detected these fires. The fastest response was obtained by the rate-of-rise criterion with 6°C over 120 seconds in line with the experimental observations in FIRESAFE II [15]. This enables the linear system to trigger an alarm more efficiently than the conventional system, especially for open ro-ro spaces where the point detectors have a smaller probability of detection because of wind and ventilation effects.

The impacts on the risk model affected are described below. It is assumed that RCO11 performs the same way on ro-ro passenger ships, ro-ro cargo ships and vehicle carriers and the risk reduction of late decision is the same following early or late detection.

- **Late detection:**

System detection failure \ Internal failure \ Manual deactivation for operational purpose \ Individual detector and System detection failure \ Internal failure \ Manual deactivation for operational purpose \ System: 65% risk reduction potential according to expert judgment. For most operational purposes, the system of linear heat detection can remain active because it is not very sensitive to normal activities such as cargo loading.

System detection failure \ Internal failure \ Technical failure \ Individual detector: 65% risk reduction potential according to expert judgment. The cables are robust, and no common cause of failure is known. Moreover, a looped system (redundancy design) will allow continued functioning from both ends of a damaged spot.

System detection failure \ Internal failure \ Technical failure \ System: 65% risk reduction potential according to expert judgment. The system constantly monitors and detects technical failures. Moreover, a looped system (redundancy design) will allow continued functioning from both ends of a damaged spot.

System detection failure \ Internal failure \ Contamination/damage \ Individual detector and System detection failure \ Internal failure \ Contamination/damage \ System: 65% risk reduction potential according to expert judgment. Ordinary external contamination will not affect the internal functioning of the sensing cable of the linear detection system.

System detection failure \ External cause \ Poor detector positioning \ Poor location and System detection failure \ External cause \ Poor detector positioning \ Poor spacing: 33% risk reduction potential according to expert judgment. The fibre optic linear system offers continuous measurements along the cable, but there will be space in the direction perpendicular to the cable, such that multiple cable lines must be used adequately to cover the beam compartments along the ceiling.

System detection failure \ External cause \ Type of fire \ Small amount of soot: 66% risk reduction potential according to expert judgment. Linear systems do not require soot for detection. Nevertheless, detection would still depend on the fire location with respect to the nearest cable, wind conditions, etc.

System detection failure \ External cause \ Type of fire \ Too rapid fire: 5% (closed ro-ro spaces) and 10% (open ro-ro spaces) risk reduction potential according to expert judgment. In a closed ro-ro space, it is likely that most rapidly developing fires will be detected reasonably using the conventional smoke/heat detection systems, while only a very limited number of scenarios will be detected faster using the linear heat detection systems via the rate-of-rise criterion or extra vicinity

to the heat source. In an open ro-ro space, windy conditions make it extra difficult to detect the fires using the conventional smoke/heat detection systems, but the linear heat detection system likely has the advantage of being closer to the heat source, thereby shortening the time for detection.

System detection failure \ External cause \ Fire position \ Inside cargo/vehicle: 1% (closed ro-ro spaces) and 2% (open ro-ro spaces) risk reduction potential according to expert judgment. Fires starting inside cargo are challenging to detect. If there is any detection at all, it is expected that the smoke is detected earlier than heat in closed ro-ro spaces. Correspondingly, the risk reduction potential of the linear system is only slightly higher in the case of an open ro-ro space.

System detection failure \ External cause \ Fire position \ Close to vent: 12% (closed ro-ro spaces) and 33% (open ro-ro spaces) risk reduction potential according to expert judgment. According to the experiments conducted during FIRESAFE II [15], fires close to the vents are more difficult to detect using conventional detectors. In a closed ro-ro space, a linear system can reasonably enhance the detection probability and shorten the time of detection. In an open ro-ro space where wind conditions affect the point detectors the most, the use of a linear system can more strongly enhance the detection probability and shorten the time of detection.

System detection failure \ External cause \ High airflow: 24% (closed ro-ro spaces) and 66% (open ro-ro spaces) risk reduction potential according to expert judgment. A high flow, e.g. due to mechanical ventilation or high cargo heights, can hinder the detection of smoke using point detectors inside ceiling compartments. The linear system is expected to be less affected by this because it relies on heat rather than smoke. However, higher rates of outflow will result in faster cooling in a closed ro-ro space scenario. Moreover, when the ro-ro space is open, the higher rates of outflow are not expected to change the cooling rate very much (as the open ro-ro space already offers plenty of ventilation to begin with). Accordingly, the risk reduction potential of the linear system in a closed ro-ro space is expected to be lower than that in an open ro-ro space.

- **Late decision:**

Late alarm interpretation \ Alarm is wrongly dismissed: 65% risk reduction potential according to expert judgment. The system of linear heat detection is not very sensitive to normal activities such as cargo loading, and it produces alarms only in cases of significant heat accumulation along the ceiling. This is expected to lower the chance that the system is muted when needed, such that the alarm from this system is not wrongly dismissed easily.

Late alarm interpretation \ Delayed acknowledgment \ Delayed alarm handling \ Alarm is missed: 65% risk reduction potential according to expert judgment. A linear detection system provides a visual heat map of the hot spots which is expected to be easy to understand, and this has the potential to reduce the probability of missing an alarm.

Late alarm interpretation \ Delayed acknowledgment \ Delayed alarm handling \ Time lost on information integration: 33% risk reduction potential according to expert judgment. A linear detection system provides a visual heat map of the hot spots, and this is expected to enhance information integration.

Late alarm interpretation \ Delayed acknowledgment \ Delayed alarm handling \ Information misinterpreted: 33% risk reduction potential according to expert judgment. A linear detection system provides a visual heat map of the hot spots which is expected to be easy to understand, and this has the potential to reduce the probability of misinterpreting the alarm.

Late assessment \ Lack of relevant information: 66% risk reduction potential according to expert judgment. A linear detection system provides and records a visual heat map that contains all the relevant temperature information for monitoring the development of the situation.

6.4.12 Effectiveness of RCO12: Visual system for fire confirmation and localization

Main author of the chapter: Davood Zeinali, FRN

6.4.12.1 Reliability

Considering their technical functionality, CCTV and thermal imaging cameras are highly reliable as indicated by their extensive applications and experimental investigations [13], [14] and [15]. The chance of a technical failure is thus very low. For thermal cameras, the chance is taken to be 0.3% as in the study of FIRESAFE II [15]. The CCTVs are expected to offer even better reliability, since they work based on simpler technology.

Considering external factors relating to the weather such as snow, rain, and wind, the evaluations on board Hollandia Seaways since March 2022 suggest that the devices have retained their functionality. The detectors can additionally be supplied with extra built-in options for fault and window cleanliness detection, and window heater to avoid condensation and icing.

6.4.12.2 Impact on the risk model

The impacts on the risk model affected are described below. It is assumed that RCO12 performs the same way on ro-ro passenger ships, ro-ro cargo ships and vehicle carriers and the risk reduction of late decision is the same following early or late detection.

- **Late decision:**

Late confirmation \ Late technical confirmation: 80% risk reduction potential according to expert judgment. A visual system of fire confirmation can strongly reduce the time required for technical confirmation. The efficiency of confirmation depends partly on the sensitivity settings and coverage quality of the cameras and partly on the simplicity of the addressing system for all the installed cameras.

Late confirmation \ Late manual confirmation \ Late localization \ Inadequate strategy: 50% risk reduction potential according to expert judgment. A visual system of fire localization can significantly reduce the time required for finding the fire and thus implementing an adequate strategy. The efficiency of localization depends partly on the coverage quality of the cameras and partly on the simplicity of the addressing system for all the installed cameras.

Late assessment \ Information is not made available readily: 50% risk reduction potential according to expert judgment. A visual system of fire confirmation can readily provide information for the assessment of a fire situation. The speed and efficiency of the system depends partly on the sensitivity settings and coverage quality of the cameras and partly on the simplicity of the addressing system for all the installed cameras.

Late assessment \ Late implementation: 66% risk reduction potential according to expert judgment. A visual fire confirmation system is expected to be very easy to understand, and this can greatly reduce the time required for the necessary implementations.

6.4.13 Effectiveness of RCO13: Dry-pipe sprinkler system for vehicle carriers

Main author of the chapter: Magnus Arvidson & Stina Andersson, RISE

6.4.13.1 Reliability

There are many studies on the overall performance of automatic sprinkler systems. Reference here is made to a recent study by the National Fire Protection Association (NFPA) that is based on data from the National Fire Incident Reporting System (NFIRS) in USA during the period 2015 - 2019 [18]. The **overall performance** of a sprinkler system in the reference is described as:

Percent where equipment operated effectively (A × B) = percent where equipment operated (A) × percent effective of those that operated (B).

The factor 'A' relies on issues like the quality of the system components, the design and installation of the system (any redundancy), means for supervision and the quality and frequency of inspection, testing and maintenance. Typical failures modes are that a system valve intended to be open is closed or that a sprinkler fails to operate.

The factor 'B' relies on issues like proper design for the specific fire hazard in terms of design densities and area of operation, correct location of sprinklers, etc. Typical failures modes are that water from a sprinkler is not reaching to the seat of the fire or that the system design has not been revised to match a change of the occupancy hazard classification.

Table 9 shows reliability data for dry pipe sprinkler systems from the analysis by NFPA [18], where factor A and B, respectively, is given for different occupancies.

Table 9. Sprinkler reliability for dry pipe sprinkler systems according to the analysis by NFPA [18].

Table 6. Sprinkler Reliability and Effectiveness When Fire Was Coded as Not Confined, Was Large Enough to Activate Sprinkler, and Sprinkler Was Present in Area of Fire by Property Use: 2015–2019 Annual Averages, (Continued)

C. Dry Pipe Sprinkler Systems Only

Property Use	Number of fires per year where sprinklers were present	Non-confined fires too small to activate or unclassified operation	Fires coded as confined fires	Number of qualifying fires per year	Percent where equipment operated (A)	Percent effective of those that operated (B)	Percent where equipment operated effectively (A x B)
All residential	2,770	230	2,280	260	91%	97%	89%
Homes	2,130	160	1,770	190	92%	98%	90%
Store or office	380	100	190	90	83%	94%	78%
Manufacturing facility	370	100	110	160	89%	93%	83%
All storage	180	30	70	80	79%	94%	74%
All structures*	5,040	690	3,540	800	87%	94%	82%

From this data, it is concluded that dry pipe systems operated in between 74% to 90% of all reported fires large enough to activate sprinklers (Factor 'A'). From a fire hazard perspective, it is likely that the occupancies "Manufacturing facility" and "All storage" resembles most of the fire hazards present on vehicle carriers.

The most common reason that sprinklers failed to operate was the system being shut-off at some point before the fire, refer to Table 10. For dry pipe systems, the system was shut-off in 64% of all fires. The second most common causes were lack of maintenance (12%) and that system components were damaged (12%).

Table 10. Reasons for sprinkler failure or ineffectiveness in structure fires large enough to activate sprinklers in the area and the reason why operating sprinklers were ineffective according to the analysis by NFPA [18].

Table 8. Reasons for Sprinkler Failure or Ineffectiveness in Structure Fires Large Enough to Activate Sprinkler Present in Fire Area (Excluding Fires with Confined Structure Fire Incident Types and Fires in Properties Under Construction): 2015–2019 Annual Averages

A. Reason Sprinkler Failed to Operate

Reason	All sprinklers	Wet pipe	Dry pipe
System shut off	430 (57%)	340 (56%)	70 (64%)
Manual intervention defeated system	130 (18%)	120 (20%)	10 (8%)
Lack of maintenance	70 (10%)	60 (9%)	10 (12%)
System components damaged	70 (9%)	50 (9%)	10 (12%)
Inappropriate system for type of fire	40 (6%)	40 (6%)	0 (4%)
Total	750 (100%)	610 (100%)	100 (100%)

B. Reason Operating Sprinkler Was Ineffective

Reason	All sprinklers	Wet pipe	Dry pipe
Water did not reach the fire	170 (50%)	140 (53%)	10 (36%)
Not enough water released	100 (31%)	70 (27%)	20 (50%)
Inappropriate system for type of fire	20 (7%)	20 (8%)	0 (3%)
System components damaged	20 (7%)	20 (8%)	0 (3%)
Lack of maintenance	10 (3%)	0 (1%)	0 (7%)
Manual intervention defeated system	10 (2%)	10 (3%)	0 (0%)
Total	340 (100%)	270 (100%)	40 (100%)

The primary reason (50% of the fires) why dry pipe sprinkler systems were ineffective (Factor 'B') was because not enough water was released, refer to Table 10. This could be understood that the actual system design was not sufficient for the fire hazard. The second most common cause was that water did not reach the fire (36%).

A study by FM Global [19] concludes that approximately 87%, by number, of all risk losses (excluding natural catastrophe) are below deductible. Based on the percentage of losses reported to FM Global that are below deductible, it is estimated that 83% of all losses are unreported. If it is assumed that 1) this unreported percentage holds for all loss subsets, i.e. fire losses in sprinklered buildings, 2) all of these unreported fires are 'successes' (activated sprinklers that were effective) and 3) the ratio of unreported information in FM Global data is comparable to the ratio of the NFIRS unreported, then the calculated activated and effective of 90% reported previously concluded [20] from data from NFIRS can be adjusted to a 98% overall performance of a sprinkler system. This number is reasonably consistent with statistics [21] from Australia and New Zealand (overall performance in excess of 99%), the most regulated and consistent data in the world.

One sprinkler is usually enough to control a fire according to the analysis by NFPA, refer to Table 11.

Table 11. The number of sprinklers that operated in structure fires by the type of sprinkler system according to the analysis by NFPA [18].

Table 7. Number of Sprinklers That Operated in Structure Fires by Type of Sprinkler System (Excluding Properties Under Construction): 2015–2019 Annual Averages

Number of Sprinklers Operating	Percentage of structure fires where that many sprinklers operated		
	Wet Pipe	Dry Pipe	All Sprinklers (Including “other”)
1	80%	47%	77%
1 or 2	91%	63%	89%
1 to 3	94%	71%	92%
1 to 4	96%	83%	95%
1 to 5	97%	90%	97%
1 to 10	99%	99%	99%

In 47% of the structure fires where sprinklers operated, only one operated in dry pipe sprinkler systems. In 90%, five or fewer sprinklers operated and in 99%, 10 or fewer sprinklers operated. As previously mentioned, the system design area for RCO13 will contain about twelve to fifteen sprinklers, all dependent on the specific coverage area of a sprinkler, that will vary from installation to installation. Based on the statistics by the analysis NFPA, this number of sprinklers in the design seems sufficient.

6.4.13.2 Impact on the risk model

Direct application of the system reliability and effectiveness figures discussed above for RCO13 is uncertain, but the figures can serve as an indication and a basis for discussion. For a dry pipe sprinkler system on a vehicle carrier, it seems unlikely that sprinkler system water supply failure would occur to the extent concluded by NFPA, i.e. in almost two thirds (64%) of all fires. All dry pipe valves should be supervised, the water pump tested regularly, and water should be present in the freshwater tanks as it is used for multiple purposes. It does also seem unlikely that the design of the system would be insufficient in as many as half (50%) of all fires.

Therefore, the judgment here is that a dry pipe system for vehicles carriers (RCO13) would operate in 95% of all fires and that the system would be effective in 95% of these fires. This would correspond to an **overall effectiveness** of 90% ($95\% \times 95\%$). This figure is somewhat higher than that for “All structures” in the analysis by NFPA (i.e. 82%) but accounts for the differences discussed above and the possible skewness in the NFRIS data raised by FM Global.

The node **Fixed system fail** constitutes the following nodes in the risk model for a fixed firefighting system providing ‘early’ detection and operation:

Technical failure as a results from the any of the following failures:

- Supply fail (pump etc.).
- Distribution failure due to:
 - Section valve.
 - Pipe & nozzles.
 - Shielding.
- Removal of water
 - Scuppers.
 - Valves.
 - Other.

Design incapacity of the:

- Fixed system.

The analysis by NFPA does not contain reliability figures for all of the listed nodes. As an example, there are no figures to determine the failure rate of a **Section valve** or **Pipe & nozzles**. For **Shielding**, the figure related to “Water did not reach the fire” may, however, apply. In order to simplify the approach, it is suggested that a reliability figure of 95% is applied for the top node **Technical failure**, in other words that the failure rate for all technical failures is 5%.

The node **Design incapacity** directly relates to “Percent effective of those that operated”, i.e. Factor ‘B’ in the analysis by NFPA. This figure is 94% for “All structures” but the figure suggested to be used per the discussion above is 95%, in other words that a **Design incapacity** occurs in 5% of all fires where the sprinkler system operates.

The dry-pipe system is designed for a water discharge duration of a minimum of 30 min. Under favourable conditions, the duration may, however, be longer. For example, if less sprinklers than included in the design area operates or that the freshwater tanks contain a larger volume of water than required. These 30 minutes will provide the crew with time needed to activate the CO₂ system without the fire spreading, causing further damage to the cargo. The RCO is therefore considered to have a positive effect on the “decision” part of the risk model as well. The effect on Decision was quantified by using Monte Carlo simulations. The time it takes to activate the CO₂ system after detection was described with a triangular distribution with 20 minutes as the minimum value, 25 minutes as the expected value and 30 minutes as the maximum value (Figure 12). The time the sprinkler system suppresses the fire was also described with a triangular distribution. However, the minimum, expected and maximum value depended upon if the fire had been detected early or late. In case of early detection by crew/detection system, it was assumed that detection and activation of the sprinkler system are made simultaneously. The time for sprinkler suppression was then modelled with a triangular distribution with 24 minutes as the minimum value, 30 minutes as the expected value and 36 minutes as the maximum value (Figure 12). However, in case of late detection by crew/detection system, it was assumed that the sprinkler system has activated before the fire is detected by the crew/detection system. The time for sprinkler suppression was then modelled with a triangular distribution with 16 minutes as the minimum value, 20 minutes as the expected value and 24 minutes as the maximum value (Figure 12). Monte Carlo simulations were then run to get the probability that the time during which the sprinkler system suppresses the fire was longer than the time it takes to activate to CO₂ system. For Decision following Early Detection, this probability is 94.3% (Figure 13). For Decision following Late Detection, this probability is 2.5% (Figure 14). These probabilities were then used together with the 95% reliability to produce the risk reduction for the top node “Late Decision”.

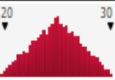
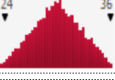
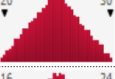
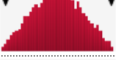
Name	Graph	Min	Mean	Max	5%	95%
Time until CO ₂ activation, following early detection		20,03504	25,00265	29,94086	21,56413	28,43812
Time until sprinkler stops controlling the fire, following early detection		24,05719	30,04877	35,90231	25,94727	34,1346
Time until CO ₂ activation, following late detection		20,07002	24,98738	29,93764	21,56928	28,45748
Time until sprinkler stops controlling the fire, following late detection		16,05828	19,98543	23,9013	17,23238	22,75777

Figure 12. Time until CO₂ activation and time during which the sprinkler system suppresses the fire.

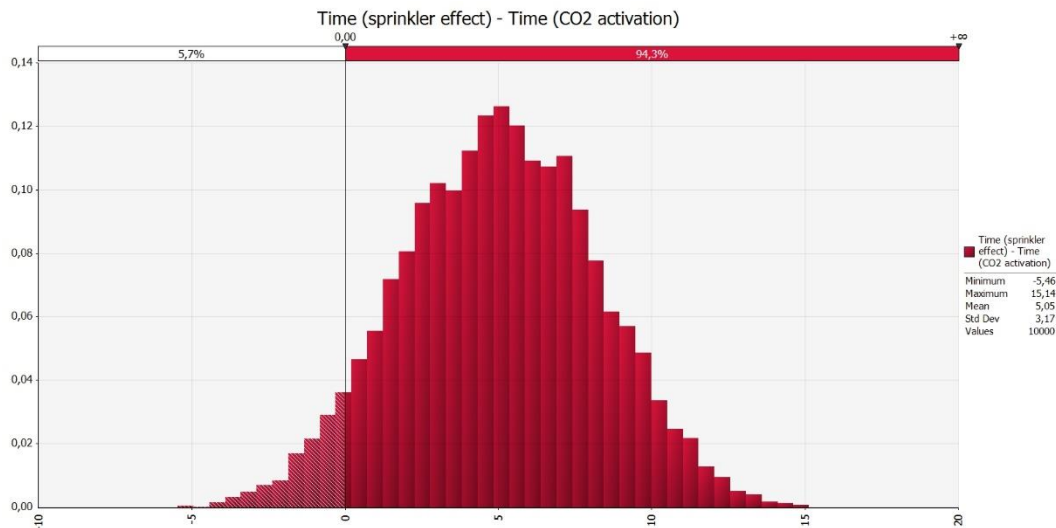


Figure 13. Time difference between CO₂ activation and sprinkler system suppression, following early detection.

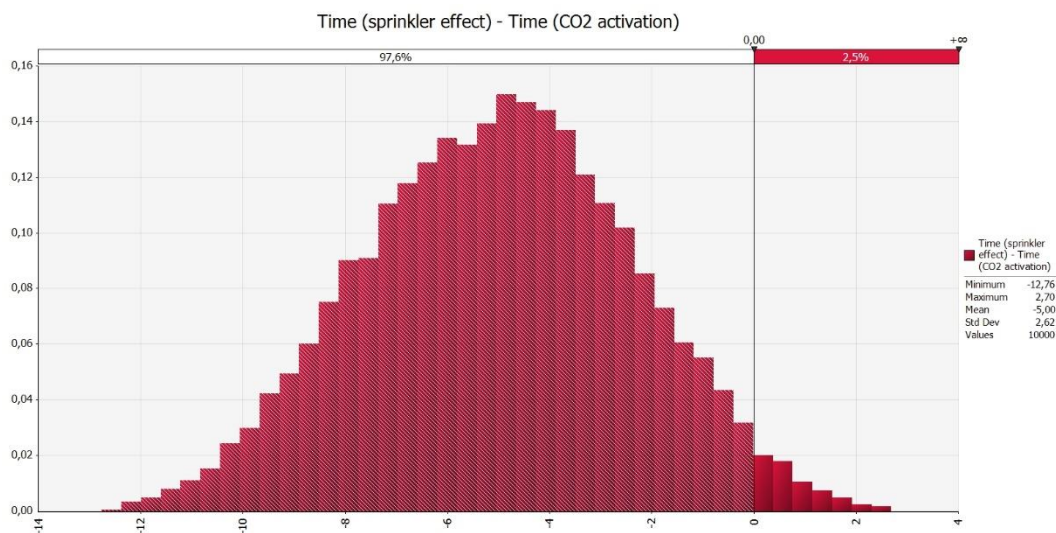


Figure 14. Time difference between CO₂ activation and sprinkler system suppression, following late detection.

Once the system runs out of water or if the system is intentionally or unintentionally stopped, it is likely that a fire will re-growth relatively rapidly, as a fire typically will not be completely extinguished, and shielded parts may not be pre-wetted by water. This was observed in the tests documented in D10.1 [10]. It is therefore important that the decisions and preparations (ventilation system stop and shut-down of dampers) are made during the initial 30 min. A decision that results in a CO₂ activation after 30 min refers to the “Extinguishment/suppression” following “Late decision” in the risk model.

To the knowledge of WP10, there are no reliability figures for the performance of drainage system on ships. If no data is found, a judgement of the failure rate is required. It is assumed that a failure of the drainage system that leads to a build-up of water over a large area, resulting in capsizing is low. For the input on the risk model, it is suggested that one out of 200 incidents (0.5%) leads to a scenario that the water to the dry pipe system needs to be stopped to prevent severe listing.

6.4.14 Effectiveness of RCO14: Fixed remotely-controlled fire monitor system using water for weather decks & RCO15: Fixed autonomous fire monitor system using water for weather decks

Main author of the chapter: Magnus Arvidson, RISE

6.4.14.1 Reliability

There is no documented field experience with fire monitor systems indicating the reliability of the system as a whole, the reliability of unique system components or the fire suppression performance. But it is assumed that reliability and longevity are good, given proper control, testing and maintenance of the system. The most common failure is that units are left unattended for years, and then are expected to work. The actual fire monitors must be kept clean, well lubricated, run periodically according to the manufacturer's recommendations, and any worn cables must be replaced. Additionally, system valves and pumps need to be conditioned and maintained.

OREDA 2002 [22] contains failure data for centrifugal pumps for firefighting that can be used as an indication how often such pumps fail when needed. The data comprises a population of 108 pumps in 37 installations and 1060 demands. In total, **11 Critical failures** have been documented, 5 cases where a pump failed to start on demand, 1 case where the output [water flow rate] was too low, 1 case with overheating and 4 cases with spurious stops. In addition, 35 cases where the pump was **Degraded** have been recorded, including for example external leakage (10 cases) and low output (15 cases). A total of 87 cases with **Incipient** failures, including for example abnormal instrument reading (40 cases) and minor in-service problems (37 cases) were recorded. In total, 133 failure modes were identified.

If assuming that the 11 critical failures and the 35 cases where the pump was degraded should be considered a supply fail, it occurred in 46 out of 1060 demands, i.e. in 4.3% of the cases.

Other events can also lead to a failure of the water supply for the fire monitor system. An electrical failure can make the fire pump inoperable; the freshwater tanks may be empty or almost empty and the connection to the seawater supply may fail. No failure data from the literature is available for such failures.

OREDA 2002 contains failure data for different types of valves in various applications. For valves used in water firefighting systems (refer to page 646 of OREDA 2002), data is available for a population of 11 valves in one installation. In total, **2 Critical failures** are listed, where the valve failed to open on demand. This corresponds to a mean failure rate of 5.93 failures per 106 hours.

For piping (hard pipe), the failure rate according to OREDA-2002 (page 818) is 0.1792 failures per 106 hours. The data are from an offshore subsea production facility and should therefore be used with some caution for the application here. Nevertheless, the data indicate that the failure rate of a passive component as a pipe is significantly lower than that of an active component as a valve.

As discussed, there is no failure rate data for fire monitors, but failure could include clogging by debris, that any of the electrical motors for the control malfunctions or any other mechanical failures. The monitors need electrical power for their operation so any failure of the power supply will result in non-operation.

For an autonomous system (RCO15), the use of a fire detection has benefits, but the increased system complexity and a failure in for example the fire detection system or the software may negatively influence the reliability and the autonomous function could fail. However, even in the

event of a failure of the autonomous functionality, the system may still be able to be controlled remotely by a human operator.

6.4.14.2 *Impact on the risk model*

RCO14:

The objective is that the discharge of at least two fire monitors should prevent a fire in a single vehicle or cargo unit from growing large by spreading to adjacent cargo. Under favourable circumstances, it is not unlikely that a fire can be completely extinguished. But in most cases, it is expected that a fire is suppressed such that it either can be fully extinguished by the crew or be allowed to burn out while being controlled by the application of water.

RCO15:

The autonomous function of RCO15 requires a separate fire detection system, software and controls. These parts will increase the probability for a technical failure. On the other hand, if working properly, it is likely that an earlier application of water will improve fire suppression performance, thereby reducing the failure rate for a **Design incapacity**. Improved fire suppression performance may also improve the chances for full fire extinguishment by the crew.

As previously noted, even in the event of a failure of the autonomous functionality, the system may still be able to be controlled remotely by a human operator.

Quantification:

- **Late detection:**

RCO15 is introducing a fire detection system that will generate a fire alarm and notify the crew. This will reduce the overall time until a fire is discovered, as fire discovery is entirely dependent on observations by the crew.

It is, however, assumed that **System detection failure** can occur. In the reference case, this figure is “100%” as no fire detection system currently is used. As a preliminary approach, it was assumed that fire is detected in 8 out of 10 cases, i.e. that the failure rate is 20%. These failures can be due to system shut-off, shielding of the fire, as well as hardware or software failures.

The above figure was updated based on the estimation of RCO10 (“Fire detection on weather decks”) done by WP09. WP09 estimates the **System detection failure** on weather decks to be 52.2%.

- **Late decision:**

It is likely that RCO14 could have a potential positive influence on the node **Late implementation**. The probability that the firefighting operation is delayed due to **Late implementation** (which in turn can be due to e.g., hesitation) could be reduced if remote controlled fire monitors (RCO14) are installed. Fire monitors would mean that the firefighting could be started from a safe location, instead of having to carry out manual firefighting (as it is today, which may cause more delay). Since RCO15 is autonomous and hence doesn't require a decision to activate, this node is not relevant for RCO15.

It is suggested that that the risk reduction for the node **Late implementation** is 25%.

- **Failure of extinguishment:**

The node **Fixed system fail** constitutes the following nodes for a fixed firefighting system:

Technical failure as a result of any of the following failures:

- Supply fail (pump etc.).
- Distribution failure due to:
 - Section valve.
 - Pipe & nozzles.
 - Shielding.
 - Wind.
- Removal of water
 - Scuppers.
 - Valves.
 - Other.

Design incapacity of the:

- Fixed system.

The same nodes apply for both RCO14 and RCO15.

Supply fail: Refer to the discussion under section 6.4.14.1.

Distribution failure: Refer to the discussion above under section 6.4.14.1.

Shielding: Shielding of the fire could occur, as the vehicles, trailers or other cargo transported on a weather deck are designed to withstand precipitation in the form of rain or snow. Shielding may also occur if a flammable liquid spill fire were to form and spread underneath a vehicle. No failure data from the literature is available for this node.

Wind: Hard wind conditions could negatively influence the water throw and reduce the fire suppression performance ability, but the suggested positioning of fire monitors at either long side of a weather deck will to some extent compensate for this. It is also believed that harsh weather conditions in terms of wind and waves may be a reason for fire if cargo gets loose. Due to the lack of data on the failure rate on fire suppression due to influence by wind, an estimation of the failure due to wind is required.

Removal of water: To the knowledge of WP10, there are no reliability figures for the performance of drainage system on ships. If no data are found, a judgement of the failure rate is required. It is assumed that a failure of the drainage system that leads to a build-up of water over a large area, resulting in capsizing is low. For the input on the risk model, it is suggested that one out of 200 incidents (0.5%) leads to a scenario where the water to the fire monitor system needs to be stopped to prevent severe listing.

In order to simplify the approach, it is suggested that a reliability figure of 95% be applied for the top node **Technical failure** for RCO14; in other words, that the failure rate for all technical failures is 5%. For RCO15, a slightly lower reliability figure of 94% is suggested to reflect a technical failure in the autonomous function.

Design incapacity: This node relates to the amount of water required to suppress a fire, given that the system operates as intended, i.e. that no technical failures per the discussion above occur. Large-scale fire tests were conducted in September 2022 to test the fire suppression performance of both a remotely-controlled and an autonomous system. The test proved that the fire was prevented to grow large in the tests where the application of water was started 'early', independent if one or two fire monitors were used. The use of one monitor simulated the case where the system is influenced by

wind to the extent that water is applied by one fire monitor only. For the cases the discharge of water was 'late', almost immediate fire suppression was proven using two fire monitors and fire suppression was accomplished with only one fire monitor.

Obviously, these fire tests cannot cover all fire scenarios that might occur on a weather deck and the test results should be regarded as indicative. It is suggested that a **Design incapacity** occurs in 2.5% of all fires for a remotely-controlled fire monitor system (RCO14) that is operated at an 'early' stage of the fire (= early decision). If the system is operated at a 'late' stage (= late decision), it is suggested that a **Design incapacity** occurs in 5% of all fires. For a remotely-controlled fire monitor system, there may be cases where the fire is not detected or discovered in time such that the fire is too large for the system to control.

For RCO15, the system operates at an 'early' stage (= early decision) per definition if the autonomous function works, which translates to a **Design incapacity** of only 1%. The rationale is that an autonomous system will detect and operate early, such that the fire is less likely to grow out of control. If the autonomous function fails, it is judged that the design incapacity is equal to that of RCO14 operated based on a late decisions, i.e. that a **Design incapacity** occurs in 5% of all fires.

Based on the discussion above it is suggested that the **overall effectiveness** (referring to the node **Fixed system fail**) of the two system solutions, respectively, is as follows:

- RCO14: $0.95 \times 0.975 = 0.926$ ('early' system operation due to an early decision).
- RCO14: $0.95 \times 0.95 = 0.903$ ('late' system operation due to a late decision).
- RCO15: $0.94 \times 0.99 = 0.931$ ('early' system operation due to early system autonomous response).
- RCO15: $0.94 \times 0.95 = 0.893$ ('late' system operation due autonomous response failure).

Both RCO14 and RCO15 will have a positive influence on the node **Failure by fire-fighting group**. As discussed above, a fire that is suppressed by a fire monitor system will be easier to fight manually by the crew and will reduce the strain on the personnel. A positive influence is expected for the two bottom nodes:

- **Manual extinguishment fail \ Failure by fire-fighting group \ Tactical failure**
- **Manual extinguishment fail \ Failure by fire-fighting group \ Lack of personnel**

It is suggested that the risk reduction for these two bottom nodes is 90% for RCO14 and 95% for RCO15, independent of the ship type (ro-ro passenger or ro-ro cargo, respectively) or if the decision to initiate manual fire-fighting is early or late.

- **Failure of containment:**

Due to the positioning of the fire monitors, it is believed that RCO14 and RCO15 will have none or small effect on the node **Failure of fire containment \ Flame spread through openings \ Aft and side openings**.

Surface cooling of the weather deck is one obvious benefit of a fire monitor system given a fire in a ro-ro space beneath. Application of water could likely efficiently prevent or limit fire spread to the weather deck. For both the generic ships in the project, the ro-ro spaces directly below the weather deck(s) are mainly open ro-ro spaces. It is suggested that the risk reduction for the node **Failure of fire containment \ Heat spread \ Failure of boundary cooling** is 50% for both RCO14 and RCO15 following unsuccessful fire suppression in an open ro-ro space and 90% following successful fire suppression. These risk reduction figures are independent of the generic ships (generic ro-ro passenger or ro-ro cargo, respectively).

A fire monitor system could also have an influence on the following nodes (for weather deck):

- **Failure of fire containment \ Flame spread**
- **Failure of fire containment \ Heat spread**
- **Failure of smoke containment**

In the reference case, without any extinguishing system on weather deck, the probability that containment fails on weather deck is very high (99% for ro-ro passenger ships, and more than 80% for ro-ro cargo ships). Fire monitors would likely decrease the probability that flames and heat spread occurs from the weather deck to other parts of the ship. It is suggested that that the risk reduction for the nodes **Failure of fire containment \ Flame spread**, **Failure of fire containment \ Heat spread** and **Failure of smoke containment** is reduced by the figures given for the node **Extinguishment/suppression failure \ Fixed system fail**.

6.4.15 Effectiveness of RCO16: Guideline for fire ventilation in closed ro-ro space

Main author of the chapter: Stina Anderson & Anna Olofsson, RISE

6.4.15.1 Reliability

This chapter lists potential causes to why RCO16 might fail.

- The guideline is not used, due to:
 - Crew members have not access to the guideline.
 - The guideline was not read before the usage (i.e. before the actual fire started).
- Human factors and organizational factors, such as:
 - The guideline is too complex to understand.
 - Design of fan activation, e.g. wrong button is pressed; fans activated in wrong direction.
 - Communication failure between crew members.
 - Issues with decision making.
- Technical failures:
 - Fans (impeller, software, motor).
 - Electrical equipment connected to fans.

In general, fans on board are considered to have a high reliability. Since this RCO is a guideline, it is not applicable to provide a reliability value on potential equipment that can be used to implement the guideline.

The following constitutes uncertainties surrounding RCO16:

- Test results are from model scale tests and scaling up to full scale is an uncertainty.
- Studies behind the RCO has not included fire spread from cargo.
- Studies behind the RCO has not included smoke spread to other spaces/staircases.
- Active drencher in combination with ventilation has not been studied.

6.4.15.2 Impact on the risk model

The identified nodes of the risk model are relevant for closed ro-ro spaces on board ro-ro passenger ships and ro-ro cargo ships, both newbuildings and existing ships.

- **Late decision:**

Late Decision \ Late implementation: This node is relevant following both early and late detection. The guideline will increase knowledge and understanding of mechanical ventilation's effects on fire and therefore is expected to have an effect on decision-making. The evaluation methods have

focused on early phase of a fire, involving one single car burning. Since no explicit evaluation of decision-making has been performed, no risk reduction estimation for decision is provided.

- **Failure of extinguishment** (following early decision):

The IMO MSC circular MSC/Circ.1002 on “*Guidelines on Alternative Design and Arrangements for Fire Safety*” [23] lists performance criteria for the four parameters, namely, air temperature, radiant heat flux, visibility, and CO concentration. These parameters are important factors when carrying out manual firefighting and were used for the evaluation of results from conducted computer simulations.

The computer simulations that have been carried out within Action 11-D show that mechanical ventilation can have a positive effect on visibility inside a closed ro-ro space. At the same time, the results show that mechanical ventilation can have negative effects on temperatures and radiation in the space.

In addition to the simulations and model scale fire tests, a survey was conducted during a firefighting drill in Jovellanos Maritime Safety Training Centre Home (conducted in conjunction with WP06 in LASH FIRE) during October 2022 using positive pressure fans to explore effects on the environment inside the fire compartment and the effect of smoke. It should be noted that the participants were located in between the fire and the outlet, contradictory to what is normally recommended during firefighting.

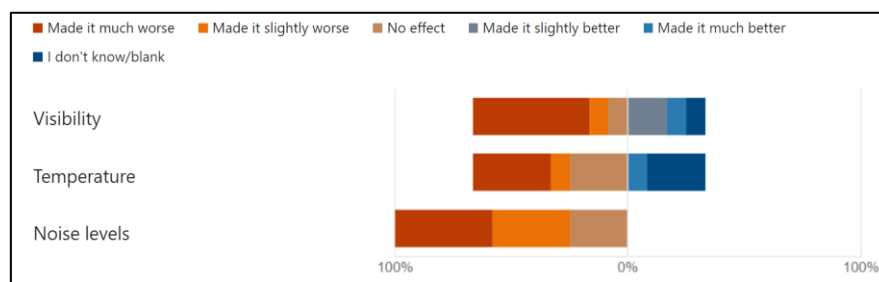


Figure 15. Survey results for the question "What effect did you think the ventilation had on:".

The survey result (Figure 15) showed that participants in the drill experienced that positive pressure fan had a negative impact on noise levels inside the fire compartment. It also showed that the experience of the effect on visibility and temperature differed among the participants. The results highlight the ambiguity regarding the perception on how the visibility and temperature can be affected by mechanical ventilation during a fire.

The guideline will include the observed effects and highlight opportunities and risks with mechanical ventilation. The guideline will include effects noted in result of computer simulations and model scale tests. In summary, this contributes to improved knowledge and skills, better possibilities to practise different scenarios, which is expected to lead to better understanding amongst the crew on using mechanical ventilation in a fire scenario. This is further expected to lead to improved tactical decisions for firefighting in closed ro-ro spaces.

The simulations and model scale tests carried out for RCO16 have focused on an early stage of a fire, involving one single car burning. Therefore, RCO16 is only deemed to influence manual firefighting that occurs in an “early” stage of a fire, i.e. following an early decision.

Based on the above, the probability of tactical failure is estimated to be reduced. A risk reduction of 22 % is estimated for the bottom node **Manual extinguishment fail \ Failure by fire-fighting group \ Tactical failure** for both ro-ro passenger and cargo ships.

- **Failure of containment** (following successful suppression):

This node is based on the fact that active mechanical ventilation could reduce hot smoke accumulating in the ro-ro space. Thus, the heat contained in the smoke that can cause heat spread through the construction would be reduced.

6.5 Impact of RCOs on the safety levels

This section summarizes the impact of each RCO on the safety levels (i.e. Potential Loss of Life, of Cargo and of Ship), by showing the global risk reduction. The details are provided in Table 28 to Table 33, in ANNEX C: Estimation of risk reduction by the implementation of RCOs.

6.5.1 Ro-ro passenger ships

Figure 16 and Figure 17 provide the relative risk reduction (%) of each RCO in terms of potential loss of life (PLL), respectively for new and existing ro-ro passenger ships.

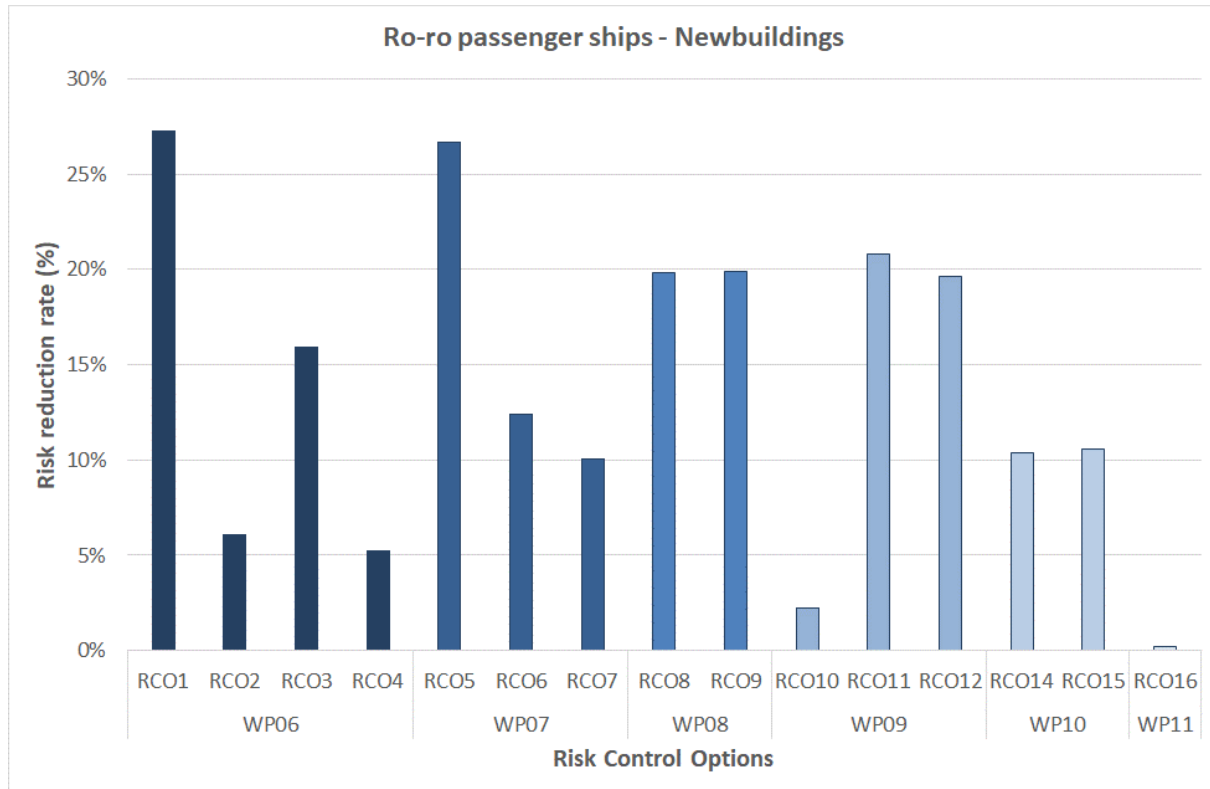


Figure 16. Risk reduction of RCOs in terms of PLL – Ro-ro passenger ships, newbuildings.

For new ro-ro passenger ships (Figure 16), the RCOs with the highest impact on the potential loss of life (top 5) are RCO1 “Improved fire patrol. Improved fire confirmation & localization” (27%), RCO5 “Alarm system interface prototype” (27%), RCO11 “Alternative fire detection in closed ro-ro spaces & open ro-ro spaces” (21%), RCO9 “Safe electrical connection of reefers and electric vehicles (EVs)” (20%) and RCO8 “Safe electrical connection for reefers” (20%). Similarly, those RCOs have a high impact on the potential loss of cargo and ship (PLC and PLS).

For existing ro-ro passenger ships (Figure 17), the RCOs with the highest impact on the potential loss of life (top 5) are RCO1 “Improved fire patrol. Improved fire confirmation & localization” (27%), RCO9 “Safe electrical connection of reefers and electric vehicles (EVs)” (20%), RCO8 “Safe electrical connection for reefers” (20%), RCO12 “Visual system for fire confirmation and localization” (20%) and RCO3 “Developed efficient first response” (16%). Similarly, those RCOs have a high impact on the potential loss of cargo and ship (PLC and PLS).

The RCOs with the highest impact are those addressing ignition prevention, detection and alarm systems, first response (i.e. early control of the fire), and covering all types of ro-ro spaces.

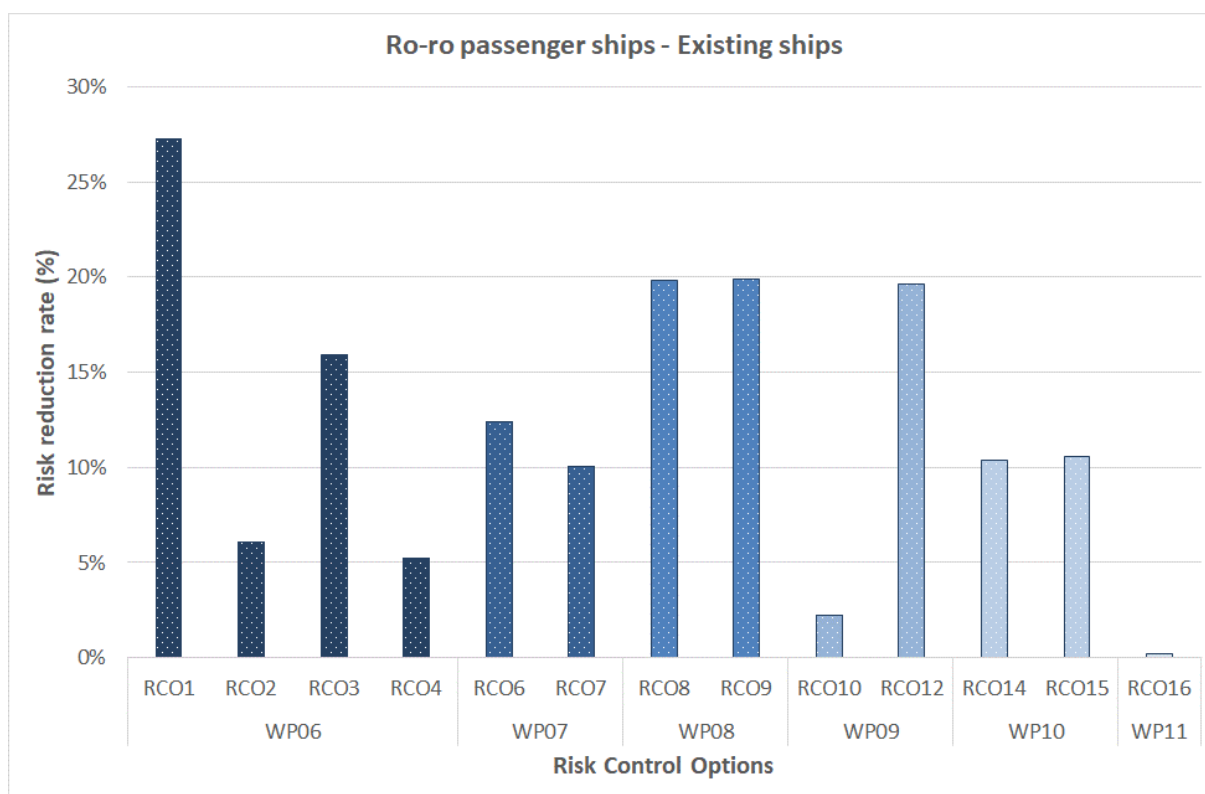


Figure 17. Risk reduction of RCOs in terms of PLL – Ro-ro passenger ships, existing ships.

6.5.2 Ro-ro cargo ships

Figure 18 and Figure 19 provide the relative risk reduction (%) of each RCO in terms of potential loss of life (PLL), respectively for new and existing ro-ro cargo ships.

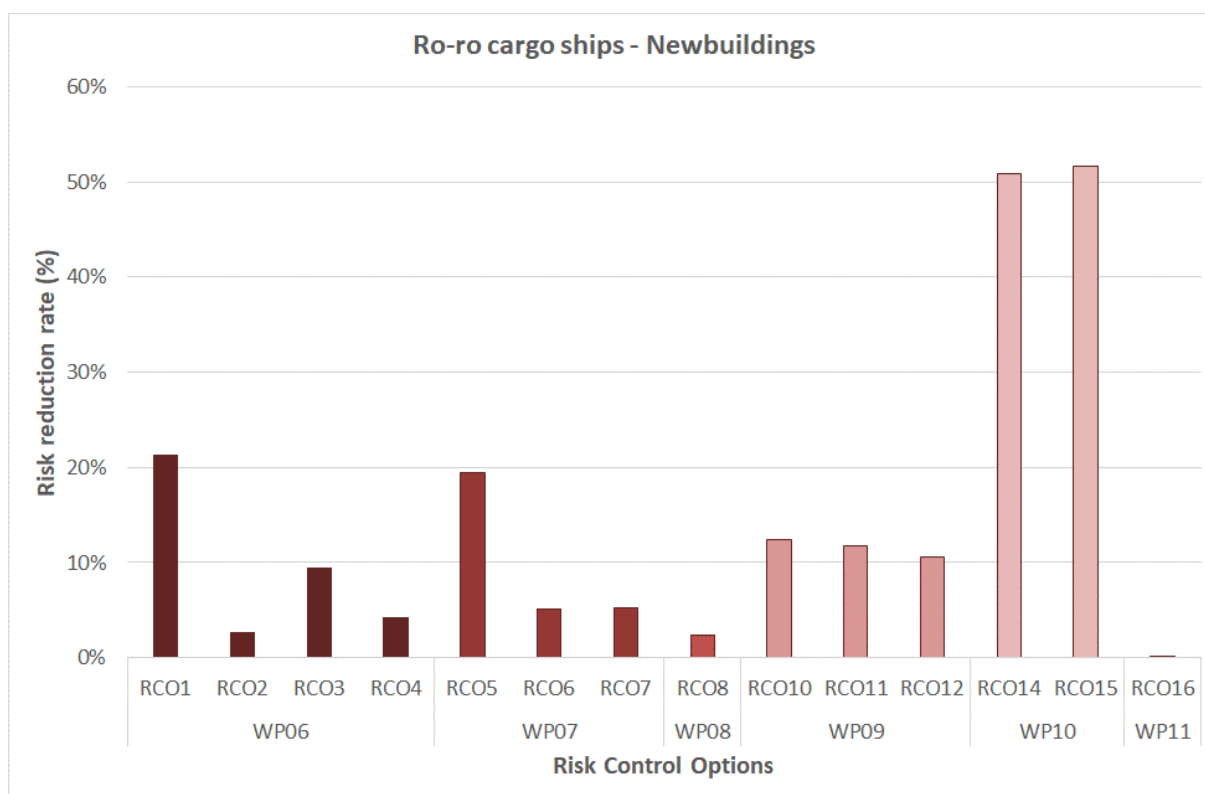


Figure 18. Risk reduction of RCOs in terms of PLL – Ro-ro cargo ships, newbuildings.

For new ro-ro cargo ships (Figure 18), the RCOs with the highest impact on the potential loss of life (top 5) are RCO15 “Fixed autonomous fire monitor system using water for weather decks” (52%), RCO14 “Fixed remotely-controlled fire monitor system using water for weather decks” (51%), RCO1 “Improved fire patrol. Improved fire confirmation & localization” (21%), RCO5 “Alarm system interface prototype” (19%) and RCO10 “Fire detection on weather decks” (12%). Similarly, those RCOs have a high impact on the potential loss of cargo and ship (PLC and PLS).

For existing ro-ro cargo ships (Figure 19), the RCOs with the highest impact on the potential loss of life (top 5) are RCO15 “Fixed autonomous fire monitor system using water for weather decks” (52%), RCO14 “Fixed remotely-controlled fire monitor system using water for weather decks” (51%), RCO1 “Improved fire patrol. Improved fire confirmation & localization” (21%), RCO10 “Fire detection on weather decks” (12%) and RCO12 “Visual system for fire confirmation and localization” (11%). Similarly, those RCOs have a high impact on the potential loss of cargo and ship (PLC and PLS).

The RCOs with the highest impact are those covering the weather decks (because of the high contribution of fires from the weather decks on the global risk of ro-ro cargo ships).

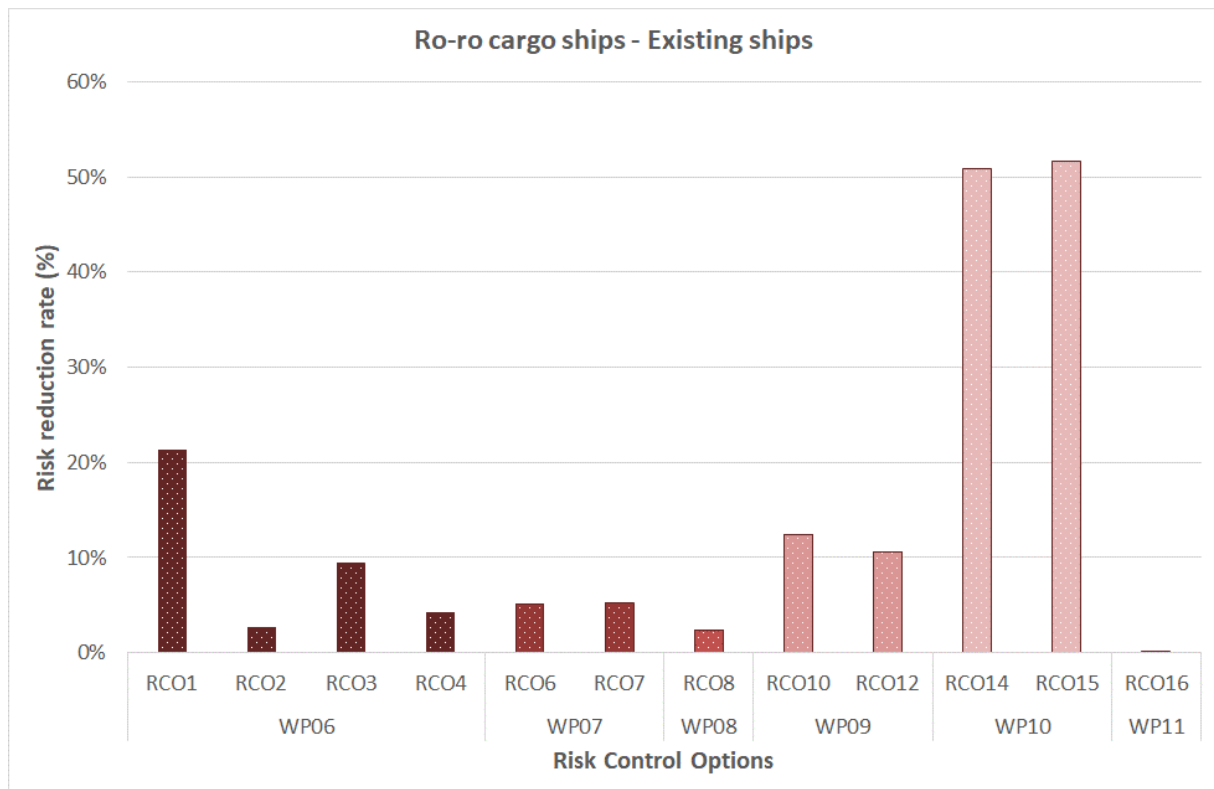


Figure 19. Risk reduction of RCOs in terms of PLL – Ro-ro cargo ships, existing ships.

6.5.3 Vehicle carriers

Figure 20 and Figure 21 provide the relative risk reduction (%) of each RCO in terms of potential loss of life (PLL), respectively for new and existing vehicle carriers.

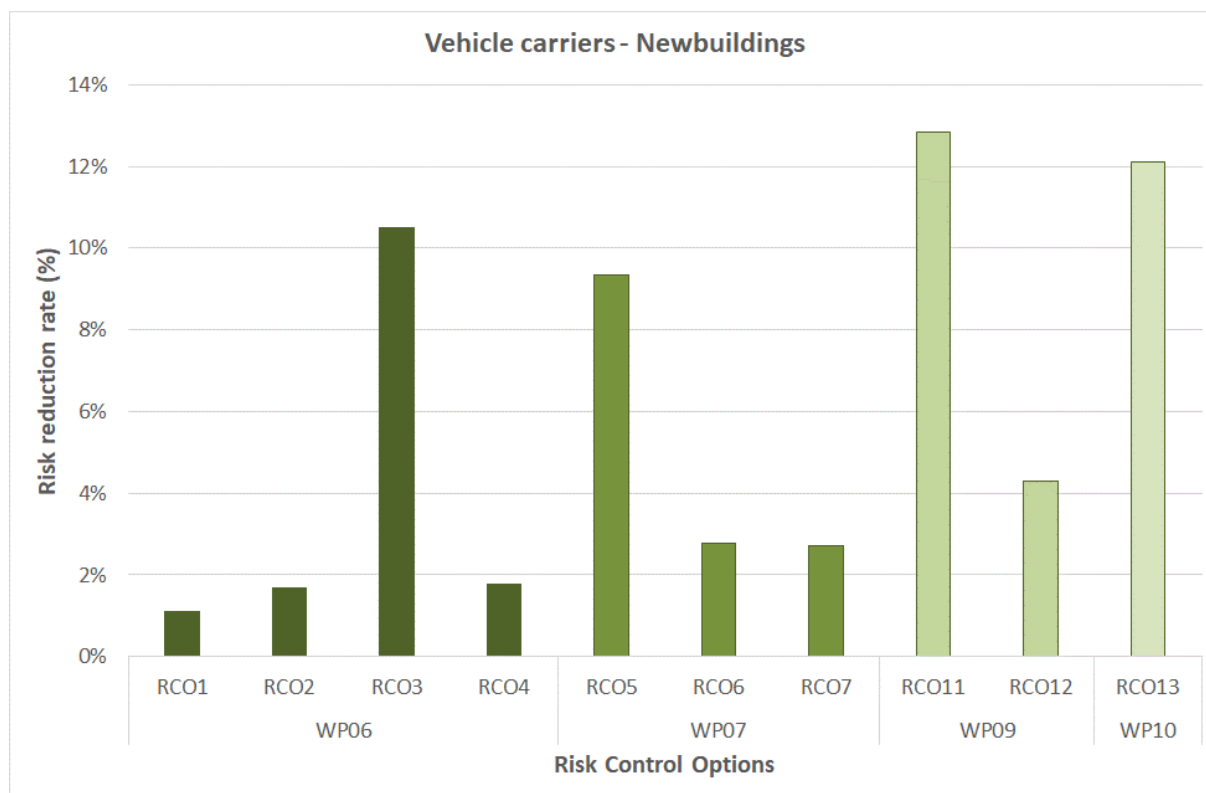


Figure 20. Risk reduction of RCOs in terms of PLL – Vehicle carriers, newbuildings.

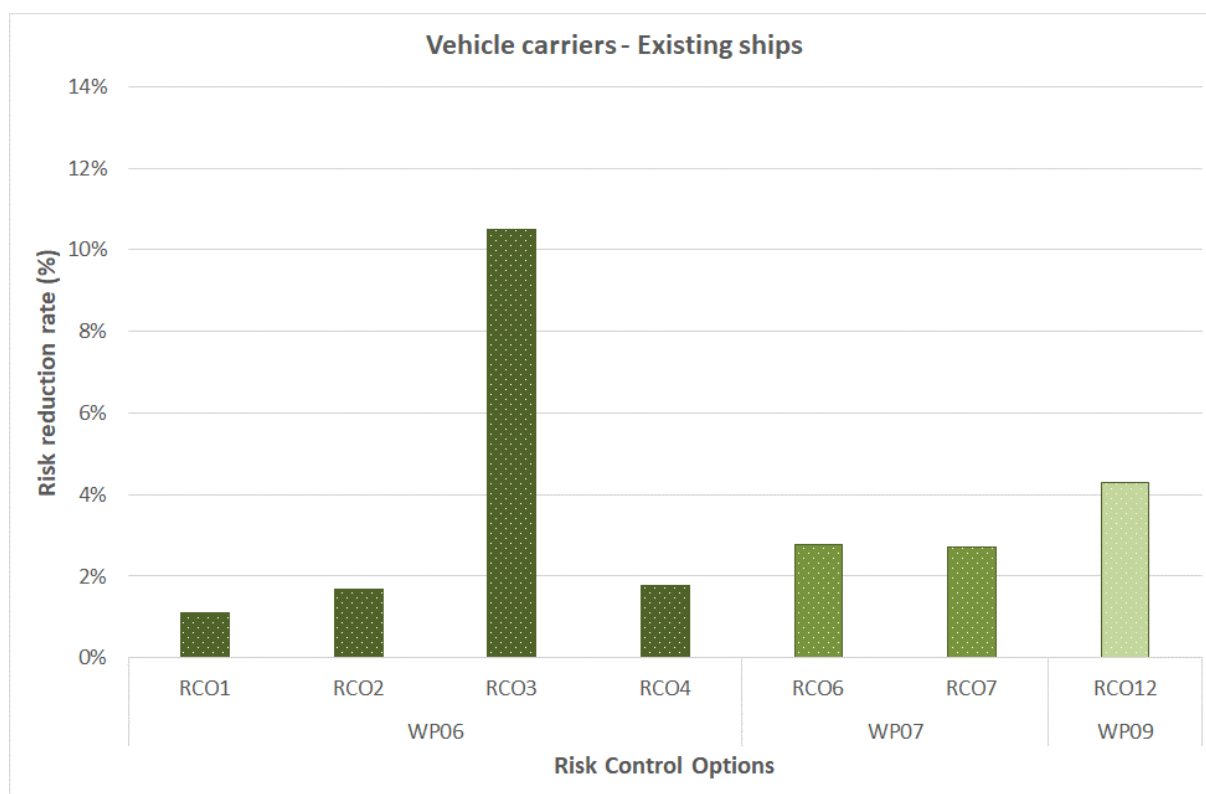


Figure 21. Risk reduction of RCOs in terms of PLL – Vehicle carriers, existing ships.

For new vehicle carriers (Figure 20), the RCOs with the highest impact on the potential loss of life (top 3) are RCO11 “Alternative fire detection in closed ro-ro spaces & open ro-ro spaces” (13%), RCO13 “Dry-pipe sprinkler system for vehicle carriers” (12%) and RCO3 “Developed efficient first response” (10%). Similarly, those RCOs have a high impact on the potential loss of cargo and ship (PLC and PLS).

For existing vehicle carriers (Figure 21), the RCOs with the highest impact on the potential loss of life (top 3) are RCO3 “Developed efficient first response” (10%), RCO12 “Visual system for fire confirmation and localization” (4%) and RCO6 “Process for development of procedures and design for efficient activation of extinguishing system” (3%). Similarly, those RCOs have a high impact on the potential loss of cargo and ship (PLC and PLS).

The RCOs have a much lower impact for vehicle carriers than for ro-ro passenger and cargo ships. The RCOs with the highest impact are those addressing detection and alarm systems, first response or early activation of fixed fire-extinguishing system (i.e. early control of the fire).

7 Cost-Effectiveness Assessment

Main author of the chapter: Eric De Carvalho, BV

7.1 Cost-effectiveness assessment background

Main author of the chapter: Léon Lewandowski, BV

This section focuses on the definition, description and choice of the different elements necessary to compute the cost-effectiveness of each selected RCO, i.e. the GCAF, NCAF, $\Delta Risk$, $\Delta Cost$, $\Delta Benefits$, etc.

7.1.1 Cost-effectiveness indices

The IMO FSA guidelines [1] provides two indices to determine the cost-effectiveness of a RCO, these indices being the Gross Cost of Averting a Fatality (GCAF) and Net Cost of Averting a Fatality (NCAF).

In the guidelines, the IMO defines the GCAF and NCAF in the following way (Annex, page 51):

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

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

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

$$NCAF = \frac{\Delta Cost - \Delta Economic Benefits}{\Delta Risk} = GCAF - \frac{\Delta Economic Benefits}{\Delta Risk} „$$

GCAF and NCAF are expressed in monetary units (e.g. euros). It is advised to start by using the GCAF first, and then, if necessary, use the NCAF (Annex, page 52):

“The reason is that NCAF also takes into account economic benefits from the RCOs under consideration. This may be misused in some cases for pushing certain RCOs, by considering more economic benefits on preferred RCOs than on other RCOs.”

$\Delta Risk$ is the number of fatalities avoided by implementing the RCO, for the lifespan of the ship. Here, it will be considered that $\Delta Risk = \Delta PLL * T$, T being the average lifespan of the fleet. In other words, $\Delta Risk$ is the difference between the potential loss of life over the expected lifetime of the ship before and after the implementation of the RCO.

$\Delta Cost$ is the total marginal cost required to implement the RCO onboard the ship (including for instance purchasing cost, implementation cost, maintenance cost, etc.). In other words, $\Delta Cost$, at present value, is the difference between the lifetime costs between reference system and the system with RCO.

$\Delta Economic Benefits$ is the total amount of money expected to be saved thanks to the implementation of the RCO irrespective of the lives saved, e.g. reduced loss of cargo and reduced loss of ship. Here, it will be considered that $\Delta Economic Benefits = (\Delta PLC + \Delta PLS) * T$. In other words, $\Delta Benefits$, at present value, is the lifetime economic benefits (reduced loss of cargo and reduced loss of ship) that follow the implementation of an RCO.

The expected lifetimes for the different types of ships are summarized in Table 12. For Potential Loss of Cargo and Ship calculations, expected lifetimes have to be adjusted. Net Present Value (NPV) was used: a discount rate of 3.5% was applied for the first 30 years, and then was lowered to 3.0% for the following years.

Table 12. Expected lifetime (in years) for the different types of ships studied, for the PLL.

	Ro-ro passenger ships	Ro-ro cargo ships	Vehicle carriers
Newbuildings	43	40	29
Existing ships	23	23	17

7.1.1.1 Indices applied to ro-ro passenger ships

The IMO FSA guidelines recommendation to use GCAF in first place will be followed for this type of ro-ro ships. This criterion should be sufficient given the presence of passengers and potential lives saved.

Other outcomes may be analyzed on a case-by-case basis to conclude on the cost-effectiveness, especially when the GCAF is close to its acceptance criterion.

7.1.1.2 Indices applied to ro-ro cargo ships and vehicle carriers

By definition, ro-ro ships not considered as passenger ships cannot carry more than 12 passengers and are carrying almost exclusively vehicles and goods. Moreover, ro-ro cargo ships and vehicle carriers sail with a limited number of crew members. This strongly limits the possible improvement in terms of life safety (i.e. there are less lives to save on those types of ro-ro ships than on ro-ro passenger ships). So, in these cases, in addition to the GCAF, the NCAF will be computed and taken into account in order to also address the possible improvement in terms of cargo and ship safety.

Other outcomes may be analyzed on a case-by-case basis to conclude on the cost-effectiveness, especially when the GCAF or NCAF are close to their acceptance criterion, or when the NCAF is negative.

7.1.2 Cost-effectiveness criterion

After computing the GCAF (and possibly the NCAF) as explained in the previous section, it is necessary to compare it to the “CAF (Cost for Averting a Fatality) criterion”. This criterion represents the cost a society is willing to pay to avoid a fatality, per unit of time (here, per year).

A first way to calculate the CAF criterion is to use the VPF (Value of Preventing a Fatality). This method is explained in MSC 72/16 [24]. The VPF is the total amount of money a society is willing to spend to slightly reduce the risk of mortality. For instance, in a society of N people, if each of them is willing to pay X € to avoid one fatality per year, the VPF would be $X * N$ € per year. This criterion is based on Gross Domestic Product (GDP) per capita and life expectancy at birth for Organization for Economic Co-operation and Development (OECD) countries, and is given in SLF.55/INF.9. The formula for each country is the following:

$$VPF_{country} = g * \frac{e}{4} * \frac{1 - w}{w}$$

With:

- g the GDP per capita of the country;
- e the life expectancy at birth for the country;
- w the portion of life spent in economic production in the country.

The global CAF criterion is then the average of all OECD countries criteria.

With this method and based on data from 2020, the CAF criterion is found to be €8.1 million.

Another method to compute the CAF criterion is based on the IMO FSA guideline. According to it, the CAF criteria *“should be updated every year according to the average risk free rate of return (approximately 5%)”* [1] (Annex, page 52). If the criteria used in FIRESAFE II with 2015 data (\$7.22 million) is updated with this method, the new criteria should be around \$9.22 million (≈€8.2 million), which is fairly close to the first method.

It was decided to take a round number. The CAF criterion used in LASH FIRE shall then be €8M.

7.1.3 GCAF and NCAF factor

If the GCAF is lower than the CAF criterion, then the RCO will be considered cost-effective in terms of GCAF. If the NCAF is lower than the CAF criterion, the RCO will be considered cost-effective in terms of NCAF. This can also be expressed the following way: if the ratio GCAF over CAF criterion (called “GCAF factor”) is below one, the RCO will be considered cost-effective in terms of GCAF.

$$GCAF\ factor = \frac{GCAF}{CAF\ crit.}$$

The same applies to NCAF to define an NCAF factor.

7.1.4 Review of previous studies

Both FIRESAFE [25] and FIRESAFE II [26] also computed the CAF criterion via the two methods described in section 7.1.2. As the data taken into account was from 2015 and 2017, respectively, their CAF criterion was €6.7M and €7M .

EMSA 3 FSA project [27] used the method described in MSC 72/16 [24]. The VPF was estimated approximately \$7 million. This was based on 2012 GDP data and updated life expectancies and fractions of time in economic activity, with the results averaged over all OECD members.

7.2 Estimation of the costs

This section summarizes the results of the Life-Cycle Cost (LCC) assessment. For more details about LCC, refer to deliverable D05.8 “Ship integration cost and environmental assessment” [4].

Table 13 and Table 14 provide the marginal cost (Δ Cost) of each RCO at present value, respectively for newbuildings and existing ships. The breakdown of marginal cost of each RCO, respectively for newbuildings and existing ships, is provided in Table 26 and Table 27, in ANNEX B: Breakdown of marginal cost of each RCO.

Table 13. Summary of the marginal costs (in euros) for the RCOs, for newbuildings.

		Δ Cost		
		Ro-Pax	Ro-Ro Cargo	Vehicle Carriers
RCO1	Impr. fire patrol. Impr. fire confirmation & localiz.	65 441 €	57 650 €	36 193 €
RCO2	Impr. signage and markings for effective localiz.	21 029 €	20 552 €	21 681 €
RCO3	Developed efficient first response	41 323 €	26 487 €	22 977 €
RCO4	Developed manual firefighting for APVs	78 152 €	64 272 €	65 851 €
RCO5	Alarm system interface prototype	85 807 €	85 807 €	80 863 €
RCO6	Process [...] for efficient activation of exting.	24 174 €	23 396 €	19 918 €
RCO7	Training module for efficient activat. of exting.	88 877 €	86 429 €	112 324 €
RCO8	Safe electrical connection for reefers	162 475 €	129 382 €	Not assessed
RCO9	Safe electrical connection of reefers and EVs	215 388 €	Not assessed	Not assessed
RCO10	Fire detection on weather decks	184 476 €	200 447 €	Not assessed
RCO11	Alternative fire detection in CRS & ORS	411 988 €	483 282 €	830 205 €
RCO12	Visual system for fire confirmation and localiz.	326 169 €	560 286 €	1 056 375 €
RCO13	Dry-pipe sprinkler system for VC	Not assessed	Not assessed	2 023 333 €
RCO14	Remote.-control. fire monitor using water for WD	261 769 €	361 223 €	Not assessed
RCO15	Autonomous fire monitor using water for WD	317 508 €	425 279 €	Not assessed
RCO16	Guideline for fire ventilation in CRS	28 049 €	27 156 €	Not assessed

Table 14. Summary of the marginal costs (in euros) for the RCOs, for existing ships.

		Δ Cost		
		Ro-Pax	Ro-Ro Cargo	Vehicle Carriers
RCO1	Impr. fire patrol. Impr. fire confirmation & localiz.	50 885 €	48 005 €	28 986 €
RCO2	Impr. signage and markings for effective localiz.	39 189 €	39 189 €	42 802 €
RCO3	Developed efficient first response	31 062 €	20 777 €	18 073 €
RCO4	Developed manual firefighting for APVs	59 210 €	53 114 €	51 301 €
RCO5	Alarm system interface prototype	Not assessed	Not assessed	Not assessed
RCO6	Process [...] for efficient activation of exting.	100 254 €	83 814 €	16 558 €
RCO7	Training module for efficient activat. of exting.	68 644 €	68 644 €	85 875 €
RCO8	Safe electrical connection for reefers	183 963 €	140 323 €	Not assessed
RCO9	Safe electrical connection of reefers and EVs	229 485 €	Not assessed	Not assessed
RCO10	Fire detection on WD	165 043 €	186 850 €	Not assessed
RCO11	Alternative fire detection in CRS & ORS	Not assessed	Not assessed	Not assessed
RCO12	Visual system for fire confirmation and localiz.	430 400 €	514 712 €	1 066 651 €
RCO13	Dry-pipe sprinkler system for VC	Not assessed	Not assessed	Not assessed
RCO14	Remote.-control. fire monitor using water for WD	245 977 €	346 973 €	Not assessed
RCO15	Autonomous fire monitor using water for WD	297 811 €	406 040 €	Not assessed
RCO16	Guideline for fire ventilation in CRS	20 667 €	20 667 €	Not assessed

7.3 GCAF and NCAF

This section summarizes the results of the cost-effectiveness assessment, providing the GCAF, NCAF for each RCO and RCOs rankings.

7.3.1 Ro-ro passenger ships

Table 15 and Table 16 list the input values $\Delta Risk$ and $\Delta Cost$, as well as the resulting cost-effectiveness indices GCAF and NCAF for each RCO on new and existing ro-ro passenger ships, respectively.

Table 15. $\Delta Risk$, $\Delta Cost$, $\Delta Benefits$, GCAF and NCAF values for the RCOs for ro-ro passenger ships, newbuildings.

Ref	Designation	$\Delta Risk$	Rank	$\Delta Cost$	Rank	$\Delta Cost-\Delta Benefits$	Rank	GCAF	GCAF Factor	Rank	NCAF	NCAF Factor
RCO 1	Impr. fire patrol. Impr. fire confirmation & localiz.	1.67E-01	1	65 441 €	5	-1 118 800 €	1	392 683 €	0.05	2	-6 713 460 €	-0.84
RCO 2	Impr. signage and markings for effective localiz.	3.72E-02	12	21 029 €	1	-205 242 €	10	565 203 €	0.07	5	-5 516 330 €	-0.69
RCO 3	Developed efficient first response	9.74E-02	7	41 323 €	4	-653 461 €	5	424 210 €	0.05	3	-6 708 300 €	-0.84
RCO 4	Developed manual firefighting for APVs	3.19E-02	13	78 152 €	6	-146 622 €	11	2 446 440 €	0.31	9	-4 589 802 €	-0.57
RCO 5	Alarm system interface prototype	1.63E-01	2	85 807 €	7	-1 045 299 €	2	526 626 €	0.07	4	-6 415 373 €	-0.80
RCO 6	Process [...] for efficient activation of exting.	7.56E-02	8	24 174 €	2	-516 180 €	7	319 579 €	0.04	1	-6 823 746 €	-0.85
RCO 7	Training module for efficient activat. of exting.	6.13E-02	11	88 877 €	8	-350 063 €	9	1 448 871 €	0.18	7	-5 706 732 €	-0.71
RCO 8	Safe electrical connection for reefers	1.21E-01	5	162 475 €	9	-777 571 €	3	1 338 894 €	0.17	6	-6 407 681 €	-0.80
RCO 9	Safe electrical connection of reefers and EVs	1.22E-01	4	215 388 €	11	-725 739 €	4	1 772 686 €	0.22	8	-5 972 972 €	-0.75
RCO 10	Fire detection on weather decks	1.35E-02	14	184 476 €	10	111 614 €	15	13 622 172 €	1.70	14	8 241 844 €	1.03
RCO 11	Alternative fire detection in CRS & ORS	1.27E-01	3	411 988 €	15	-363 513 €	8	3 241 734 €	0.41	11	-2 860 312 €	-0.36
RCO 12	Visual system for fire confirmation and localiz.	1.20E-01	6	326 169 €	14	-520 965 €	6	2 715 037 €	0.34	10	-4 336 520 €	-0.54
RCO 14	Remote-control. fire monitor using water for WD	6.35E-02	10	261 769 €	12	-33 528 €	12	4 125 560 €	0.52	12	-528 406 €	-0.07
RCO 15	Autonomous fire monitor using water for WD	6.46E-02	9	317 508 €	13	12 601 €	13	4 918 613 €	0.61	13	195 207 €	0.02
RCO 16	Guideline for fire ventilation in CRS	1.11E-03	15	28 049 €	3	16 731 €	14	25 178 962 €	3.15	15	15 019 044 €	1.88

Table 16. $\Delta Risk$, $\Delta Cost$, $\Delta Benefits$, GCAF and NCAF values for the RCOs for ro-ro passenger ships, existing ships.

Ref	Designation	$\Delta Risk$	Rank	$\Delta Cost$	Rank	$\Delta Cost-\Delta Benefits$	Rank	GCAF	GCAF Factor	Rank	NCAF	NCAF Factor
RCO 1	Impr. fire patrol. Impr. fire confirmation & localiz.	8.91E-02	1	50 885 €	4	-442 040 €	1	570 853 €	0.07	1	-4 959 030 €	-0.62
RCO 2	Impr. signage and markings for effective localiz.	1.99E-02	10	39 189 €	3	-52 368 €	7	1 969 177 €	0.25	3	-2 631 423 €	-0.33
RCO 3	Developed efficient first response	5.21E-02	5	31 062 €	2	-258 246 €	2	596 165 €	0.07	2	-4 956 413 €	-0.62
RCO 4	Developed manual firefighting for APVs	1.71E-02	11	59 210 €	5	-33 853 €	8	3 465 203 €	0.43	7	-1 981 226 €	-0.25
RCO 6	Process [...] for efficient activation of exting.	4.05E-02	6	100 254 €	7	-123 649 €	5	2 477 796 €	0.31	5	-3 055 985 €	-0.38
RCO 7	Training module for efficient activat. of exting.	3.28E-02	9	68 644 €	6	-113 249 €	6	2 092 111 €	0.26	4	-3 451 551 €	-0.43
RCO 8	Safe electrical connection for reefers	6.49E-02	3	183 963 €	9	-209 289 €	3	2 834 211 €	0.35	6	-3 224 393 €	-0.40
RCO 9	Safe electrical connection of reefers and EVs	6.50E-02	2	229 485 €	10	-164 217 €	4	3 531 061 €	0.44	8	-2 526 788 €	-0.32
RCO 10	Fire detection on weather decks	7.24E-03	12	165 043 €	8	135 692 €	12	22 784 651 €	2.85	12	18 732 758 €	2.34
RCO 12	Visual system for fire confirmation and localiz.	6.43E-02	4	430 400 €	13	79 761 €	10	6 698 005 €	0.84	9	1 241 262 €	0.16
RCO 14	Remote-control. fire monitor using water for WD	3.39E-02	8	245 977 €	11	129 623 €	11	7 247 709 €	0.91	10	3 819 325 €	0.48
RCO 15	Autonomous fire monitor using water for WD	3.45E-02	7	297 811 €	12	177 283 €	13	8 625 213 €	1.08	11	5 134 486 €	0.64
RCO 16	Guideline for fire ventilation in CRS	5.96E-04	13	20 667 €	1	15 918 €	9	34 685 361 €	4.34	13	26 714 739 €	3.34

For new ro-ro passenger ships (Table 15), most of RCOs are found cost-effective, except RCO10 “Fire detection on weather decks” and RCO16 “Guideline for fire ventilation in closed ro-ro space”, whose GCAF and NCAF factors are greater than 1. For RCO10, it can be explained by one of the lowest $\Delta Risk$ among all the RCOs and a high $\Delta Cost$. For RCO16, it can be explained by its lowest $\Delta Risk$ among all the RCOs. The GCAF and NCAF factors of RCO10 and the NCAF factor of RCO16 are close to 1. The sensitivity analysis should provide a final conclusion about their cost-effectiveness. The RCOs with the lowest GCAF (top 5) are RCO6 “Process for development of procedures and design for efficient activation of extinguishing system”, RCO1 “Improved fire patrol. Improved fire confirmation & localization”, RCO3 “Developed efficient first response”, RCO5 “Alarm system interface prototype” and RCO2 “Improved signage and markings for effective wayfinding and localization”. They should be prioritized when developing recommendations for decision-making (step 5 of FSA).

For existing ro-ro passenger ships (Table 16), there is the same trend as observed for newbuildings, except that the GCAF factor of RCO15 “Fixed autonomous fire monitor system using water for weather decks” is now greater than 1 but close to 1. The GCAF factor of RCO12 “Visual system for fire confirmation and localization” and RCO14 “Fixed remotely-controlled fire monitor system using water for weather decks” are lower than 1 but close to 1. The sensitivity analysis should provide a final conclusion about their cost-effectiveness. The RCOs with the lowest GCAF (top 5) are RCO1 “Improved fire patrol. Improved fire confirmation & localization”, RCO3 “Developed efficient first response”, RCO2 “Improved signage and markings for effective wayfinding and localization”, RCO7 “Training module for efficient activation of extinguishing system” and RCO6 “Process for development of procedures and design for efficient activation of extinguishing system”. They should be prioritized when developing recommendations for decision-making (step 5 of FSA).

For ro-ro passenger ships, the RCOs only covering weather decks (e.g. RCO10, 14 and 15) have a low ranking in terms of GCAF because of their high Δ Cost and the low contribution of fires from the weather decks on the global risk model for ro-ro passenger ships (10%). The influence of weather decks should be further analyzed as sensitivity.

7.3.2 Ro-ro cargo ships

Table 17 and Table 18 list the input values Δ Risk and Δ Cost, as well as the resulting cost-effectiveness indices GCAF and NCAF for each RCO on new and existing ro-ro cargo ships, respectively.

Table 17. Δ Risk, Δ Cost, Δ Benefits, GCAF and NCAF values for the RCOs for ro-ro cargo ships, newbuildings.

Ref	Designation	Δ Risk	Rank	Δ Cost	Rank	Δ Cost- Δ Benefits	Rank	GCAF	GCAF Factor	Rank	NCAF	NCAF Factor
RCO 1	Impr. fire patrol. Impr. fire confirmation & localiz.	1.10E-03	3	57 650 €	5	-322 572 €	1	52 445 708 €	6.56	1	-293 451 260 €	-36.68
RCO 2	Impr. signage and markings for effective localiz.	1.35E-04	12	20 552 €	1	-19 857 €	8	152 526 820 €	19.07	6	-147 368 195 €	-18.42
RCO 3	Developed efficient first response	4.85E-04	8	26 487 €	3	-152 484 €	5	54 636 997 €	6.83	2	-314 544 179 €	-39.32
RCO 4	Developed manual firefighting for APVs	2.18E-04	11	64 272 €	6	-9 989 €	9	295 295 921 €	36.91	8	-45 894 312 €	-5.74
RCO 5	Alarm system interface prototype	1.00E-03	4	85 807 €	7	-274 096 €	2	85 680 937 €	10.71	3	-273 694 357 €	-34.21
RCO 6	Process [...] for efficient activation of exting.	2.64E-04	10	23 396 €	2	-87 953 €	6	88 673 751 €	11.08	4	-333 359 180 €	-41.67
RCO 7	Training module for efficient activat. of exting.	2.73E-04	9	86 429 €	8	-28 413 €	7	316 699 836 €	39.59	10	-104 114 589 €	-13.01
RCO 8	Safe electrical connection for reefers	1.25E-04	13	129 382 €	9	73 136 €	12	1 038 403 768 €	129.80	13	586 984 024 €	73.37
RCO 10	Fire detection on weather decks	6.38E-04	5	200 447 €	10	48 327 €	11	314 015 405 €	39.25	9	75 707 571 €	9.46
RCO 11	Alternative fire detection in CRS & ORS	6.05E-04	6	483 282 €	13	275 581 €	13	798 750 897 €	99.84	11	455 470 298 €	56.93
RCO 12	Visual system for fire confirmation and localiz.	5.48E-04	7	560 286 €	14	352 390 €	14	1 023 240 774 €	127.91	12	643 563 135 €	80.45
RCO 14	Remote-control. fire monitor using water for WD	2.62E-03	2	361 223 €	11	-219 195 €	3	137 913 452 €	17.24	5	-83 687 790 €	-10.46
RCO 15	Autonomous fire monitor using water for WD	2.66E-03	1	425 279 €	12	-172 661 €	4	159 714 750 €	19.96	7	-64 843 559 €	-8.11
RCO 16	Guideline for fire ventilation in CRS	2.01E-06	14	27 156 €	4	26 105 €	10	13 499 054 855 €	1687.38	14	12 976 911 902 €	1622.11

Table 18. Δ Risk, Δ Cost, Δ Benefits, GCAF and NCAF values for the RCOs for ro-ro cargo ships, existing ships.

Ref	Designation	Δ Risk	Rank	Δ Cost	Rank	Δ Cost- Δ Benefits	Rank	GCAF	GCAF Factor	Rank	NCAF	NCAF Factor
RCO 1	Impr. fire patrol. Impr. fire confirmation & localiz.	6.32E-04	3	48 005 €	4	-71 942 €	1	75 949 972 €	9.49	2	-113 821 619 €	-14.23
RCO 2	Impr. signage and markings for effective localiz.	7.75E-05	10	39 189 €	3	25 980 €	4	505 809 709 €	63.23	7	335 324 015 €	41.92
RCO 3	Developed efficient first response	2.79E-04	6	20 777 €	2	-35 426 €	2	74 537 142 €	9.32	1	-127 089 397 €	-15.89
RCO 4	Developed manual firefighting for APVs	1.25E-04	9	53 114 €	5	30 052 €	5	424 401 199 €	53.05	5	240 124 519 €	30.02
RCO 6	Process [...] for efficient activation of exting.	1.52E-04	8	83 814 €	7	49 393 €	7	552 473 626 €	69.06	9	325 577 574 €	40.70
RCO 7	Training module for efficient activat. of exting.	1.57E-04	7	68 644 €	6	33 138 €	6	437 446 205 €	54.68	6	211 179 443 €	26.40
RCO 8	Safe electrical connection for reefers	7.16E-05	11	140 323 €	8	122 862 €	8	1 958 644 841 €	244.83	11	1 714 922 807 €	214.37
RCO 10	Fire detection on weather decks	3.67E-04	4	186 850 €	9	137 590 €	9	509 068 896 €	63.63	8	374 861 109 €	46.86
RCO 12	Visual system for fire confirmation and localiz.	3.15E-04	5	514 712 €	12	450 199 €	12	1 634 798 789 €	204.35	10	1 429 896 059 €	178.74
RCO 14	Remote-control. fire monitor using water for WD	1.51E-03	2	346 973 €	10	159 546 €	10	230 387 311 €	28.80	3	105 937 110 €	13.24
RCO 15	Autonomous fire monitor using water for WD	1.53E-03	1	406 040 €	11	212 665 €	11	265 199 219 €	33.15	4	138 898 898 €	17.36
RCO 16	Guideline for fire ventilation in CRS	1.16E-06	12	20 667 €	1	20 349 €	3	17 867 234 445 €	2233.40	12	17 591 925 226 €	2198.99

For new ro-ro cargo ships (Table 17), the GCAF factor of all the RCOs is far above 1. Therefore, no RCO is found cost-effective in terms of GCAF. It can be explained by their low Δ Risk. The NCAF factor of some RCOs is far above 1. Therefore, they are found not cost-effective in terms of NCAF. Nine RCOs (RCO1, 2, 3, 4, 5, 6, 7, 14 and 15) have a negative NCAF. Therefore, they are found economically beneficial in saving the cargo and ship, even if their contribution to life safety is not cost-effective. RCO1 “Improved Fire patrol. Improved fire confirmation & localization”, RCO5 “Alarm system interface prototype”, RCO14 “Fixed remotely-controlled fire monitor system using water for weather decks” and RCO15 “Fixed autonomous fire monitor system using water for weather decks” have high Δ Risk and high negative Δ Cost- Δ Benefits. They should be recommended when developing recommendations for decision-making (step 5 of FSA). RCO3 “Developed efficient first response” and RCO6 “Process for development of procedures and design for efficient activation of extinguishing system” have high negative Δ Cost- Δ Benefits but low Δ Risk (in comparison to previous RCOs). They need further analysis to conclude. The three other RCOs (RCO2, 4 and 7) with low Δ Risk and low Δ Cost- Δ Benefits should not be prioritized when developing recommendations for decision-making (step 5 of FSA).

For existing ro-ro cargo ships (Table 18), the GCAF factor of all the RCOs is far above 1. Therefore, no RCO is found cost-effective in terms of GCAF. The NCAF factor of most of the RCOs is far above 1. Therefore, they are found not cost-effective in terms of NCAF. Two RCOs (RCO1 and 3) have a negative NCAF. Therefore, they are found economically beneficial in saving the cargo and ship, even if their contribution to life safety is not cost-effective. RCO1 “Improved fire patrol. Improved fire confirmation & localization” and RCO3 “Developed efficient first response” have high Δ Risk and high negative Δ Cost- Δ Benefits. They should be recommended when developing recommendations for decision-making (step 5 of FSA).

7.3.3 Vehicle carriers

Table 19 and Table 20 list the input values Δ Risk and Δ Cost, as well as the resulting cost-effectiveness indices GCAF and NCAF for each RCO on new and existing vehicle carriers, respectively.

Table 19. Δ Risk, Δ Cost, Δ Benefits, GCAF and NCAF values for the RCOs for vehicle carriers, newbuildings.

Ref	Designation	Δ Risk	Rank	Δ Cost	Rank	Δ Cost- Δ Benefits	Rank	GCAF	GCAF Factor	Rank	NCAF	NCAF Factor
RCO 1	Improved fire confirmation & localization	3.59E-05	10	36 193 €	4	-51 134 €	7	1 009 269 873 €	126.16	5	-1 425 931 895 €	-178.24
RCO 2	Impr. signage and markings for effective localiz.	5.54E-05	9	21 681 €	2	-95 562 €	5	391 059 688 €	48.88	4	-1 723 656 243 €	-215.46
RCO 3	Developed efficient first response	3.46E-04	3	22 977 €	3	-234 839 €	2	66 500 157 €	8.31	1	-679 672 767 €	-84.96
RCO 4	Developed manual firefighting for APVs	5.81E-05	8	65 851 €	5	-74 524 €	6	1 132 869 348 €	141.61	6	-1 282 079 696 €	-160.26
RCO 5	Alarm system interface prototype	3.07E-04	4	80 863 €	6	-633 279 €	1	263 124 884 €	32.89	3	-2 060 671 372 €	-257.58
RCO 6	Process [...] for efficient activation of exting.	9.17E-05	6	19 918 €	1	-203 479 €	3	217 118 118 €	27.14	2	-2 218 083 650 €	-277.26
RCO 7	Training module for efficient activat. of exting.	8.96E-05	7	112 324 €	7	-105 954 €	4	1 253 132 386 €	156.64	7	-1 182 069 382 €	-147.76
RCO 11	Alternative fire detection in CRS & ORS	4.22E-04	1	830 205 €	8	253 689 €	8	1 965 142 973 €	245.64	8	600 496 133 €	75.06
RCO 12	Visual system for fire confirmation and localiz.	1.42E-04	5	1 056 375 €	9	712 828 €	9	7 454 599 983 €	931.82	10	5 030 270 129 €	628.78
RCO 13	Dry-pipe sprinkler system for VC	3.99E-04	2	2 023 333 €	10	1 055 498 €	10	5 076 522 834 €	634.57	9	2 648 232 425 €	331.03

Table 20. Δ Risk, Δ Cost, Δ Benefits, GCAF and NCAF values for the RCOs for vehicle carriers, existing ships.

Ref	Designation	Δ Risk	Rank	Δ Cost	Rank	Δ Cost- Δ Benefits	Rank	GCAF	GCAF Factor	Rank	NCAF	NCAF Factor
RCO 1	Improved fire confirmation & localization	2.10E-05	7	28 986 €	3	-15 477 €	6	1 378 866 571 €	172.36	4	-736 251 962 €	-92.03
RCO 2	Impr. signage and markings for effective localiz.	3.25E-05	6	42 802 €	4	-19 561 €	4	1 316 976 564 €	164.62	3	-601 889 679 €	-75.24
RCO 3	Developed efficient first response	2.03E-04	1	18 073 €	2	-112 767 €	1	89 228 759 €	11.15	1	-556 750 022 €	-69.59
RCO 4	Developed manual firefighting for APVs	3.41E-05	5	51 301 €	5	-18 804 €	5	1 505 536 634 €	188.19	5	-551 854 658 €	-68.98
RCO 6	Process [...] for efficient activation of exting.	5.38E-05	3	16 558 €	1	-97 186 €	2	307 905 158 €	38.49	2	-1 807 213 375 €	-225.90
RCO 7	Training module for efficient activat. of exting.	5.25E-05	4	85 875 €	6	-25 263 €	3	1 634 330 417 €	204.29	6	-480 788 116 €	-60.10
RCO 12	Visual system for fire confirmation and localiz.	8.31E-05	2	1 066 651 €	7	893 522 €	7	12 840 375 013 €	1605.05	7	10 756 245 180 €	1344.53

For new vehicle carriers (Table 19), the GCAF factor of all the RCOs is far above 1. Therefore, no RCO is found cost-effective in terms of GCAF. It can be explained by their low Δ Risk. The NCAF factor of some RCOs is far above 1. Therefore, they are found not cost-effective in terms of NCAF. Seven RCOs (RCO1, 2, 3, 4, 5, 6 and 7) have a negative NCAF. Therefore, they are found economically beneficial in saving the cargo and ship, even if their contribution to life safety is not cost-effective. RCO3 “Developed efficient first response”, RCO5 “Alarm system interface prototype”, RCO6 “Process for development of procedures and design for efficient activation of extinguishing system” and RCO7 “Training module for efficient activation of extinguishing system” have high Δ Risk and high negative Δ Cost- Δ Benefits. They should be recommended when developing recommendations for decision-making (step 5 of FSA). RCO1 “Improved fire confirmation & localization”, RCO2 “Improved signage and markings for effective wayfinding and localization” and RCO4 “Developed manual firefighting for Alternatively Powered Vehicles” have high negative Δ Cost- Δ Benefits but low Δ Risk (in comparison to previous RCOs). They need further analysis to conclude.

For existing vehicle carriers (Table 20), the GCAF factor of all the RCOs is far above 1. Therefore, no RCO is found cost-effective in terms of GCAF. The NCAF factor of RCO12 “Visual system for fire confirmation and localization” is far above 1. Therefore, it is found not cost-effective in terms of NCAF. Six RCOs (RCO1, 2, 3, 4, 6 and 7) have a negative NCAF. Therefore, they are found economically beneficial in saving the cargo and ship, even if their contribution to life safety is not cost-effective. RCO3 “Developed efficient first response” has a high Δ Risk and high negative Δ Cost- Δ Benefits. It should be recommended when developing recommendations for decision-making (step 5 of FSA). RCO6 “Process for development of procedures and design for efficient activation of extinguishing system” has high negative Δ Cost- Δ Benefits but low Δ Risk (in comparison to previous RCOs). It needs further analysis to conclude. The three other RCOs (RCO1, 2, 4 and 7) with low Δ Risk and low Δ Cost- Δ Benefits should not be prioritized when developing recommendations for decision-making (step 5 of FSA).

7.4 Comparison with previous study

The results from LASH FIRE were compared with the results of the FIRESAFE studies [28]. Since only ro-ro passenger ships were addressed in the FIRESAFE studies, a comparison for only ro-ro passenger ships is possible. The generic ship *Standard RoPax* of FIRESAFE II was selected for comparison. The generic ship *Standard RoPax* of FIRESAFE II is the same ship as is used as reference ship for ro-ro passenger ships in LASH FIRE (Stena Flavia). Only RCOs that are deemed comparable between the two studies are included in the exercise. It should be noted that the definitions of the RCOs are not strictly identical from one study to the other. Generally, the RCOs of the LASH FIRE project include more features/functionalities than in the FIRESAFE studies.

Table 21 and Table 22 provides the comparison. The RCOs that were found cost-effective in the FIRESAFE studies remain cost-effective in the LASH FIRE project, except RCO10 “Fire detection on weather decks”.

RCO10 “Fire detection on weather decks” has a lower ΔRisk and a higher ΔCost than RCO WP41 “Thermal Imaging Camera”. It can be explained by the lower contribution of fires from the weather decks on the global risk in the LASH FIRE risk model (initially, 33% of PLL for weather decks in FIRESAFE II vs. 10% of PLL for weather decks in LASH FIRE). To be noted that the GCAF factor of RCO10 for newbuildings and WP41 for existing ships are close to 1 (i.e. a small change in ΔRisk or ΔCost can easily modify the conclusion).

RCO12 “Visual system for fire confirmation and localization” and RCO14 “Fixed remotely-controlled fire monitor system using water for weather decks” for existing ships have GCAF factor close to 1, which was not the case for Su6 “CCTV” and Cont2 “Fire monitors on weather deck”. For RCO14 vs. Cont2, it is again explained by the decrease in contribution of fires from the weather decks on the global risk. For RCO12 vs. Su6, it is explained by the additional features of RCO12 (e.g. video algorithm, possibility of thermal camera...) and therefore a higher ΔCost .

Table 21. Comparison GCAF FIRESAFE vs. LASH FIRE – Ro-ro passenger ships, newbuildings.

FIRESAFE studies - Standard RoPax - Newbuildings				LASH FIRE - Ro-ro passenger ships - Newbuildings			
RCO	Designation	GCAF	GCAF Factor	RCO	Designation	GCAF	GCAF Factor
Dec2	Improved markings/signage for localiz.	94 265 €	0.01	RCO2	Impr. signage and markings for effective localiz.	565 203 €	0.07
Dec1	Alarm system design & integration	323 091 €	0.05	RCO5	Alarm system interface prototype	526 626 €	0.07
WP41	Thermal Imaging Camera	3 288 984 €	0.47	RCO10	Fire detection on weather decks	13 622 172 €	1.70
WP42	Linear Fibre Optic	732 006 €	0.10	RCO11	Alternative fire detection in CRS & ORS	3 241 734 €	0.41
Su6	CCTV	1 948 163 €	0.28	RCO12	Visual system for fire confirmation and localiz.	2 715 037 €	0.34
Cont2	Fire monitors on weather deck	351 615 €	0.05	RCO14	Remote-control. fire monitor using water for WD	4 125 560 €	0.52

Table 22. Comparison GCAF FIRESAFE vs. LASH FIRE – Ro-ro passenger ships, existing ships.

FIRESAFE studies - Standard RoPax - Existing ships				LASH FIRE - Ro-ro passenger ships - Existing ships			
RCO	Designation	GCAF	GCAF Factor	RCO	Designation	GCAF	GCAF Factor
Dec2	Improved markings/signage for localiz.	189 958 €	0.03	RCO2	Impr. signage and markings for effective localiz.	1 969 177 €	0.25
Dec1	Alarm system design & integration	4 351 531 €	0.62	RCO5	Alarm system interface prototype	Not assessed	Not assessed
WP41	Thermal Imaging Camera	6 339 491 €	0.91	RCO10	Fire detection on weather decks	22 784 651 €	2.85
WP42	Linear Fibre Optic	1 368 050 €	0.20	RCO11	Alternative fire detection in CRS & ORS	Not assessed	Not assessed
Su6	CCTV	4 128 395 €	0.59	RCO12	Visual system for fire confirmation and localiz.	6 698 005 €	0.84
Cont2	Fire monitors on weather deck	907 858 €	0.13	RCO14	Remote-control. fire monitor using water for WD	7 247 709 €	0.91

8 Conclusion

Main author of the chapter: Eric De Carvalho, BV

Among all the technical and operational solutions developed in the LASH FIRE project, 16 RCOs were selected and defined. Their marginal cost and risk reduction in terms of fatalities, cargo losses and ship losses were estimated. Finally, their cost-effectiveness indices were computed and analyzed.

Table 23 and Table 24 summarize the cost-effectiveness results for all RCOs. These results are interim and will be ascertained by the sensitivity and uncertainty analyses that will be conducted as a next step in the project.

Table 23. Cost-effective RCOs in increasing life safety.

Ref	Designation	Cost-effective in increasing life safety?					
		Ro-pax		Ro-ro cargo		Vehicle carrier	
		NB	Ex	NB	Ex	NB	Ex
RCO 1	Impr. fire patrol. Impr. fire confirmation & localiz.	Yes	Yes	No	No	No	No
RCO 2	Impr. signage and markings for effective localiz.	Yes	Yes	No	No	No	No
RCO 3	Developed efficient first response	Yes	Yes	No	No	No	No
RCO 4	Developed manual firefighting for APVs	Yes	Yes	No	No	No	No
RCO 5	Alarm system interface prototype	Yes	Not assessed	No	Not assessed	No	Not assessed
RCO 6	Process [...] for efficient activation of exting.	Yes	Yes	No	No	No	No
RCO 7	Training module for efficient activat. of exting.	Yes	Yes	No	No	No	No
RCO 8	Safe electrical connection for reefers	Yes	Yes	No	No	Not assessed	Not assessed
RCO 9	Safe electrical connection of reefers and EVs	Yes	Yes	Not assessed	Not assessed	Not assessed	Not assessed
RCO 10	Fire detection on weather decks	TBC	No	No	No	Not assessed	Not assessed
RCO 11	Alternative fire detection in CRS & ORS	Yes	Not assessed	No	Not assessed	No	Not assessed
RCO 12	Visual system for fire confirmation and localiz.	Yes	TBC	No	No	No	No
RCO 13	Dry-pipe sprinkler system for VC	Not assessed	Not assessed	Not assessed	Not assessed	No	Not assessed
RCO 14	Remote.-control. fire monitor using water for WD	Yes	TBC	No	No	Not assessed	Not assessed
RCO 15	Autonomous fire monitor using water for WD	Yes	TBC	No	No	Not assessed	Not assessed
RCO 16	Guideline for fire ventilation in CRS	No	No	No	No	Not assessed	Not assessed

Table 24. Cost-effective RCOs in saving cargo and ship.

Ref	Designation	Cost-effective in saving cargo and ship?					
		Ro-pax		Ro-ro cargo		Vehicle carrier	
		NB	Ex	NB	Ex	NB	Ex
RCO 1	Impr. fire patrol. Impr. fire confirmation & localiz.	Yes	Yes	Yes	Yes	TBC	TBC
RCO 2	Impr. signage and markings for effective localiz.	Yes	Yes	TBC	No	TBC	TBC
RCO 3	Developed efficient first response	Yes	Yes	TBC	Yes	Yes	Yes
RCO 4	Developed manual firefighting for APVs	Yes	Yes	TBC	No	TBC	TBC
RCO 5	Alarm system interface prototype	Yes	Not assessed	Yes	Not assessed	Yes	Not assessed
RCO 6	Process [...] for efficient activation of exting.	Yes	Yes	TBC	No	Yes	TBC
RCO 7	Training module for efficient activat. of exting.	Yes	Yes	TBC	No	Yes	TBC
RCO 8	Safe electrical connection for reefers	Yes	Yes	No	No	Not assessed	Not assessed
RCO 9	Safe electrical connection of reefers and EVs	Yes	Yes	Not assessed	Not assessed	Not assessed	Not assessed
RCO 10	Fire detection on weather decks	TBC	No	No	No	Not assessed	Not assessed
RCO 11	Alternative fire detection in CRS & ORS	Yes	Not assessed	No	Not assessed	No	Not assessed
RCO 12	Visual system for fire confirmation and localiz.	Yes	Yes	No	No	No	No
RCO 13	Dry-pipe sprinkler system for VC	Not assessed	Not assessed	Not assessed	Not assessed	No	Not assessed
RCO 14	Remote.-control. fire monitor using water for WD	Yes	Yes	Yes	No	Not assessed	Not assessed
RCO 15	Autonomous fire monitor using water for WD	Yes	Yes	Yes	No	Not assessed	Not assessed
RCO 16	Guideline for fire ventilation in CRS	TBC	No	No	No	Not assessed	Not assessed

CRS = closed ro-ro space, ORS = open ro-ro space, WD = weather deck, NB = newbuildings, Ex = existing ships, TBC = To Be Confirmed.

- **Ro-ro passenger ships - Newbuildings:**

Most of RCOs (13 RCOs over 15) were found cost-effective in terms of life safety, saving the cargo and ship.

RCO10 “Fire detection on weather decks” and RCO16 “Guideline for fire ventilation in closed ro-ro space” need further analysis to conclude.

- **Ro-ro passenger ships - Existing ships:**

Most of RCOs (8 RCOs over 13) were found cost-effective in terms of life safety, saving the cargo and ship. RCO12 “Visual system for fire confirmation and localization”, RCO14 “Fixed remotely-controlled fire monitor system using water for weather decks” and RCO15 “Fixed autonomous fire monitor system using water for weather decks” were found cost-effective in saving the cargo and ship.

RCO12, RCO14 and RCO15 need further analysis to conclude.

- **Ro-ro cargo ships - Newbuildings:**

No RCOs were found cost-effective in terms of life safety. RCO1 “Improved fire patrol. Improved fire confirmation & localization”, RCO5 “Alarm system interface prototype”, RCO14 “Fixed remotely-controlled fire monitor system using water for weather decks” and RCO15 “Fixed autonomous fire monitor system using water for weather decks” were found cost-effective in saving the cargo and ship and are further recommended.

RCO3 “Developed efficient first response” and RCO6 “Process for development of procedures and design for efficient activation of extinguishing system” need further analysis to conclude.

- **Ro-ro cargo ships - Existing ships:**

No RCOs were found cost-effective in terms of life safety. RCO1 “Improved fire patrol. Improved fire confirmation & localization” and RCO3 “Developed efficient first response” were found cost-effective in saving the cargo and ship and are further recommended.

- **Vehicle carriers - Newbuildings:**

No RCOs were found cost-effective in terms of life safety. RCO3 “Developed efficient first response”, RCO5 “Alarm system interface prototype”, RCO6 “Process for development of procedures and design for efficient activation of extinguishing system” and RCO7 “Training module for efficient activation of extinguishing system” were found cost-effective in saving the cargo and ship and are further recommended.

RCO1 “Improved fire confirmation & localization”, RCO2 “Improved signage and markings for effective wayfinding and localization” and RCO4 “Developed manual firefighting for Alternatively Powered Vehicles” need further analysis to conclude.

- **Vehicle carriers - Existing ships:**

No RCOs were found cost-effective in terms of life safety. RCO3 “Developed efficient first response” was found cost-effective in saving the cargo and ship and is further recommended.

RCO6 “Process for development of procedures and design for efficient activation of extinguishing system” needs further analysis to conclude.

The work presented in this deliverable will be completed with sensitivity and uncertainty analyses. This will be reported in deliverable D04.7 “Cost-effectiveness assessment report: Uncertainty and sensitivity analysis report” [5]. Then, the final conclusions about cost-effectiveness of the RCOs will be drawn. The next step will be to develop recommendations on decision-making (T04.9) based on the cost-effective RCOs.

This deliverable (with deliverable D04.7 [5]) is the summary of task T04.6 and T04.7, respectively ‘*Cost and benefit (risk reduction) integration for operational and technical solutions*’ and ‘*Cost-effectiveness assessment*’. It contributes to the strategic objective:

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

and to the specific objective 3:

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

9 References

- [1] IMO, *Revised Guidelines for Formal Safety Assessment (FSA) for the use in the IMO rule-making process, MSC-MEPC.2/Circ.12/Rev.2*, 2018.
- [2] L. Lewandowski, E. De Carvalho and A. Cassez, *Holistic risk model (D04.4)*, LASH FIRE, 2022.
- [3] L. Lewandowski, E. De Carvalho and A. Cassez, *Development of holistic risk model report (D04.5)*, LASH FIRE, 2022.
- [4] V. Radolovic, *Ship integration cost and environmental assessment (D05.8)*, LASH FIRE, 2023.
- [5] E. De Carvalho and L. Lewandowski, *Cost-effectiveness assessment report: Uncertainty and sensitivity analysis report (D04.7)*, LASH FIRE, 2023.
- [6] E. De Carvalho, *Preliminary impact of solutions and related testing and demonstrations plan (D04.9)*, LASH FIRE, 2022.
- [7] V. Radolovic and O. Kuzmanovic, *Ship integration evaluation (D05.7)*, LASH FIRE, 2022.
- [8] B. Loicq, *First proposal on updated rules and regulations on fire safety (D03.5)*, LASH FIRE, 2022.
- [9] E. Hollnagel, D. Woods and N. Leveson, *Resilience Engineering: concepts and precepts*, Aldershot, UK: Ashgate, 2006.
- [10] M. Arvidson, *Description of the development of automatic first response fire protection systems for ro-ro spaces on vehicle carriers (D10.1)*, LASH FIRE, 2022.
- [11] IMO, *Guidelines for the drainage of fire-fighting water from closed vehicle and ro-ro spaces and special category spaces of passenger and cargo ships, MSC.1/Circ.1320*, 2009.
- [12] J. Steinke, H. Aminoff, L. S. Pantelatos, F. M. Petermann and E. S. Petersen, *Alarm system interface prototype development and testing (D07.6)*, LASH FIRE, 2022.
- [13] INERIS, *Program EAT-DRA73: Assessment of Technical Safety Barriers Performance - Comparative performance tests on flame detectors, DRA-11-117743-08553A*, 2011.
- [14] F. Evgren, *proFLASH: Methanol fire detection and extinguishment, SP Rapport 2017:22*, RISE Research Institutes of Sweden, 2017.
- [15] J. Leroux et al., *FIRESAFE II Detection systems in open ro-ro and weather decks, Version 2.2, 2017/EMSA/OP/17/2017*, EMSA, 2018.
- [16] Fike, "Fike High-Speed Flame Detection," YouTube, 2020. [Online]. Available: https://www.youtube.com/watch?v=dj2PQv_1OMo. [Accessed 10 11 2022].
- [17] European Committee for Standardization (CEN), *Fire detection and fire alarm systems - Part 22: Resettable line-type heat detectors, EN 54-22+A1*, 2020.
- [18] M. Ahrens, *U.S. Experience with Sprinklers*, National fire Protection Association, 2021.

- [19] R. G. Bill et al., *Research Technical Memorandum. Sprinkler and Sprinkler Reliability*, FM Global, 2007.
- [20] J. Hall and R. John, *U.S. Experience with Sprinklers and other Automatic Fire Extinguishing Equipment*, National Fire Protection Association, 2010.
- [21] H. Maryatt, *Fire: A Century of Automatic Sprinkler Protection in Australia and New Zealand 1886-1986*, Australian Fire Protection Association, 1988.
- [22] OREDA, *Offshore Reliability Data Handbook, 4th Edition*, 2022.
- [23] IMO, *Guidelines on alternative design and arrangements, MSC/Circ.1002*, 2001.
- [24] IMO, *Decision parameters including risk acceptance criteria, MSC 72/16*, 2000.
- [25] J. Wikman et al., *Study investigating cost effective measures for reducing the risk from fires on ro-ro passenger ships (FIRESAFE)*, EMSA, 2016.
- [26] J. Leroux et al., *FIRESAFE II Detection and Decision, Final Report, Version 1.1, 2017/EMSA/OP/17/2017*, EMSA, 2018.
- [27] EMSA, *Risk Acceptance Criteria and Risk Based Damage Stability. Final Report, part 1: Risk Acceptance Criteria*, Lisbon: European Maritime Safety Agency, 2015.
- [28] J. Leroux et al., *FIRESAFE II Combined Assessment, Final Report, Version 1.1, 2017/EMSA/OP/17/2017*, EMSA, 2018.

10 Indexes

10.1 Index of tables

Table 1. Summary of the 44 RCMs proposed by the D&D WPs.	10
Table 2. Colour code used to split RCMs in different categories, based on their risk reduction.	15
Table 3. Colour code used to split RCMs in different categories, based on their integration feasibility.	16
Table 4. Colour code used to split RCMs in different categories, based on their preliminary cost.	16
Table 5. Colour code used to split RCMs in different categories, based on their regulatory compatibility.	17
Table 6. Colour code used to split RCMs in different categories, based on the inputs from maritime stakeholders.	18
Table 7. List of the 16 selected RCOs.	20
Table 8. Percentage of fires from light vehicles among all fires originating from ro-ro spaces.	48
Table 9. Sprinkler reliability for dry pipe sprinkler systems according to the analysis by NFPA [18]. ..	63
Table 10. Reasons for sprinkler failure or ineffectiveness in structure fires large enough to activate sprinklers in the area and the reason why operating sprinklers were ineffective according to the analysis by NFPA [18].	64
Table 11. The number of sprinklers that operated in structure fires by the type of sprinkler system according to the analysis by NFPA [18].	65
Table 12. Expected lifetime (in years) for the different types of ships studied, for the PLL.	81
Table 13. Summary of the marginal costs (in euros) for the RCOs, for newbuildings.	83
Table 14. Summary of the marginal costs (in euros) for the RCOs, for existing ships.	83
Table 15. Δ Risk, Δ Cost, Δ Benefits, GCAF and NCAF values for the RCOs for ro-ro passenger ships, newbuildings.	84
Table 16. Δ Risk, Δ Cost, Δ Benefits, GCAF and NCAF values for the RCOs for ro-ro passenger ships, existing ships.	84
Table 17. Δ Risk, Δ Cost, Δ Benefits, GCAF and NCAF values for the RCOs for ro-ro cargo ships, newbuildings.	85
Table 18. Δ Risk, Δ Cost, Δ Benefits, GCAF and NCAF values for the RCOs for ro-ro cargo ships, existing ships.	85
Table 19. Δ Risk, Δ Cost, Δ Benefits, GCAF and NCAF values for the RCOs for vehicle carriers, newbuildings.	86
Table 20. Δ Risk, Δ Cost, Δ Benefits, GCAF and NCAF values for the RCOs for vehicle carriers, existing ships.	86
Table 21. Comparison GCAF FIRESAFE vs. LASH FIRE – Ro-ro passenger ships, newbuildings.	89
Table 22. Comparison GCAF FIRESAFE vs. LASH FIRE – Ro-ro passenger ships, existing ships.	89
Table 23. Cost-effective RCOs in increasing life safety.	90
Table 24. Cost-effective RCOs in saving cargo and ship.	90
Table 25. Detailed list of the 16 selected RCOs.	97
Table 26. Breakdown of the marginal costs (in euros) for the RCOs, for newbuildings.	98
Table 27. Breakdown of the marginal costs (in euros) for the RCOs, for existing ships.	100
Table 28. Risk reduction of RCOs – Ro-ro passenger ships, newbuildings.	102
Table 29. Risk reduction of RCOs – Ro-ro passenger ships, existing ships.	102
Table 30. Risk reduction of RCOs – Ro-ro cargo ships, newbuildings.	102
Table 31. Risk reduction of RCOs – Ro-ro cargo ships, existing ships.	102
Table 32. Risk reduction of RCOs – Vehicle carriers, newbuildings.	103
Table 33. Risk reduction of RCOs – Vehicle carriers, existing ships.	103

10.2 Index of figures

Figure 1. Ranking of all the RCMs by risk reduction for ro-ro passenger ships.....	14
Figure 2. Ranking of all the RCMs by risk reduction for ro-ro cargo ships.	15
Figure 3. Ranking of all the RCMs by risk reduction for vehicle carriers.	15
Figure 4. Steps of the methodology.	19
Figure 5. Detail from the excel file used to select the RCOs.	20
Figure 6. Typical first response outfit on board Stena Flavia.	25
Figure 7. Elements of reflection, evaluation and change process.	30
Figure 8. Example flame detector (left) and thermal imaging camera (right).	34
Figure 9. Example ceiling installation of a linear heat detection cable (isolated from a pipe using a spacer).	36
Figure 10. Example CCTV camera (left) and thermal imaging camera (right).	37
Figure 11. Square law between distance and area of detection (applicable when $D2 \gg D1$): if an object that has an area of $A1$ is detectable at the distance of $D1$, detection at a distance of $2 \times D1$ requires nearly an area of $4 \times A1$	37
Figure 12. Time until CO_2 activation and time during which the sprinkler system suppresses the fire..	66
Figure 13. Time difference between CO_2 activation and sprinkler system suppression, following early detection.	67
Figure 14. Time difference between CO_2 activation and sprinkler system suppression, following late detection.	67
Figure 15. Survey results for the question "What effect did you think the ventilation had on:".	73
Figure 16. Risk reduction of RCOs in terms of PLL – Ro-ro passenger ships, newbuildings.	75
Figure 17. Risk reduction of RCOs in terms of PLL – Ro-ro passenger ships, existing ships.	76
Figure 18. Risk reduction of RCOs in terms of PLL – Ro-ro cargo ships, newbuildings.	76
Figure 19. Risk reduction of RCOs in terms of PLL – Ro-ro cargo ships, existing ships.	77
Figure 20. Risk reduction of RCOs in terms of PLL – Vehicle carriers, newbuildings.	78
Figure 21. Risk reduction of RCOs in terms of PLL – Vehicle carriers, existing ships.	78

11 ANNEXES

11.1 ANNEX A: Detailed list of the 16 selected RCOs

Table 25. Detailed list of the 16 selected RCOs.

ID	RCM(s) of origin	Title of Risk Control Option (RCO)	Ship types	Ro-ro space types	NB + Ex?
WP06					
RCO1	Op1, Op4	Improved fire patrol. Improved fire confirmation & localization	Ro-Pax, Ro-Ro, VC	CRS, ORS, WD	NB + Ex
RCO2	Op3	Improved signage and markings for effective wayfinding and localization	Ro-Pax, Ro-Ro, VC	CRS, ORS, WD	NB + Ex
RCO3	Op5	Developed efficient first response	Ro-Pax, Ro-Ro, VC	CRS, ORS, WD	NB + Ex
RCO4	Op7	Developed manual firefighting for Alternately Powered Vehicles	Ro-Pax, Ro-Ro, VC	CRS, ORS, WD	NB + Ex
WP07					
RCO5	Des2	Alarm system interface prototype	Ro-Pax, Ro-Ro, VC	CRS, ORS, WD	NB
RCO6	Des3	Process for development of procedures and design for efficient activation of extinguishing system	Ro-Pax, Ro-Ro, VC	CRS, ORS	NB + Ex
RCO7	Des4	Training module for efficient activation of extinguishing system	Ro-Pax, Ro-Ro, VC	CRS, ORS	NB + Ex
WP08					
RCO8	Pre3	Safe electrical connection for reefers	Ro-Pax, Ro-Ro	CRS, ORS, WD	NB + Ex
RCO9	Pre4, Pre3	Safe electrical connection of reefers and electric vehicles (EVs)	Ro-Pax	CRS, ORS, WD	NB + Ex
WP09					
RCO10	Ex: Det1, Det8	Fire detection on weather decks	Ro-Pax, Ro-Ro	WD	NB + Ex
RCO11	Det7	Alternative fire detection in closed ro-ro spaces & open ro-ro spaces	Ro-Pax, Ro-Ro, VC	CRS, ORS	NB
RCO12	Ex: Det5, Det6, Det8	Visual system for fire confirmation and localization	Ro-Pax, Ro-Ro, VC	CRS, ORS, WD	NB + Ex
WP10					
RCO13	Ext1a	Dry-pipe sprinkler system for vehicle carriers	VC	CRS	NB
RCO14	Ext3a	Fixed remotely-controlled fire monitor system using water for weather decks	Ro-Pax, Ro-Ro	WD	NB + Ex
RCO15	Ext3	Fixed autonomous fire monitor system using water for weather decks	Ro-Pax, Ro-Ro	WD	NB + Ex
WP11					
RCO16	Cont13, Cont14	Guideline for fire ventilation in closed ro-ro space	Ro-Pax, Ro-Ro	CRS	NB + Ex

Ro-Pax = ro-ro passenger ships, Ro-Ro = ro-ro cargo ships, VC = vehicle carriers.

CRS = closed ro-ro spaces, ORS = open ro-ro spaces, WD = weather decks.

NB = newbuildings, Ex = existing ships.

11.2 ANNEX B: Breakdown of marginal cost of each RCO

Table 26. Breakdown of the marginal costs (in euros) for the RCOs, for newbuildings.

			ΔCost		
			Ro-Pax	Ro-Ro Cargo	Vehicle Carriers
RCO1	Improved fire patrol. Improved fire confirmation & localization	Investment	24 200 €	21 320 €	18 820 €
		Operation	0 €	0 €	0 €
		Maintenance	41 241 €	36 330 €	17 373 €
		Total	65 441 €	57 650 €	36 193 €
RCO2	Improved signage and markings for effective wayfinding and localization	Investment	8 840 €	8 840 €	12 040 €
		Operation	0 €	0 €	0 €
		Maintenance	12 189 €	11 712 €	9 641 €
		Total	21 029 €	20 552 €	21 681 €
RCO3	Developed efficient first response	Investment	8 590 €	6 550 €	6 550 €
		Operation	32 733 €	19 937 €	16 427 €
		Maintenance	0 €	0 €	0 €
		Total	41 323 €	26 487 €	22 977 €
RCO4	Developed manual firefighting for APVs	Investment	23 700 €	22 260 €	27 260 €
		Operation	22 607 €	15 225 €	12 544 €
		Maintenance	31 845 €	26 787 €	26 047 €
		Total	78 152 €	64 272 €	65 851 €
RCO5	Alarm system interface prototype	Investment	73 700 €	73 700 €	73 700 €
		Operation	0 €	0 €	0 €
		Maintenance	12 107 €	12 107 €	7 163 €
		Total	85 807 €	85 807 €	80 863 €
RCO6	Process for development of procedures and design for efficient activation of extinguishing system	Investment	3 640 €	3 640 €	3 640 €
		Operation	20 534 €	19 756 €	16 278 €
		Maintenance	0 €	0 €	0 €
		Total	24 174 €	23 396 €	19 918 €
RCO7	Training module for efficient activation of extinguishing system	Investment	24 330 €	24 330 €	23 730 €
		Operation	64 547 €	62 099 €	88 594 €
		Maintenance	0 €	0 €	0 €
		Total	88 877 €	86 429 €	112 324 €
RCO8	Safe electrical connection for reefers	Investment	138 926 €	106 726 €	Not assessed
		Operation	0 €	0 €	
		Maintenance	23 549 €	22 656 €	
		Total	162 475 €	129 382 €	
RCO9	Safe electrical connection of reefers and EVs	Investment	168 291 €	Not assessed	Not assessed
		Operation	0 €		
		Maintenance	47 097 €		
		Total	215 388 €		
RCO10	Fire detection on WD	Investment	66 733 €	87 169 €	Not assessed
		Operation	0 €	0 €	
		Maintenance	117 743 €	113 278 €	
		Total	184 476 €	200 447 €	
RCO11	Alternative fire detection in CRS & ORS	Investment	209 469 €	288 444 €	589 400 €
		Operation	0 €	0 €	0 €
		Maintenance	202 519 €	194 838 €	240 805 €
		Total	411 988 €	483 282 €	830 205 €

			ΔCost		
			Ro-Pax	Ro-Ro Cargo	Vehicle Carriers
RCO12	Visual system for fire confirmation and localization	Investment	184 877 €	265 764 €	935 039 €
		Operation	23 549 €	22 656 €	18 667 €
		Maintenance	117 743 €	271 866 €	102 669 €
		Total	326 169 €	560 286 €	1 056 375 €
RCO13	Dry-pipe sprinkler system for vehicle carriers	Investment	Not assessed	Not assessed	1 293 118 €
		Operation			480 588 €
		Maintenance			249 628 €
		Total			2 023 333 €
RCO14	Fixed remotely-controlled fire monitor system using water for WD	Investment	148 735 €	225 290 €	Not assessed
		Operation	0 €	0 €	
		Maintenance	113 034 €	135 933 €	
		Total	261 769 €	361 223 €	
RCO15	Fixed autonomous fire monitor system using water for WD	Investment	185 635 €	266 690 €	Not assessed
		Operation	0 €	0 €	
		Maintenance	131 873 €	158 589 €	
		Total	317 508 €	425 279 €	
RCO16	Guideline for fire ventilation in CRS	Investment	4 500 €	4 500 €	Not assessed
		Operation	23 549 €	22 656 €	
		Maintenance	0 €	0 €	
		Total	28 049 €	27 156 €	

Table 27. Breakdown of the marginal costs (in euros) for the RCOs, for existing ships.

			ΔCost		
			Ro-Pax	Ro-Ro Cargo	Vehicle Carriers
RCO1	Improved fire patrol. Improved fire confirmation & localization	Investment	24 200 €	21 320 €	18 820 €
		Operation	0 €	0 €	0 €
		Maintenance	26 685 €	26 685 €	10 166 €
		Total	50 885 €	48 005 €	28 986 €
RCO2	Improved signage and markings for effective wayfinding and localization	Investment	30 840 €	30 840 €	36 040 €
		Operation	0 €	0 €	0 €
		Maintenance	8 349 €	8 349 €	6 762 €
		Total	39 189 €	39 189 €	42 802 €
RCO3	Developed efficient first response	Investment	8 590 €	6 550 €	6 550 €
		Operation	22 472 €	14 227 €	11 523 €
		Maintenance	0 €	0 €	0 €
		Total	31 062 €	20 777 €	18 073 €
RCO4	Developed manual firefighting for APVs	Investment	23 700 €	22 260 €	27 260 €
		Operation	15 520 €	10 864 €	8 799 €
		Maintenance	19 989 €	19 989 €	15 242 €
		Total	59 210 €	53 114 €	51 301 €
RCO5	Alarm system interface prototype	Investment	Not assessed	Not assessed	Not assessed
		Operation			
		Maintenance			
		Total			
RCO6	Process for development of procedures and design for efficient activation of extinguishing system	Investment	84 540 €	68 100 €	5 140 €
		Operation	14 098 €	14 098 €	11 418 €
		Maintenance	1 617 €	1 617 €	0 €
		Total	100 254 €	83 814 €	16 558 €
RCO7	Training module for efficient activation of extinguishing system	Investment	24 330 €	24 330 €	23 730 €
		Operation	44 314 €	44 314 €	62 145 €
		Maintenance	0 €	0 €	0 €
		Total	68 644 €	68 644 €	85 875 €
RCO8	Safe electrical connection for reefers	Investment	167 796 €	124 156 €	Not assessed
		Operation	0 €	0 €	
		Maintenance	16 167 €	16 167 €	
		Total	183 963 €	140 323 €	
RCO9	Safe electrical connection of reefers and EVs	Investment	197 151 €	Not assessed	Not assessed
		Operation	0 €		
		Maintenance	32 334 €		
		Total	229 485 €		
RCO10	Fire detection on WD	Investment	84 207 €	106 014 €	Not assessed
		Operation	0 €	0 €	
		Maintenance	80 836 €	80 836 €	
		Total	165 043 €	186 850 €	
RCO11	Alternative fire detection in CRS & ORS	Investment	Not assessed	Not assessed	Not assessed
		Operation			
		Maintenance			
		Total			

			ΔCost		
			Ro-Pax	Ro-Ro Cargo	Vehicle Carriers
RCO12	Visual system for fire confirmation and localization	Investment	220 227 €	304 539 €	981 539 €
		Operation	16 167 €	16 167 €	13 094 €
		Maintenance	194 005 €	194 005 €	72 018 €
		Total	430 400 €	514 712 €	1 066 651 €
RCO13	Dry-pipe sprinkler system for vehicle carriers	Investment	Not assessed	Not assessed	Not assessed
		Operation			
		Maintenance			
		Total			
RCO14	Fixed remotely-controlled fire monitor system using water for WD	Investment	168 375 €	249 970 €	Not assessed
		Operation	0 €	0 €	
		Maintenance	77 602 €	97 003 €	
		Total	245 977 €	346 973 €	
RCO15	Fixed autonomous fire monitor system using water for WD	Investment	207 275 €	292 870 €	Not assessed
		Operation	0 €	0 €	
		Maintenance	90 536 €	113 170 €	
		Total	297 811 €	406 040 €	
RCO16	Guideline for fire ventilation in CRS	Investment	4 500 €	4 500 €	Not assessed
		Operation	16 167 €	16 167 €	
		Maintenance	0 €	0 €	
		Total	20 667 €	20 667 €	

11.3 ANNEX C: Estimation of risk reduction by the implementation of RCOs

Table 28. Risk reduction of RCOs – Ro-ro passenger ships, newbuildings.

Ref	Designation	New PLL	ΔPLL	Risk Red.	Rank	New PLC	ΔPLC	Risk Red.	Rank	New PLS	ΔPLS	Risk Red.	Rank
RCO1	Impr. fire patrol. Impr. fire confirmation & localiz.	1.03E-02	3.88E-03	27.2%	1	1.69E+04	6.31E+03	27.2%	1	1.21E+05	4.57E+04	27.4%	1
RCO2	Impr. signage and markings for effective localiz.	1.34E-02	8.65E-04	6.1%	12	2.18E+04	1.34E+03	5.8%	12	1.58E+05	8.60E+03	5.2%	13
RCO3	Developed efficient first response	1.20E-02	2.27E-03	15.9%	7	1.95E+04	3.69E+03	15.9%	7	1.40E+05	2.68E+04	16.1%	7
RCO4	Developed manual firefighting for APVs	1.35E-02	7.43E-04	5.2%	13	2.20E+04	1.17E+03	5.1%	13	1.58E+05	8.70E+03	5.2%	12
RCO5	Alarm system interface prototype	1.04E-02	3.79E-03	26.6%	2	1.71E+04	6.10E+03	26.3%	2	1.23E+05	4.36E+04	26.2%	2
RCO6	Process [...] for efficient activation of exting.	1.25E-02	1.76E-03	12.4%	8	2.03E+04	2.87E+03	12.4%	8	1.46E+05	2.09E+04	12.5%	8
RCO7	Training module for efficient activat. of exting.	1.28E-02	1.43E-03	10.0%	11	2.08E+04	2.33E+03	10.1%	9	1.50E+05	1.69E+04	10.2%	9
RCO8	Safe electrical connection for reefers	1.14E-02	2.82E-03	19.8%	5	1.83E+04	4.89E+03	21.1%	4	1.30E+05	3.64E+04	21.8%	4
RCO9	Safe electrical connection of reefers and Evs	1.14E-02	2.83E-03	19.9%	4	1.83E+04	4.90E+03	21.1%	3	1.30E+05	3.64E+04	21.9%	3
RCO10	Fire detection on weather decks	1.39E-02	3.15E-04	2.2%	14	2.27E+04	4.40E+02	1.9%	14	1.64E+05	2.76E+03	1.7%	14
RCO11	Alternative fire detection in CRS & ORS	1.13E-02	2.96E-03	20.8%	3	1.86E+04	4.59E+03	19.8%	5	1.37E+05	2.95E+04	17.7%	6
RCO12	Visual system for fire confirmation and localiz.	1.14E-02	2.79E-03	19.6%	6	1.87E+04	4.50E+03	19.4%	6	1.34E+05	3.27E+04	19.6%	5
RCO14	Remote-control. fire monitor using water for WD	1.27E-02	1.48E-03	10.4%	10	2.13E+04	1.88E+03	8.1%	11	1.55E+05	1.11E+04	6.7%	11
RCO15	Autonomous fire monitor using water for WD	1.27E-02	1.50E-03	10.6%	9	2.12E+04	1.93E+03	8.3%	10	1.55E+05	1.15E+04	6.9%	10
RCO16	Guideline for fire ventilation in CRS	1.42E-02	2.59E-05	0.2%	15	2.31E+04	5.54E+01	0.2%	15	1.66E+05	4.42E+02	0.3%	15
BASE CASE		1.42E-02				2.32E+04				1.67E+05			

Table 29. Risk reduction of RCOs – Ro-ro passenger ships, existing ships.

Ref	Designation	New PLL	ΔPLL	Risk Red.	Rank	New PLC	ΔPLC	Risk Red.	Rank	New PLS	ΔPLS	Risk Red.	Rank
RCO1	Impr. fire patrol. Impr. fire confirmation & localiz.	1.03E-02	3.88E-03	27.2%	1	1.69E+04	6.31E+03	27.2%	1	6.68E+04	2.52E+04	27.4%	1
RCO2	Impr. signage and markings for effective localiz.	1.34E-02	8.65E-04	6.1%	10	2.18E+04	1.34E+03	5.8%	10	8.75E+04	4.52E+03	4.9%	11
RCO3	Developed efficient first response	1.20E-02	2.27E-03	15.9%	5	1.95E+04	3.69E+03	15.9%	5	7.72E+04	1.48E+04	16.1%	5
RCO4	Developed manual firefighting for APVs	1.35E-02	7.43E-04	5.2%	11	2.20E+04	1.17E+03	5.1%	11	8.72E+04	4.79E+03	5.2%	10
RCO6	Process [...] for efficient activation of exting.	1.25E-02	1.76E-03	12.4%	6	2.03E+04	2.87E+03	12.4%	6	8.05E+04	1.15E+04	12.5%	6
RCO7	Training module for efficient activat. of exting.	1.28E-02	1.43E-03	10.0%	9	2.08E+04	2.33E+03	10.1%	7	8.27E+04	9.31E+03	10.1%	7
RCO8	Safe electrical connection for reefers	1.14E-02	2.82E-03	19.8%	3	1.83E+04	4.89E+03	21.1%	3	7.17E+04	2.03E+04	22.0%	3
RCO9	Safe electrical connection of reefers and Evs	1.14E-02	2.83E-03	19.9%	2	1.83E+04	4.90E+03	21.1%	2	7.17E+04	2.03E+04	22.1%	2
RCO10	Fire detection on weather decks	1.39E-02	3.15E-04	2.2%	12	2.27E+04	4.40E+02	1.9%	12	9.06E+04	1.44E+03	1.6%	12
RCO12	Visual system for fire confirmation and localiz.	1.14E-02	2.79E-03	19.6%	4	1.87E+04	4.50E+03	19.4%	4	7.41E+04	1.79E+04	19.5%	4
RCO14	Remote-control. fire monitor using water for WD	1.27E-02	1.48E-03	10.4%	8	2.13E+04	1.88E+03	8.1%	9	8.64E+04	5.57E+03	6.1%	9
RCO15	Autonomous fire monitor using water for WD	1.27E-02	1.50E-03	10.6%	7	2.12E+04	1.93E+03	8.3%	8	8.62E+04	5.78E+03	6.3%	8
RCO16	Guideline for fire ventilation in CRS	1.42E-02	2.59E-05	0.2%	13	2.31E+04	5.54E+01	0.2%	13	9.17E+04	2.49E+02	0.3%	13
BASE CASE		1.42E-02				2.32E+04				9.20E+04			

Table 30. Risk reduction of RCOs – Ro-ro cargo ships, newbuildings.

Ref	Designation	New PLL	ΔPLL	Risk Red.	Rank	New PLC	ΔPLC	Risk Red.	Rank	New PLS	ΔPLS	Risk Red.	Rank
RCO1	Impr. fire patrol. Impr. fire confirmation & localiz.	1.01E-04	2.75E-05	21.3%	3	1.87E+04	5.33E+03	22.2%	3	4.12E+04	1.20E+04	22.6%	3
RCO2	Impr. signage and markings for effective localiz.	1.25E-04	3.37E-06	2.6%	12	2.34E+04	6.30E+02	2.6%	13	5.20E+04	1.21E+03	2.3%	13
RCO3	Developed efficient first response	1.17E-04	1.21E-05	9.4%	8	2.15E+04	2.48E+03	10.3%	7	4.75E+04	5.69E+03	10.7%	7
RCO4	Developed manual firefighting for APVs	1.23E-04	5.44E-06	4.2%	11	2.30E+04	1.03E+03	4.3%	11	5.09E+04	2.36E+03	4.4%	11
RCO5	Alarm system interface prototype	1.04E-04	2.50E-05	19.4%	4	1.89E+04	5.04E+03	21.0%	4	4.18E+04	1.14E+04	21.4%	4
RCO6	Process [...] for efficient activation of exting.	1.22E-04	6.60E-06	5.1%	10	2.25E+04	1.51E+03	6.3%	10	4.97E+04	3.57E+03	6.7%	10
RCO7	Training module for efficient activat. of exting.	1.22E-04	6.82E-06	5.3%	9	2.24E+04	1.56E+03	6.5%	9	4.96E+04	3.68E+03	6.9%	9
RCO8	Safe electrical connection for reefers	1.26E-04	3.11E-06	2.4%	13	2.32E+04	7.54E+02	3.1%	12	5.14E+04	1.81E+03	3.4%	12
RCO10	Fire detection on weather decks	1.13E-04	1.60E-05	12.4%	5	2.17E+04	2.30E+03	9.6%	8	4.86E+04	4.65E+03	8.7%	8
RCO11	Alternative fire detection in CRS & ORS	1.14E-04	1.51E-05	11.7%	6	2.09E+04	3.07E+03	12.8%	5	4.68E+04	6.41E+03	12.0%	6
RCO12	Visual system for fire confirmation and localiz.	1.15E-04	1.37E-05	10.6%	7	2.11E+04	2.86E+03	11.9%	6	4.66E+04	6.63E+03	12.5%	5
RCO14	Remote-control. fire monitor using water for WD	6.34E-05	6.55E-05	50.8%	2	1.50E+04	8.95E+03	37.3%	2	3.57E+04	1.75E+04	33.0%	2
RCO15	Autonomous fire monitor using water for WD	6.23E-05	6.66E-05	51.7%	1	1.48E+04	9.19E+03	38.3%	1	3.51E+04	1.81E+04	34.0%	1
RCO16	Guideline for fire ventilation in CRS	1.29E-04	5.03E-08	0.0%	14	2.40E+04	1.37E+01	0.1%	14	5.32E+04	3.42E+01	0.1%	14
BASE CASE		1.29E-04				2.40E+04				5.32E+04			

Table 31. Risk reduction of RCOs – Ro-ro cargo ships, existing ships.

Ref	Designation	New PLL	ΔPLL	Risk Red.	Rank	New PLC	ΔPLC	Risk Red.	Rank	New PLS	ΔPLS	Risk Red.	Rank
RCO1	Impr. fire patrol. Impr. fire confirmation & localiz.	1.01E-04	2.75E-05	21.3%	3	1.87E+04	5.33E+03	22.2%	3	8.01E+03	2.35E+03	22.7%	3
RCO2	Impr. signage and markings for effective localiz.	1.25E-04	3.37E-06	2.6%	10	2.34E+04	6.30E+02	2.6%	11	1.01E+04	2.15E+02	2.1%	11
RCO3	Developed efficient first response	1.17E-04	1.21E-05	9.4%	6	2.15E+04	2.48E+03	10.3%	5	9.24E+03	1.12E+03	10.8%	5
RCO4	Developed manual firefighting for APVs	1.23E-04	5.44E-06	4.2%	9	2.30E+04	1.03E+03	4.3%	9	9.91E+03	4.47E+02	4.3%	9
RCO6	Process [...] for efficient activation of exting.	1.22E-04	6.60E-06	5.1%	8	2.25E+04	1.51E+03	6.3%	8	9.67E+03	6.90E+02	6.7%	8
RCO7	Training module for efficient activat. of exting.	1.22E-04	6.82E-06	5.3%	7	2.24E+04	1.56E+03	6.5%	7	9.65E+03	7.12E+02	6.9%	7
RCO8	Safe electrical connection for reefers	1.26E-04	3.11E-06	2.4%	11	2.32E+04	7.54E+02	3.1%	10	1.00E+04	3.63E+02	3.5%	10
RCO10	Fire detection on weather decks	1.13E-04	1.60E-05	12.4%	4	2.17E+04	2.30E+03	9.6%	6	9.51E+03	8.54E+02	8.2%	6
RCO12	Visual system for fire confirmation and localiz.	1.15E-04	1.37E-05	10.6%	5	2.11E+04	2.86E+03	11.9%	4	9.09E+03	1.27E+03	12.2%	4
RCO14	Remote-control. fire monitor using water for WD	6.34E-05	6.55E-05	50.8%	2	1.50E+04	8.95E+03	37.3%	2	7.31E+03	3.05E+03	29.4%	2
RCO15	Autonomous fire monitor using water for WD	6.23E-05	6.66E-05	51.7%	1	1.48E+04	9.19E+03	38.3%	1	7.17E+03	3.19E+03	30.8%	1
RCO16	Guideline for fire ventilation in CRS	1.29E-04	5.03E-08	0.0%	12	2.40E+04	1.37E+01	0.1%	12	1.04E+04	6.69E+00	0.1%	12
BASE CASE		1.29E-04				2.40E+04				1.04E+04			

Table 32. Risk reduction of RCOs – Vehicle carriers, newbuildings.

Ref	Designation	New PLL	ΔPLL	Risk Red.	Rank	New PLC	ΔPLC	Risk Red.	Rank	New PLS	ΔPLS	Risk Red.	Rank
RCO1	Improved fire confirmation & localization	1.12E-04	1.24E-06	1.1%	10	7.89E+04	3.14E+03	3.8%	10	4.42E+04	1.70E+03	3.7%	10
RCO2	Impr. signage and markings for effective localiz.	1.12E-04	1.91E-06	1.7%	9	7.75E+04	4.51E+03	5.5%	9	4.39E+04	1.99E+03	4.3%	9
RCO3	Developed efficient first response	1.02E-04	1.19E-05	10.5%	3	7.28E+04	9.17E+03	11.2%	5	4.08E+04	5.12E+03	11.2%	5
RCO4	Developed manual firefighting for APVs	1.12E-04	2.00E-06	1.8%	8	7.71E+04	4.91E+03	6.0%	8	4.30E+04	2.87E+03	6.3%	8
RCO5	Alarm system interface prototype	1.03E-04	1.06E-05	9.3%	4	5.58E+04	2.62E+04	31.9%	2	3.25E+04	1.34E+04	29.2%	2
RCO6	Process [...] for efficient activation of exting.	1.10E-04	3.16E-06	2.8%	6	7.40E+04	8.03E+03	9.8%	6	4.15E+04	4.36E+03	9.5%	6
RCO7	Training module for efficient activat. of exting.	1.10E-04	3.09E-06	2.7%	7	7.42E+04	7.85E+03	9.6%	7	4.16E+04	4.26E+03	9.3%	7
RCO11	Alternative fire detection in CRS & ORS	9.90E-05	1.46E-05	12.8%	1	5.99E+04	2.21E+04	26.9%	3	3.60E+04	9.89E+03	21.6%	3
RCO12	Visual system for fire confirmation and localiz.	1.09E-04	4.89E-06	4.3%	5	6.98E+04	1.22E+04	14.8%	4	3.90E+04	6.88E+03	15.0%	4
RCO13	Dry-pipe sprinkler system for VC	9.98E-05	1.37E-05	12.1%	2	4.75E+04	3.45E+04	42.0%	1	2.67E+04	1.92E+04	41.8%	1
BASE CASE		1.14E-04				8.20E+04				4.59E+04			

Table 33. Risk reduction of RCOs – Vehicle carriers, existing ships.

Ref	Designation	New PLL	ΔPLL	Risk Red.	Rank	New PLC	ΔPLC	Risk Red.	Rank	New PLS	ΔPLS	Risk Red.	Rank
RCO1	Improved fire confirmation & localization	1.12E-04	1.24E-06	1.1%	7	7.89E+04	3.14E+03	3.8%	7	1.01E+04	3.75E+02	3.6%	7
RCO2	Impr. signage and markings for effective localiz.	1.12E-04	1.91E-06	1.7%	6	7.75E+04	4.51E+03	5.5%	6	1.01E+04	4.22E+02	4.0%	6
RCO3	Developed efficient first response	1.02E-04	1.19E-05	10.5%	1	7.28E+04	9.17E+03	11.2%	2	9.35E+03	1.17E+03	11.1%	2
RCO4	Developed manual firefighting for APVs	1.12E-04	2.00E-06	1.8%	5	7.71E+04	4.91E+03	6.0%	5	9.89E+03	6.33E+02	6.0%	5
RCO6	Process [...] for efficient activation of exting.	1.10E-04	3.16E-06	2.8%	3	7.40E+04	8.03E+03	9.8%	3	9.56E+03	9.60E+02	9.1%	3
RCO7	Training module for efficient activat. of exting.	1.10E-04	3.09E-06	2.7%	4	7.42E+04	7.85E+03	9.6%	4	9.58E+03	9.38E+02	8.9%	4
RCO12	Visual system for fire confirmation and localiz.	1.09E-04	4.89E-06	4.3%	2	6.98E+04	1.22E+04	14.8%	1	9.01E+03	1.52E+03	14.4%	1
BASE CASE		1.14E-04				8.20E+04				1.05E+04			