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 D04.9

Preliminary impact of solutions and related testing and demonstrations plan

April 2022

Dissemination level: **Public**

Abstract

Ro-ro ships are an important component of the global transportation system and one of the most successful types of vessels today. However, a significant number of fire incidents on ro-ro ships in recent years and lacking signs of such diminishing call for improved fire protection.

LASH FIRE is a European Union-funded research project, aiming to strengthen the independent fire protection of ro-ro ships by developing and validating effective operative and design solutions. For that purpose, LASH FIRE will address a total of twenty challenges in all stages of fire course originating in ro-ro spaces. Several solutions will be developed, validated and demonstrated to address those challenges.

This deliverable provides a compilation of the solutions selected for further consideration in the cost-effectiveness assessment. A total of 44 solutions were preliminary selected by the Development and Demonstration Work Packages (D&D WPs). The list of solutions is covering the entire "fire protection chain", it comprises both preventive and mitigating risk controls, as well as both engineering, inherent and procedural risk controls.

As next steps, those solutions will be assessed by WP03, WP04 and WP05. Meanwhile, the D&D WPs will continue and refine the on-going developments, conduct the validation and the demonstration of solutions.

This deliverable reflects an intermediate stage of the project and shall not be understood or used as a final outcome of the LASH FIRE project.

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

Document data

Document Title:	D04.9 – Preliminary impact of solutions and related testing and demonstrations plan		
Work Package:	WP04 – Formal safety Assessment		
Related Task(s):	T04.06		
Dissemination level:	Public		
Deliverable type:	R, Report		
Lead beneficiary:	8 – BV		
Responsible author:	Eric De Carvalho		
Co-authors:			
Date of delivery:	2022-04-08		
References:	IR04.23		
Approved by	Vito Radolovic on 2022-03-18	Stina Andersson on 2022-03-25	Maria Hjohlman on 2022-04-04

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 Staffan Bram – staffan.bram@ri.se Robert Rylander – robert.rylander@ri.se Vasudev Ramachandra – vasudev.ramachandra@ri.se Anna Sandinge – anna.sandinge@ri.se David Schmidt – david.schmidt@ri.se Magnus Arvidson – magnus.arvidson@ri.se Anna Olofsson – anna.olofsson@ri.se
2	VTT	Teknologian tutkimuskeskus VTT Oy	Tuula Hakkarainen – tuula.hakkarainen@vtt.fi
3	FRN	Rise Fire Research AS	Reidar Stølen – reidar.stolen@risefr.no
4	FLOW	FLOW Ship Design DOO za Projektiranje, Konzalting I Inzenjering u Brodogradnji	Vito Radolovic – vito.radolovic@flowship.eu
5	MAR	Marioff Corporation Oy	Antti Virkajarvi – antti.virkajarvi@carrier.com
6	UNF	Unifire Aktiebolag	Roger James – roger@unifire.com
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
9	APS	AP Sensing Gmbh	Bernd Drapp – bernd.drapp@apsensing.com
10	STL	Stena Rederi AB	Martin Carlsson – Martin.Carlsson@stena.com

No.	Short name	Full name of Partner	Name and contact info of persons involved
13	SCK	SICK AG	Markus Haas – Markus1.Haas@sick.de
14	NTNU	Norges Teknisk-Naturvitenskapelige Universitet NTNU	Erik Styhr Petersen – Erik.Styhr.Petersen@hvl.no
15	SAS	Sociedad de Salvamento y Seguridad Maritima	Jaime Bleye Vicario – jaimebv@centrojovellanos.es
16	CIM	Centre Internacional de Metodes Numerics en Enginyeria	Francisco Rodero – francisco.rodero@upc.edu
17	MAG	Magellan-Associacao para a Representacao dos Intresses Portugueses no Exterior	Manuela Flacchi – maf@magellan-association.org
18	LUL	Universite de Lorraine	Pascal Boulet – pascal.boulet@univ-lorraine.fr
19	NSR	NTNU Samfunnsforskning AS	Lucia Liste Munoz – lucia.liste@samforsk.no Torgeir Kolstø Haavik – torgeir.haavik@samforsk.no Martin Rasmussen Skogstad – martin.rasmussen@samforsk.no Martin Inge Standal – martin.standal@samforsk.no Brit-Eli Danielsen – brit-eli.danielsen@samforsk.no
20	FKE	Fike Safety Technology Limited	Rick Jeffress – Rick.Jeffress@fike.com
21	RS2N	RS2N	Bernard Porterie – bernard.porterie@rs2n.eu
23	UCY	University of Cyprus	Demetris Zeinalipour – dzeina@ucy.ac.cy
24	DFDS	DFDS AS	Sif Lundsvig – silun@dfds.com
25	F4M	FIFI4MARINE BV	Martin Teela – m.teela@fifi4marine.com
27	WAL	Wallenius Marine AB	Urban Lishajko – Urban.Lishajko@walleniusmarine.com

Document history

Version	Date	Prepared by	Description
01	2021-10-27	Eric De Carvalho	Draft of structure
02	2022-01-26	Eric De Carvalho	Draft of final report, circulated to D&D WPs
03	2022-03-18	Eric De Carvalho	Draft of final report, circulated to reviewers
04	2022-04-08	Eric De Carvalho	Final report

Content

1 Executive summary

1.1 Problem definition

Ro-ro ships are an important component of the global transportation system and one of the most successful types of vessels today. However, a significant number of fire incidents on ro-ro ships in recent years and lacking signs of such diminishing call for improved fire protection. Several initiatives to minimize the incidence and consequences of fires on ro-ro spaces of new and existing ro-ro passenger ships were successfully conducted (e.g., the FIRESAFE studies by EMSA) or are still on-going (e.g., review of SOLAS Chapter II-2 and associated codes by the International Maritime Organization (IMO)). However, there is also a need to address cargo transformation, such as Alternatively Powered Vehicles, and to address other types of ro-ro ships (i.e., ro-ro cargo ships and vehicle carriers) and not only the ro-ro passenger ships.

Hence, there is a need to update the fire protection of ro-ro ships from a wide and long-term perspective. There are significant challenges to address but there is also great potential in using new and advancing technologies and procedures. The innovative solutions need to be in balance with effects on the environment, cost and crew operations, in order to be considered for regulatory amendments. Then, the fire safety of ro-ro ships can be robustly enhanced, without support from external intervention.

1.2 Method

To address the described problems above, LASH FIRE aims to strengthen the independent fire protection of ro-ro ships by developing and validating effective operative and design solutions. For that purpose, six Development and Demonstration Work Packages (D&D WPs) address a total of twenty challenges, also called actions, in all stages of fire course originating in ro-ro spaces. Each action was initiated by a task for “Definition of conditions”, such as regulation review by Work Package 04 (WP04) and ship requirements definition by Work Package05 (WP05), related to the challenge to be addressed. These inputs defined the scope and required functions for the solutions to be developed. Next, the development of new solutions used the generic ships selected by the WP05 as starting point and included theoretical investigations, small-scale development testing and manufacturing of selected solutions. In parallel and in communication with the developers, the test facilitating research partners started planning the tests to validate the performance of the solutions.

An important step in the development and selection of the solutions was the LASH FIRE’s Milestone 15 (MS15), for which a set of solutions was preliminary selected and reported by D&D WPs to Work Package 04 (WP04) for further consideration in the cost-effectiveness assessment.

1.3 Results and achievements

This deliverable provides a compilation of the selected solutions at this intermediate stage of the project, including the actual or foreseen impact on fire safety and the related testing and demonstrations plan. It shall not be understood or used as a final outcome of the LASH FIRE project.

A total of 44 solutions were preliminary selected by the D&D WPs (Table 4). The list of solutions is covering the entire “fire protection chain”, it comprises both preventive and mitigating risk controls, as well as both engineering, inherent and procedural risk controls.

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, in part through this deliverable.

This deliverable will furthermore lay the groundwork for achieving the LASH FIRE 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 1:

> "LASH FIRE will strengthen the **independent** fire protection of ro-ro ships by developing and validating effective **operative and design** solutions addressing **current and future** challenges in **all stages of a fire**".

1.5 Exploitation

The present deliverable can be used as input for the different assessments carried out by WP03, WP04 and WP05. Meanwhile, the D&D WPs will continue and refine the on-going developments, conduct the validation and the demonstration of solutions.

This deliverable provides useful knowledge and insights to address the technical challenges related to fires originating in ro-ro spaces. It targets both the maritime rule-makers and industry. It provides practical example of the solutions being developed.

2 List of symbols and abbreviations

ACPH	Air Changes Per Hour
AI	Artificial Intelligence
AGV	Automated Guided Vehicle
APV	Alternatively Powered Vehicle
BEV	Battery Electric Vehicle
BLEVE	Boiling Liquid Expanding Vapour Explosion
CAF	Compressed Air Foam
CAFS	Compressed Air Foam Systems
CCTV	Closed-Circuit Television
CFD	Computational Fluid Dynamics
CNG	Compressed Natural Gas
CO_2	Carbon dioxide
D&D WPs	Development and Demonstration Work Packages (WP06-11)
DG	Dangerous Goods
EV	Electric Vehicle
FDS	Fire Dynamics Simulator
FRMC	Firefighting Resource Management Centre
GNSS	Global Navigation Satellite System
HazId	Hazard Identification
HEV	Hybrid Electric Vehicle
HGV	Heavy Goods Vehicle
HMI	Human-Machine Interface
HSE	Health, Safety and Environment
ICEV	Internal Combustion Engine Vehicle
IMDG	IMO's International Maritime Dangerous Goods (Code)
IMO	International Maritime Organization
IR	Infrared
LED	Light-Emitting Diode
LiDAR	Light Detection And Ranging

LSA	Life-Saving Appliance
MAAG	LASH FIRE's Maritime Authorities Advisory Group
MOAG	LASH FIRE's Maritime Operators Advisory Group
MS	Milestone
MSC	IMO's Maritime Safety Committee
OOW	Officer On Watch
PC	Personal Computer
PLC	Programmable Logic Controller
PPE	Personal Protective Equipment
PTT	Press-To-Talk
RCM	Risk Control Measure
RCO	Risk Control Option
RV	Recreational Vehicle
SMS	Safety Management System
SOLAS	IMO's Safety Of Life At Sea (Convention)
SPT	Stowage Planning Tool
STCW	IMO's Standards of Training, Certification and Watchkeeping (Convention)
SW	StoWage plan
TRL	Technology Readiness Level
UHF	Ultra High Frequency
UV	Ultraviolet
UWB	Ultra Wideband
VFD	Video Flame Detection
VHD	Vehicle Hotspot Detection
VHF	Very High Frequency
VSD	Video Smoke Detection
WP03	LASH FIRE's Work Package 03 (Cooperation and communication)
WP04	LASH FIRE's Work Package 04 (Formal Safety Assessment)
WP05	LASH FIRE's Work Package 05 (Ship integration)

3 Terminology

The IMO Formal Safety Assessment (FSA) guidelines [1] defines risk control measure and risk control option as it follows:

Risk control measure	A means of controlling a single element of risk.
Risk control option	A combination of risk control measures.

In LASH FIRE, the terms “Risk Control Measure” (RCM) and “solution” are used as equivalent, even if risk control measures developed in LASH FIRE may control more than one single element of risk.

4 Introduction

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

LASH FIRE is a European Union-funded research project, aiming to strengthen the independent fire protection of ro-ro ships by developing and validating effective operative and design solutions. For that purpose, six Development and Demonstration Work Packages (D&D WPs) will address a total of twenty challenges, also called actions, in all stages of fire course originating in ro-ro spaces (Figure 1).

WP06	**Effective Manual Operations**
6-A	Manual screening of cargo fire hazards and effective fire patrols
6-B	Quick manual fire confirmation and localization
6-C	Efficient first response
6-D	Effective and efficient manual firefighting
WP07	**Inherently Safe Design**
7-A	Improved fire detection system interface design
7-B	Efficient extinguishing system activation and inherently safe design
7-C	Firefighting resource management centre
WP08	**Ignition Prevention**
8-A	Automatic screening and management of cargo fire hazards
8-B	Guidelines and solutions for safe electrical connections
8-C	Fire requirements for new ro-ro space materials
WP09	**Detection**
9-A	Detection on weather deck
9-B	Detection in closed and open ro-ro spaces
9-C	Technologies for visual fire confirmation and localization
WP10	**Extinguishment**
10-A	Local application fire-extinguishing systems
10-B	Weather deck fixed fire-extinguishing systems
10-C	Updated performance of alternative fixed fire-fighting systems
WP11	**Containment**
11-A	Division of ro-ro spaces
11-B	Ensuring safe evacuation
11-C	Safe design with ro-ro space openings
11-D	Ro-ro space ventilation and smoke extraction

Figure 1. LASH FIRE 20 challenges (or actions).

Throughout the project, several solutions, also called Risk Control Measures (RCMs), will be developed, validated and demonstrated to address those challenges. The most promising ones will be grouped into Risk Control Options (RCOs), evaluated and demonstrated mainly in terms of ship integration feasibility, cost and risk reduction in order to finally propose at least fifteen regulatory proposals.

An important step in the development and selection of the solutions was the LASH FIRE's Milestone 15 (MS15), due to the half of the project (31st of August 2021), for which a set of solutions was preliminary selected and reported by D&D WPs to Work Package 04 (WP04) for further consideration in the cost-effectiveness assessment.

Based on this preliminary list of selected solutions and from the inputs provided by the D&D WPs, this deliverable provides an intermediate compilation of the actual or foreseen fire safety improvements gained by the selected solutions. It shall not be understood or used as a final outcome of the LASH FIRE project. It provides a status and summary about the preliminary developments of the different solutions (including the actual or foreseen impact on fire safety and the related testing and demonstrations plan).

5 Preliminary list of solutions

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

Each solution is described action per action. More details are provided for the solutions preliminary selected by the D&D WPs. For the solutions preliminary selected, a short technical description and specification are provided. The benefits and critical aspects in term of fire safety are described. Lastly, the related testing and demonstrations plan is summarized.

Effective Manual Operations

5.1 Action 6-A: Manual screening of cargo fire hazards and effective fire patrols

5.1.1 RCM Op1: Improved fire patrol procedures and minimum assisting equipment for a more effective screening of fire hazards

Main author of the chapter: Jaime Bleye, SAS.

5.1.1.1 Technical description

Current regulations regarding fire patrols states in SOLAS II-2/7.8 [2] that "*For ships carrying more than 36 passengers an efficient patrol system shall be maintained so that an outbreak of fire may be promptly detected. Each member of the fire patrol shall be trained to be familiar with the arrangements of the ship as well as the location and operation of any equipment he may be called upon to use*" and in SOLAS II-2/7.10 [2] that "*Each member of the fire patrol shall be provided with a two-way portable radiotelephone apparatus*" providing very little information about the procedures, the risks to be identified, the zones to be inspected or the equipment needed for an effective fire patrol.

Therefore, maritime regulations on this regard are very vague. Fire patrolling frequency can vary from 45 minutes to 2 hours (being 1 hour the most common time slot among patrolling) and the key locations to check can also vary. Effective fire patrols have to check and prevent the most critical spaces on board in terms of fire safety, and be ready to respond to fires in their early stage (in relation to the fire growth rate).

Fire patrol members should wear outer layer protective clothing, wearing long sleeves, long trousers, and safety shoes. The gear will protect against radiant heat in case the fire patrol member needs to approach to an incipient fire. Fire patrol member should keep physically fit to walk long distances (between 2 or 3 kilometres up/downstairs) and mentally prepared to act as first responder.

Fire patrols periodically inspect critical zones preventing risks from a double perspective (safety & security). Security inspections are out of the scope of the LASHFIRE. Focusing on the fire safety prevention, fire patrol members should look for the identification of potential fire hazards such us:

- Fuel leakage (solid, gas);
- Presence of ignition sources (like sparks or hot spot/surfaces);
- Electrical faults;
- Presence of smoke;
- Suspicious noises or smell;
- Thermal runaway on Li-ion batteries of Alternatively Powered Vehicles (APVs);
- Self-reactions with Dangerous Goods (DGs);
- Unsolicited activity;

- Handmade electrical installations on vehicles; and
- Lashing arrangements failure (specifically with bad weather forecast).

Having said that, the equipment for the fire patrolling shall be useful for a first response since it is expected that the fire patrol will carry out initial firefighting actions when a fire is detected. For that reason, the proposed equipment should be light and let both hands of the fire patrol member free to act in a cargo deck environment with very limited access.

5.1.1.2 Impact on safety

The implementation of a better defined SOLAS assisting equipment (preferably certified as EX-proof type) for the fire patrol member that allows the manual identification of potential fire risks and the confirmation of the fire with the Officer On Watch (OOW), allowing hands free ready to act if firefighting first response is needed. Assisting proposed equipment are:

- Check point reader (Figure 2) that can check the label of the location without direct contact with the metal pin-tag reducing the time of the whole fire patrol. The easiest and quicker the equipment, the better. Fire patrolling is a repetitive activity, carried out usually every hour during a whole ship campaign. Keeping the motivation high for a good performance is a total challenge for ship´s operators.

Figure 2. Check point reader.

- Light and robust safety torch (Figure 3) that can be magnetic attached to the helmet with enough Light-Emitting Diode (LED) intensity to detect leaks or smoke under low visibility condition spaces. A flashlight is useful during night patrolling, specially to inspect exposed areas, like weather decks.

Figure 3. Safety torch.

- Infrared (IR) light handheld camera (Figure 4) that can be hanged around the neck for hot spots detection. Dimensions like a smart-phone, light around 250 g, temperature range from bellow cero up to 150°C. The purpose of IR camera is not the constant screening of cargo. The IR camera should be use when the fire patrol member may suspect the presence of a ignition source like a suspicious noise or smell, smoke or sparks. The use of thermal imaging devices is recommended through the interim guidelines MSC.1/Circ.1615 [3].

Figure 4. IR camera.

- Press-To-Talk (PTT) bottoms for the portable Very High Frequency (VHF)/ Ultra High Frequency (UHF) radios (Figure 5) that allow to keep both hands free to communicate the presence and position of a fire. Raising the alarm by confirming and informing the presence of a fire should be the first action to be taken, before any further actions or first response [4]. Keeping both hands for additional actions is prior important. Identifying blind spots during radio communication must be part of the duties of the fire patrol as well as know alternatives means of communication by internal telephones or manually call points buttons.

Figure 5. PTT, portable VHF/UHF radio.

Fire patrol member should receive additional training, besides the compulsory content of the STCW (Standards of Training, Certification and Watchkeeping) Advanced Fire Fighting A-VI/3 [5], on the following topics:

- Training to detect fires in their initial stage and training to provide a first response;
- Familiarization with risks associated with APVs. They should be able to switch off main power in case of an emergency;
- Training on the use of first firefighting equipment (handheld extinguishers);
- Fire patrol member should be trained to trigger the drencher system if requested by OOW or Captain;
- Fire patrol member should be trained on the route to be followed during patrolling, should be familiar with the whole ship´s layout and the different locations to be inspected. The fire patrol route should be completed without hesitation before commencing a patrol. They must know how to unlock doors and be familiar with loading plan and high risks units. They must

be trained on reaching different decks from different entrances (those different from the standard fire patrol route);

- Fire patrol should be aware that there is a higher risk of fire incident within the first 1.5 hours after departure;
- Fire patrol members should be trained on the use of equipment; and
- Fire patrol members should be familiar with the standard communication phrases to be utilized for confirming or disconfirming the presence of a fire with the OOW.

5.1.1.3 Planned method of evaluation

RCM Op1 will be validated and demonstrated on board a ro-ro passenger ship with a Technology Readiness Level (TRL) of 6 and 7.

Preliminary tests on the efficacy of new assisting equipment and procedures for fire patrolling were carried out by SASEMAR the 10th July 2021 on board the ro-ro passenger ship Bahama Mama belonged to Baleària in route from the port of Malaga to Melilla (Spain) at 01:00 Local Time. 1.5 hours after departure. 25 different locations were inspected during 37 minutes in duration (Figure 6).

Further tests were conducted in November 2021 in partnership with MAGELLAN and STENA also on board a ro-ro passenger ship from Baleària.

Figure 6. Fire patrol member equipped with IR camera, UHF radio, checkpoint reader, gas detector and safety torch.

5.1.2 RCM Op2: Manual screening of cargo at port before loading operations

Main author of the chapter: Jaime Bleye, SAS.

5.1.2.1 Technical description

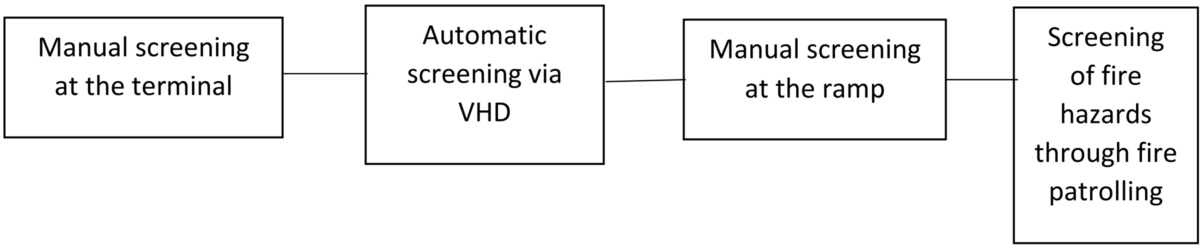
The main aim of the manual screening of cargo is the identification of fire risks at the ramp during the loading process. No specific IMO regulations related to the manual screening of cargo fire hazards. Only ship operators' procedures.

Today´s screening of incoming cargo is managed by each shipping operator. Deck officers and crew must focus on the loading process, stowing and traffic management on the ramp (which includes, APV and DG) leaving little time for inspections. So that, the risk identification is only about the most obvious issues (fuel leaks, sparks-electrical failures, or even real fires).

The loading process is carried out very fast making the identification of risks very difficult. That identification should start at the port before the loading process.

Current procedure is to perform the manual screening of cargo fire hazards during loading (only related to the most obvious issues) and periodically (1 hour as standard) during the fire patrol routine. RCM Op2 proposes a previous screening of cargo fire hazards at the terminal preceding the automatic and the manual screening at the ramp.

In this context, a basic scheme of the screening of cargo fire hazards will be as follows:



5.1.2.2 Impact on safety

More efficient identification of the hazards associated to the **high-risk cargo**; this is to say, those vehicles and cargo units that may present a higher hazard from the fire risk assessment.

Before any high-risk cargo will be loaded on board, a quick screening of the unit shall be performed at the dock focusing on:

- The status of reefer units;
- Substandard electrical connections;
- Suspicious noise or smell;
- Heat radiations;
- Any leakage;
- Portable fuel containers or added fuel tanks;
- Handmade installations on Recreational Vehicles (RVs) like Christmas trees or heaters;
- Stowaways' activities; and
- Other obvious fire hazards.

If any of these risks are detected the high-risk cargo should be rejected or notified to the deck officer.

Conclusions from LASH FIRE Hazard Identification (HazId) workshop are:

- The vessel equipment is rarely the cause of fire, rather the ship's cargo is generally the culprit;
- Electrical fault originating in the ship's cargo is the most common cause of fires in ro-ro spaces;
- Although refrigerated units typically constitute a relatively limited proportion of all the carried cargo on board it is statistically the most fire hazardous type of cargo in terms of probability and severity;

- While electrical failures in internal combustion engine vehicles constitute an apparent hazard, especially if the vehicles are in poor condition, there is little, if any, data that suggests electrical vehicles are more prone to fire than internal combustion engine vehicles; and
- Gas leaks in APVs that leads to fire is a rare occurrence.

The LASH FIRE deliverable D08.01, "Definition and parametrization of critical fire hazards, classification of cargoes, transport units, engines, fuels and vessels and identification methodologies" [6], provides more up-to-date records of fire origin and causes (period 2013-2020).

RCM Op2 proposes a previous screening of cargo **carried out by own crew** in terminal. This procedure goes in line with the recommendation of the MSC.1/Circ.1471 [7] where states that "*The shipper should provide a signed certificate or declaration that the vehicle fuel system, as offered for carriage, has been checked for leak-tightness and the vehicle is in proper condition for carriage prior to loading. In addition, the shipper is to mark, label or placard each vehicle, after it has been checked for leak-tightness and that it is in proper condition for carriage. During loading, the crew should check each vehicle for the shipper's markings.*"

RCM Op2 would be applicable to ro-ro passenger and cargo ships. Due to the type of cargo loaded on a vehicle carrier (new brand cars), we consider vehicle carriers out of the scope of RCM Op2.

5.1.2.3 Planned method of evaluation

RCM Op2 will be validated and demonstrated on board a ro-ro passenger ship with a TRL of 6 and 7. Initial on board testing were performed using the Baleària ro-ro passenger ship Bahama Mama in the Port of Melilla (Spain) on 10th July 2021. Faulty electrical connections on reefers can be identified at the terminal (Figure 7).

Figure 7. Faulty and dirty electrical connections on reefer.

Further tests were conducted in November 2021 in partnership with MAGELLAN and STENA also on board a ro-ro passenger ship from Baleària.

5.2 Action 6-B: Quick manual fire confirmation and localization

5.2.1 RCM Op3: Improvement of current signage and marking standards/conditions to support effective wayfinding and localization

Main author of the chapter: Lucia Liste, NSR.

5.2.1.1 Technical description

Consistency between signage and marking onboard systems and information displayed in the ship's fire management system interfaces

The information provided by the different fire management system interfaces (including any printed instruction and verbal terminology) and the signage and marking systems on the ships shall coincide. For instance, the section numbering indicated inside the ro-ro space shall be the same as the section valve identification and section identification numbering at the safety centre or continuously manned control station.

For new ships, consistency shall guide the design and construction phase.

Existing ships shall conduct a mapping study to identify actual mismatches between the different marking and signage systems on the ship and various fire management system interfaces. The study shall consist of a comparison of the information/numbering provided by ships' different fire management system interfaces (such as alarm panel, integrated fire management system, video monitoring system, any fire suppression system, any other documentation and printed instruction, verbal terminology, etc.) and relevant marking/signs numbering (such as painted markings on deck/bulkhead, sections, zones and localities, fire suppression system's valves/pipes, sensors, etc.). All the mismatches shall be registered and addressed with solutions (for a template that can be used to conduct the mismatches mapping study please, refer to LASH FIRE deliverable D06.1 [8]).

Solutions based on ship's specific characteristics and needs shall be developed and implemented to align the identified mismatches between current marking and signage onboard systems and fire management system interfaces. Solutions may encompass: the reprinting of printed instructions; reprograming of fire management systems; the replacement of markings and signs; the use of colour coding, etc.

Note, colour schemes shall not conflict with colour-coding of access stairways from ro-ro spaces to accommodation in ro-ro passenger ships.

Note, wayfinding and orientation for safety reasons shall come above normal customer access wayfinding in the signage hierarchy in ro-ro passenger ships.

Easily readable signage and marks standard

Signs and marks shall be easily identifiable and interpretable (for examples please, refer to LASH FIRE deliverable D06.1, "Development of and guidelines for quick manual fire confirmation and localization" [8]) in compliance with established vocabularies and symbols described in ISO 24409-01:2020 [9]. The following shall be considered:

- Size: Markings and signs shall have a minimum size of 400 x 400 mm;
- 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:
    - Both pained markings and prefabricated signs are permitted; and

    - 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 [10].
- Maintenance:
    - Signage and markings shall be resistant to wear and tear; and
    - Signage and markings shall be included in maintenance schemes.
- Location: Placing shall be decided by performing an in-situ analysis based on to 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; and
    - Closed vehicle, ro-ro spaces and special category spaces with water-spraying systems are fitted shall be provided with suitable signage and marking on deck and vertical boundaries to easily identify the sections of the fixed fire-extinguishing system.

5.2.1.2 Impact on safety

The objective of Action 6-B is to set a standard for quick manual fire confirmation, localization and assessment. Action 6-B has reviewed existing information finding that even if the technical fire detection is quick, the manual fire confirmation and localization is generally time consuming. This is reported by several accident investigations and a few research projects. Current praxis of sending a runner to manually confirm and localize the fire takes significant time due to human, organizational and technical factors.

RCM Op3 will arguably support a quicker and more effective manual fire confirmation and localization by addressing the following previously identified challenges:

- Lack of easily readable position descriptions (drencher zones, frame markings, decks, etc.);
- Common mismatches between naming/framing of vertical zones in the cargo space and the information gathered at the bridge; and
- Very scarce scientific literature on the manual fire confirmation that happens in this time gap between a fire alarm and the fire fighting.

For a more detailed description of challenges, please, refer to LASH FIRE deliverable D06.1 [8].

5.2.1.3 Planned method of evaluation

RCM Op3 will be validated and demonstrated on board a ro-ro passenger ship with a TRL of 6 and 7. Initial on-board testing were performed using the Baleària ro-ro passenger ship Bahama Mama in the Port of Melilla (Spain) on 10th July 2021. Mismatches between the colouring code of the drencher sections and the section plan located at the bridge were identified (Figure 8).

Figure 8. Colour coding sections. Bahama Mama Baleària July 2021.

Further tests were conducted in November 2021 in partnership with MAGELLAN and STENA also on board a ro-ro passenger ship from Baleària.

5.2.2 RCM Op4: Guidelines for the standardization and formalization of manual confirmation and localization

Main author of the chapter: Lucia Liste, NSR.

5.2.2.1 Technical description

Description of the role, the task and the conditions for performance

Company procedures shall include concise, simple, and useful descriptions of the role of the runner, the task and its conditions for the performance. The following descriptions are suggested:

- Role:
  - Runner: Crew member, normally one of the able seamen on duty, sent to the point of fire detection with the task of confirming or disconfirming the existence of a fire [11].
- Task:
  - Manual fire confirmation and localization is a first response in the event of a fire alarm, consisting of sending a runner to the point of detection with the task of confirming or disconfirming the existence of fire and its location.
- Conditions for the performance:
  - The runner shall be familiarized with manual fire confirmation and localization related activities and the ship by completing company's familiarization routines and participating in several fire drills including events the performance of the task has been trained.
  - The runner shall be an experienced crew member that report him/herself confident to perform the task and is assessed as capable by the person sending him/her.

- The runner shall wear equipment that allows to keep his/her both hands free and ready to act if firefighting first response is needed. The equipment needed shall encompass:
  - Cotton (rather than polyester) and long-sleeve clothing to protect from fire;
  - Light and robust safety torch that can be magnetic attached to the helmet with enough LED intensity (around 100 lumens) to detect leaks or smoke under low visibility condition spaces. A flashlight is useful during night patrolling, specially to inspect unprotected areas, like weather decks;
  - A thermal imaging device such as an IR light handheld camera that can be hanged around the neck for hot spots detection. Desired Specs: Dimensions (like a smart-phone, light around 250 g, temperature range from bellow cero up to 150°C). The IR camera shall be used when the runner member may suspect the presence of an ignition source like a suspicious noise or smell, smoke, or sparks; and
  - A communication device such as portable VHF/UHF radios that allow with press to talk bottoms.

Clear communication between bridge and runner during the performance of the task

Ships with English as working language shall standardize language and terminology used by adopting the use of IMO Standard Marine Communication Phrases (see section B2/3 FIRE PROTECTION AND FIRE FIGHTING; for a more description of relevant content, refer to LASH FIRE deliverable D06.1 [8]).

Potential blind spots for communication and radio shadows shall be identified. A study of wave propagation limits and coverage of radio signal in metal structures shall be performed on board (Figure 9 includes the template for the study questionnaire).

Communication equipment with sufficient coverage shall be used by crews. Not less than the 85% of the ship area shall have radio coverage with full cargo after the adoption of solutions. Solutions to eliminate radio blind sports and shadows shall be adopted. Solutions may comprise repeaters, a user-friendly combination of different technologies, use of UHF radio transmitters, etc. Alternative means of communication shall be deployed in case of few remaining radio blind spots and shadows in non-significant locations.

Familiarization with the task

Manual fire confirmation and localization activities shall be trained in realistic fire drills. Realistic fire drills shall include sub-events in which concerned crew get familiarized with potential scenarios and challenges during fire confirmation, such as typical signs of an incident, typical personal safety risks and default actions depending on situation.

Manual fire confirmation and localization related concerns shall be discussed in Health, Safety and Environment (HSE) meetings. The performance of manual fire confirmation and localization related drill's activities shall be assessed and discussed in drill debriefs.

The use of IMO Standard Marine Communication Phrases shall be practiced during drills.

Fire patrols shall practice the use of IMO Standard Marine Communication Phrases during non-emergency situations.

5.2.2.2 *Impact on safety*

The objective of Action 6-B is to set a standard for quick manual fire confirmation, localization and assessment. Action 6-B has reviewed existing information finding that even if the technical fire detection is quick, the manual fire confirmation and localization is generally time consuming. This is reported by several accident investigations and a few research projects. Current praxis of sending a runner to manually confirm and localize the fire takes significant time due to human, organizational and technical factors.

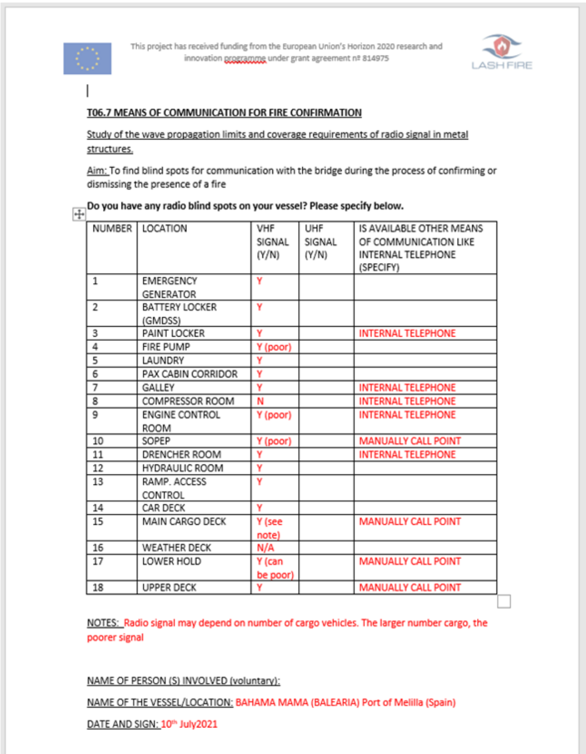
RCM Op4 proposed will arguably support a quicker and more effective manual fire confirmation and localization by increasing safety culture by addressing the following previously identified challenges:

- Runner's lack of familiarization with the vessel;
- Very scarce scientific literature on the manual fire confirmation that happens in this time gap between a fire alarm and the firefighting;
- Manual fire confirmation and localization is rarely systematized and trained for: lack of standards, company procedures and/or description of routines regarding the manual fire confirmation and localization;
- Poor communication with bridge (radio shadows, lack of a common language, etc.);

For a more detailed description of challenges, please, refer to LASH FIRE deliverable D06.1 [8].

5.2.2.3 *Planned method of evaluation*

RCM Op4 will be validated and demonstrated on board a ro-ro passenger ship with a TRL of 6 and 7. Initial on board testing were performed using the Baleària ro-ro passenger ship Bahama Mama in the Port of Melilla (Spain) on 10th July 2021. Radio coverage between the bridge and key locations were explored as well as the alternative means of communication during the event of a fire (Figure 9).



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

LASH FIRE

T06.7 MEANS OF COMMUNICATION FOR FIRE CONFIRMATION

Study of the wave propagation limits and coverage requirements of radio signal in metal structures.

Aim: To find blind spots for communication with the bridge during the process of confirming or dismissing the presence of a fire

Do you have any radio blind spots on your vessel? Please specify below.

NUMBER	LOCATION	VHF SIGNAL (Y/N)	UHF SIGNAL (Y/N)	IS AVAILABLE OTHER MEANS OF COMMUNICATION LIKE INTERNAL TELEPHONE (SPECIFY)
1	EMERGENCY GENERATOR	Y		
2	BATTERY LOCKER (GMDSS)	Y		
3	PAINT LOCKER	Y		INTERNAL TELEPHONE
4	FIRE PUMP	Y (poor)		
5	LAUNDRY	Y		
6	PAX CABIN CORRIDOR	Y		
7	GALLEY	Y		INTERNAL TELEPHONE
8	COMPRESSOR ROOM	N		INTERNAL TELEPHONE
9	ENGINE CONTROL ROOM	Y (poor)		INTERNAL TELEPHONE
10	SOPEP	Y (poor)		MANUALLY CALL POINT
11	DRENCHER ROOM	Y		INTERNAL TELEPHONE
12	HYDRAULIC ROOM	Y		
13	RAMP. ACCESS CONTROL	Y		
14	CAR DECK	Y		
15	MAIN CARGO DECK	Y (see note)		MANUALLY CALL POINT
16	WEATHER DECK	N/A		
17	LOWER HOLD	Y (can be poor)		MANUALLY CALL POINT
18	UPPER DECK	Y		MANUALLY CALL POINT

NOTES: Radio signal may depend on number of cargo vehicles. The larger number cargo, the poorer signal

NAME OF PERSON (S) INVOLVED (voluntary):

NAME OF THE VESSEL/LOCATION: BAHAMA MAMA (BALEARIA) Port of Melilla (Spain)

DATE AND SIGN: 10th July2021

Figure 9. Questionnaire to find blind spots of communication and alternative means of communication.

5.3 Action 6-C: Efficient first response

5.3.1 RCM Op5: First response guidelines and new equipment to put out the fire in the initial stage

Main author of the chapter: Jaime Bleye, SAS.

5.3.1.1 Technical description

The concept of "**first response**" is not well recognized among crew members and is not mentioned in any relevant part of SOLAS [2] or in any other resolution of the IMO-MSC. There is not difference between first response and manual firefighting, being different tiers in the firefighting chain. Crew on board must have a clear idea about the procedure to follow when discover a fire in the initial stage and the correct equipment or technology to use.

A safe first response is typically only possible during the early stages of a fire, where fire effluents are such that they do not compromise the life safety of people setting up the first response, hence the importance of early detection. If the detection is too late, the extinguishment of the fire at its initial stage (for example with a hand-held fire extinguisher) cannot be done safely. Therefore, for an efficient firefighting intervention, it is a key factor to reduce both times.

The "early" detection criterion should be based on the capacity to attempt a first response on the fire in safe conditions. It is commonly agreed that on a ro-ro space, the first response consists of the use of portable fire extinguishers where dry chemical powder will be likely the firefighting media inside.

Any crewmember has training competency to take first response actions and act as first responder. Actions 6-C aims to boost this concept beyond the use of a hand-held fire extinguisher to those members who have a regular access to cargo decks where is most likely to a fire to occur by mental awareness of a potential fire to occur and by focusing on the specific training on the use of new equipment and technology. Action 6-C will call those crew members as "**designated first responders**".

Proposals for developments are listed below:

- Calibrate role in most efficient way. Any crew member may act as first responder by raising the alarm regardless 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; and
  - 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 a standard role description to increase awareness of **designated first response** concept, since this concept is non existing today;
- Develop electronic or other learning material than can be shared across the ro-ro passenger and cargo 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 (like technology for localization, fire blankets, Compressed Air Foam (CAF) backpacks and breathing protection);

- 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; and
- Investigate smartphone-based solutions for information sharing to/from first responder.

5.3.1.2 Impact on safety

There are two important concepts (defined in the FIRESAFE studies [11]) to consider:

1. The **Available Time for Safe First Response** (the time available until conditions become untenable around the fire, disallowing first response); and
2. The **Required Time for Safe First Response** (the time to detect the fire and to set up all actions for first response). If the detection is too late, the first response might not be possible.

By stating the raising of the alarm as the first action to be taken when discovering a fire, the Required Time for Safe First Response will be slightly larger, as the first responder may need some time to raise the alarm, but at the end, once the OOW or the Captain are aware of the presence of a fire, the decision-making process will be more effective than without that knowledge.

By using new equipment, the **designated first responder** (Figure 10) may be more effective in the new challenges that we may find on board like the APVs. The dry chemical powder/carbon dioxide that we may find inside the extinguisher has limitations in efficacy and accessibility restrictions when attacking a Li-ion battery fire produced by a reaction called thermal runaway. For that reason, RCM Op5 will explore other equipment besides handheld dry powder/carbon dioxide extinguisher like grenades, CAF backpacks or fire blankets.

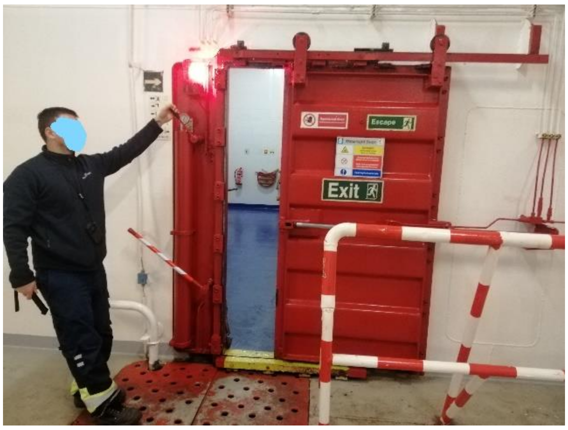


Figure 10. Typical first responder gear. If needed, ready to use hand-held extinguisher.

Lately, the **designated first responder** will be more protected against toxic gases produced by an internal reaction (called thermal runaway) of the Li-ion battery of an electric car by using a breathing protection device.

5.3.1.3 Planned method of evaluation

The effectiveness of RCM Op5 will be tested through a training module on the effective first response, gear and equipment that will be developed in the Maritime Safety Training Centre Jovellanos that belongs to SASEMAR. The training module is expected to be carried out during two days of the second semester of 2022 involving at least 8 crewmembers from STENA selected from their fleet of ro-ro passenger and cargo ships and APVs. More concretely , 3 Battery Electrical Vehicles will be involved in the firefighting creating a thermal runaway and testing the effectiveness of the fire suppression in the initial stage of the fire.

5.3.2 RCM Op6: Technology for localization of first responders through digital information processed via network

Main author of the chapter: Demetris Zeinalipour, UCY.

5.3.2.1 Technical description

The aim of RCM Op6 is the development and demonstration of smart alert of nearby first responders. Particularly, the research objective is to develop an innovative geo-positioning technology to allow more efficient first response to initial fires on ro-ro ships. Besides the core geo-positioning technology, the aim is also to provide the building blocks of a novel ship indoor information system and an application-based platform of a ro-ro indoor navigation and indoor fire intelligence system showing on a map the first responders and their chat interactions. The bridge will also be able to engage and interact with the personnel through a chat wall, text-to-audio synthesis and audio-to-text transcription readily available on modern smartphones. By equipping first responders with powerful mobile computing devices has many additional benefits as it will allow them to increase their cyber-physical senses (i.e., multiple sensing devices, like heat scanner, measuring apps, etc. in a tiny device), be connected (with the bridge and other personnel, discarding possibly outdated communication gear), be informed (e.g., carrying bulky manuals and maps in digital form), be intelligent (e.g., carrying deep learning neural networks that can recognize and track objects) and location-aware (i.e., localization, navigation and tracking of mobile and static assets). These are all dimensions that will increase fire safety to a new level by the means of state-of-the-art information technology that has proven itself in everyday life scenarios and that is for the same reason also unobtrusive, with a low learning curve, adaptable through software and economically-viable for massive deployment.

For the above purpose, RCM Op6 capitalizes upon the technology ecosystem of Anyplace, which is a Wi-Fi localization, navigation, crowdsourcing and indoor modelling platform developed over the years at the UNIVERSITY OF CYPRUS. Although Wi-Fi, 4G and 5G is available to some limited degree on vessels to provide network (and Internet) connectivity, what is not widely available is the dense deployment of radio antennas necessary to provide accurate localization. Providing multiple reference points (i.e., Antennas) for the task of localization is critical in the complete spectrum of the localization landscape (i.e., Global Navigation Satellite System (GNSS), Beacon, Light, Sound, Wi-Fi, Ultra Wideband (UWB) to name a few). Unfortunately, such dense antenna deployments will not be available on ro-ro ships in the years to come, due to the installation and maintenance costs but also relevant risks (radio signals might be a fire safety hazard in their own right). This led to the design and development of an innovative geo-positioning technology with “zero” infrastructure. Particularly, the aim was to offer similar accuracy to Wi-Fi localization (i.e., room-level accuracy to about 1-10 meters and low installation and maintenance cost) without relying on Wi-Fi access points as reference points but rather use static elements of vessel spaces as reference points (e.g., deck patterns, bulkhead patterns, hoses, fixed installations, signs, control buttons) and their spatial location as collected through a crowdsourcing task during a one-off installation process.

The proposed method relies on three stages:

1. **Training:** Ship owners supply video recordings of vessel interior spaces to the software team. The video recordings (Figure 11) are analysed on a deep learning data centre to produce a so-called Machine Learning Model. This process is carried out once per ship type (or ship family - in case multiple vessels have similar internal objects);
2. **Logging:** Subsequently, the model is loaded to a smartphone app provided to the ship owners, which are asked to walk around the vessel by clicking on a map yielding a Fingerprint database. Logging is carried out once per unique vessel and can be part of the installation process; and
3. **Localization:** The first responders utilize a smartphone application using the constructed database of step 2., which shows shares with nearby responders and the bridge the location of a first responder.

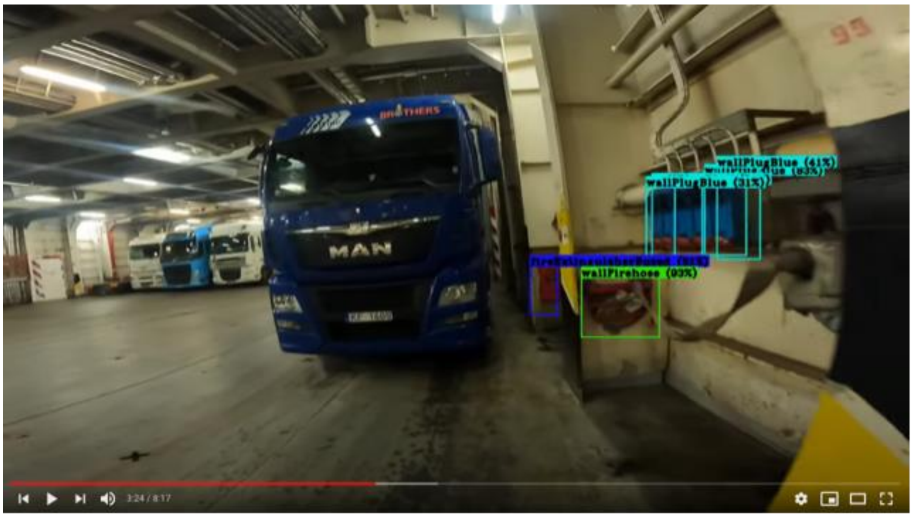


Figure 11. Object recognition on ship static assets creates a "zero" infrastructure vessel localization referencing system.

5.3.2.2 Impact on safety

RCM Op6 is expected to improve significantly fire safety on vessels for the below reasons:

- As human and cargo assets can be localized introducing better overview of fire hazard situations and operations before an incident;
- The bridge and port can have access to patrol data before or after an incident, analysing it through a visual interface and identify important aspects of vessel safety that require improvement;
- Certain smartphones feature an IR heat camera that allows fire respondents and patrol personnel to continuously monitor in an unobtrusive way hazardous condition on vessel and communicate this information seamlessly to the bridge. Our aim is to incorporate this functionality as a side benefit of the core fire responder's localization task showing that besides location and chat, heat scanning can also be a side benefit of RCM Op6; and
- The developed technology introduces no additional fire hazards as it relies on no installed infrastructure (i.e., infrastructure-free means that the installation of technology, batteries or moving objects on a vessel are not necessary), which might be a source of fire in their own right.

In the context of RCM Op6, we outline the background and preliminary testing of such a state-of-the-art system available to nearby responders that relies on an infrastructure-free localization method we develop that can run on commodity smartphone devices carried (or attached to) nearby responders.

5.3.2.3 Planned method of evaluation

These stages are validated through a remote study on the Stena Flavia vessel but also through extensive laboratory testing with video traces from the given vessel. As a result, we will obtain a complete understanding of the feasibility an infrastructure-free localization method running on commodity smartphone devices by nearby responders. This should pave the way for groundbreaking indoor localization technologies on ro-ro ships in the complete identification-tracking-positioning spectrum, namely live fire detection and localization, live monitoring, and tactical support, monitoring of cargo, quality control and optimization of cargo load and distribution on ro-ro ships.

5.4 Action 6-D: Effective and efficient manual firefighting

5.4.1 RCM Op7: Training, new equipment and procedures to suppress fires in Alternatively Powered Vehicles with special focus on Li-ion batteries fires

Main author of the chapter: Jaime Bleye, SAS.

5.4.1.1 Technical description

RCM Op7 aims to transfer the competence of how fire in APVs should be handled in ro-ro spaces, including evaluation of new firefighting methods and equipment.

APVs represent other types of hazards than vehicles with traditional fuel (e.g., gasoline, diesel).

Gas tanks can for example produce a jet flame or they may explode.

Lithium-Ion batteries can produce large quantities of combustible and toxic gases and can be difficult to extinguish if thermal runaway occurs.

The new type of hazards introduced by APVs require new routines, tactics, equipment and training to ensure the safety of crew and passengers on ro-ro ships.

A Compressed Natural Gas (CNG) gas tank explosion in ro-ro space can produce a Boiling Liquid Expanding Vapour Explosion (BLEVE). If the explosion occurs near an opening, e.g., in the stern, the risks are reduced considerably. A vehicle can act as protection against the pressure wave from an explosion, but at the same time the pressure wave from the explosion can cause the nearest vehicles to be overturned or moved. Furthermore, there may be damage to the interior which may lead to the risk of people being hit by falling parts. The material in gas tanks exposed to fire regains much of its strength when it has cooled. Also, the pressure in the tank decreases with decreasing temperature. This means that tanks that have not exploded during the fire have a safety margin against exploding when they have cooled down. At the same time, there are reports that composite tanks after a fire can leak gas through the tank material.

The critical hazards from lithium-ion batteries are judged to primarily be that they are difficult to extinguish and if damaged can start a fire several hours/days after the damaging event. The toxic gases that can be produced from a battery even though the vehicle is not on fire is also identified as a critical hazard while the toxicity of the combustion products from a vehicle on fire are not judged to be significantly more severe if there is a battery involved than when it is not. This is particularly problematic in poorly ventilated spaces such as in closed ro-ro spaces where the gases can accumulate.

A battery fire in an electric vehicle is difficult to extinguish. The battery is often difficult to access, and it can be complicated to cool the battery with water. Normally there are no risks of electric shock when extinguishing water is applied, but the fire may continue for an extended period.

There is also a risk that a battery fire will re-ignite after extinguishing. For ro-ro spaces, this means that monitoring the battery is necessary until the vehicle can be unloaded and placed where there is no risk of fire propagation.

Fire development in vehicles varies greatly depending on where the fire started, on materials and on vehicle fuel storage. However, a “normal” passenger car fire can generally be considered to have a burning time of just over half an hour with a maximum fire effect (around 4-5 MW) after about 10-15 minutes. The literature research shows that time for fire spread to the nearest vehicle in a parking garage with conventional vehicles differs quite considerably, 5 to 40 minutes, while fire spread to the next closest and third closest vehicles goes faster. If the vehicles instead include gas tanks another study shows a high risk of a domino effect where jet flames trigger additional jet flames from adjacent vehicles.

If the fire is small and does not affect the fuel storage, regardless of the fuel the vehicle has, a quick response with e.g. handheld fire extinguisher or fire hose is recommended. However, if a quick first response fails, there is a risk of rapid-fire development, and the drencher system should be activated soon. When a manual firefighting operation is required, the risk of explosion, jet flame, toxic gases is overveiling. Difficulties in extinguishing the vehicle must be considered when selecting tactics for such fires.

If a fuel storage in an APV is affected, a defensive tactic is usually selected on land. Defensive tactic can be obtained by securing the area around the vehicle and prevent fire propagation from a distance.

There is no legal minimum distance required between parked vehicles which may be as little as 0.15 m. This makes it almost impossible to manually fight the fire. The close stowage of cargo coupled with the large open area means fires can spread quickly and become very large if the fire does not become ventilation controlled. This can also reduce the effectiveness of water drenching systems.

The proposals for development are listed below:

- Due to the new challenges that APVs pose on board the ro-ro industry, the compulsory training that seafarers received through the STCW Code should be adapted; and
- RCM Op7 proposes the inclusion of a new column on section A-V/2 “*Mandatory minimum requirements for the training and qualification of masters, officers, ratings and other personnel on passenger ships*” of the resolution MSC. 417(97) adopted on 25 November 2016.
- RMC Op7 proposes new requirements for personal protective equipment for firefighting on ro-ro SOLAS ships where the equipment must be wheel marked standard. Minimum protection requirements should be in relation to expected risks when manual firefighting shall be applied on APV.

5.4.1.2 Impact on safety

The expected impact on safety are the following:

- Awareness on the hazards with the carriage and charging of electric cars will ensure that crew members are compliant and competent managing new challenges on board in a safe environment;
- 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 safety awareness of APVs will help to build and sustain a safe workplace, protect the cargo on board and the sea environment; and
- Training that includes the use of new equipment like (cooling water nozzles, CAF backpacks or fire blankets) will reduce the possibilities of fire escalation to vehicles that are parked close to the fire site.
- Proper and updated Personal Protective Equipment (PPE) for manual firefighting will provide the right protection to fire squad members against health and new risks associated to new challenges onboard like APV.

5.4.1.3 Planned method of evaluation

RCM Op7 will be validated and demonstrated in a relevant environment (fire ground of the Jovellanos Training Centre of SASEMAR, located in Gijon north of Spain) with a TRL of 5 and 6. Several tests were conducted in March-April 2022, varying fire stages, number of fire squad members, indoors/outdoors, firefighting equipment used, etc. Li-ion battery fires were tested (Figure 12).

Figure 12. Battery Electric Vehicles for the fire testing.

Inherently Safe Design

5.5 Action 7-A: Improved fire detection system interface design

5.5.1 RCM Des1: User friendly alarm system interface design guidelines

Main author of the chapter: Staffan Bram, RISE.

5.5.1.1 Technical description

LASH FIRE WP07 is concerned with the development of digital systems and environments supporting shared situation awareness and effective decision-making during fire management. Studies within the project have shown that fire safety system interfaces found on ro-ro passenger ships are often old or under-developed, and that system selection and integration often pays limited respect to the practical needs of their users (i.e., various members of the crew).

An important question that goes beyond pure design solutions is why these observations are so common. In order to increase fire safety systems usability on a broad scale, stakeholders involved in the process of commissioning and building ro-ro ships must be provided with the right support. If the ship design process is more geared towards practical usability, then onboard working environments will more consistently support the needs and activities of the crew, something that is an important prerequisite for safety. This is the aim of RCM Des1.

RCM Des1 will provide design process guidance to improve the usability of fire safety systems and environments as they are specified, designed and installed along the shipbuilding process. For this purpose, WP07 researchers have previously carried out a design process analysis, as well as a Stakeholder Analysis, identifying the main actors of this process. The LASH FIRE deliverable D07.1, “Study and analysis of regulations, accident investigations and stakeholders for bridge alarm panel design” [12], provides several suggestions to process activities and artefacts that could be augmented to provide a more thorough consideration of user needs. Guidelines will primarily be directed towards the stakeholders represented in the LASH FIRE consortium, i.e., shipping companies and possibly equipment manufacturers. Guidelines may include:

- User persona representing key actors in onboard fire management, their activities and typical needs in connection to fire incidents;
- Suggestions on key activities along the design process where usability-centred interventions would have the maximum impact and cost-effectiveness;
- Templates for design specifications, e.g., design guidelines for central environments and technical systems, describing key properties that affect usability; and
- Guidelines for inspection of designs, off-the-shelf systems and finished installations.

The introduction of a user-friendly fire alarm system interface (RCM Des2) will be used as a working case for the development of design- and design process guidelines. Practices demonstrated for this case should be transferable to many other applications.

Work on WP07 design guidance is currently ongoing and will be carried out in close collaboration with partner organizations from the industry, to make sure that this solution meets the practical needs of stakeholders in the design process. The suggestions outlined above should therefore be seen as preliminary examples of the outcome of RCM Des1.

5.5.1.2 Impact on safety

Reviews of ro-ro passenger ships fire incidents performed in the LASH FIRE and FIRESAFE II projects have shown that Human Factors issues often serve to delay or obstruct the crew's fire response. A large portion of the crew will be involved and fire management activities may be spread out over many different onboard environments. Creating the right conditions for these activities requires a holistic perspective on fire safety design, taking the practical needs of the crew into account. If such a perspective can be applied when ships are designed or re-designed, not only safety may benefit. Working environments that are well-adapted and ergonomic will also increase crew wellbeing and personal safety in their day-to-day activities.

However, previous research has also indicated that the shipping industry can be conservative and that the ship design process is tightly constrained, both in terms of time and economics. A critical aspect of design guidance is to provide support that is easy to understand and integrate into current practices. It is also important to demonstrate the benefits of changes to the design process. One example might be to show how the project workflow can be improved and the risk of late and costly design alterations may be reduced by applying a user-centred perspective throughout the project.

5.5.1.3 Planned method of evaluation

Validation of design guidelines would require them to be utilized in actual design work, confronting them with the many limitations and trade-offs of a real design process. Since this will not be possible within the LASH FIRE project, the guidelines will instead be validated through a joint assessment workshop together with shipping company partners. At this workshop, the participants will evaluate the applicability, usefulness, effort, cost and possible barriers of any design guidance developed by Action 7-A.

Should the opportunity arise, another possible mean of evaluation is to shadow an ongoing design project among the shipping company partners, evaluating the prospect of design process interventions together with process stakeholders. Activities or tools could be tested directly or tested as "shadow" alternative approaches in the background. Either way, interaction and discussions with design process stakeholders would be sure to give many insights around real-world applicability of the guidelines.

5.5.2 RCM Des2: Alarm system interface prototype

Main author of the chapter: Staffan Bram, RISE.

5.5.2.1 Technical description

RCM Des2 involves the development of a fire alarm system interface, or a Digital Fire Panel. This panel is meant to provide the best possible support for fire management, and its design provides solutions to deficiencies in existing systems that have been observed in previous studies.

The current prototype of the fire alarm system has been designed to support situation awareness and to offload the user's mental load. It builds on a high level of realism and contains:

- An interface calibrated for user ergonomics, e.g., for symbols, colours and luminance;
- Graphical depictions of decks with representations of detectors, fire appliances and cargo;
- Clearly indicated detector status, together with pre-alerts and temperature trends;
- User-friendly interface for temporary deactivation of detectors;
- Indications of heat levels and smoke spread;
- A scrubber; and

- Situation-dependent decision support for common actions.

Researchers within the LASH FIRE project stress the importance of design consistency for related equipment, on the bridge or elsewhere. A digital tool will only serve its full purpose if it is well adapted to its environment and the work that goes on there. Therefore it is important to see the Digital Fire Panel as part of a whole. This whole is represented by Action 7-C and its work on a Firefighting Resource Management Centre (FRMC).

5.5.2.2 Impact on safety

Reviews of past ro-ro passenger ships fire incidents performed both within the LASH FIRE and FIRESAFE II projects have shown that Human Factors issues often serve to delay or obstruct the crew's fire response. A large portion of the crew will be involved and fire management activities may be spread out over many different onboard environments. Creating a common understanding of the situation among these actors, enabling them to work efficiently and effectively, is highly important.

The design of the Digital Fire Panel revolves around the crew needs identified through user studies within the LASH FIRE project, but it has also explicitly been carried out to counter common alarm panel deficiencies. This includes distractions from nuisance alarms, alarms causing a high workload, alarm messages that are confusing or unclear, difficulties in localizing and differentiating between detectors and difficulties in judging alarm priorities. Reducing time in the fire management process is a key goal for work around the Digital Fire Panel. Deficiencies such as these increase the risk of misunderstandings and delays, allowing the fire to grow and making it harder to contain.

5.5.2.3 Planned method of evaluation

Evaluation of the Digital Fire Panel will be twofold:

1. A usability-centred evaluation performed by NTNU, focusing on user experience and ergonomics. This evaluation will involve test persons recruited from partner shipping company organizations and will show whether the Digital Fire Panel fulfils fundamental usability demands.
2. A session at the SASEMAR Jovellanos Training Centre (Spain), where the Digital Fire Panel will be tested as part of the FRMC. This evaluation will take the form of a full-scale simulation exercise involving seafarers, manning the ship's bridge and a fire team. The participants will be gathered from partner shipping company organizations, with DFDS as a preliminary main contributor.

5.6 Action 7-B: Efficient extinguishing system activation and inherently safe design

5.6.1 RCM Des3: Procedures and design for efficient extinguishment system activation

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

5.6.1.1 Technical description

Fire extinguishing system activation (drencher and carbon dioxide) 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 carbon dioxide system activation have documented a number of practice related issues where efficiency can be improved, uncertainties can be lowered, and time spent can be reduced.

RCM Des3 addresses the following challenges (themes) associated with today's (diverse) activation processes:

- Confirmation of fire;
- Location from where drenchers are activated;
- Responsibility for drencher activation;
- Drencher zone identification;
- Relocation to CO_2 room;
- Dangerous goods;
- Operating instructions for extinguishing system;
- Combination of manual/electric/automatic solutions for operating fire-related equipment (e.g., fire dampers);
- Radio communication – form; and
- Communication content and feedback loops related to extinguishment activation.

RCM Des3 must take into account the significant differences in ship design, fire system design and operational procedures and practices between the ship operators and ship types, and hence the procedures and design modifications of RCM Des3 will be a combination of (a) *ready-made measures* that may be adopted by all operators directly, and (b) *process measures* for tailoring procedures and design needs to fit the particular context of any ship (Table 1).

Table 1. Measures for efficient extinguishing system activation. (tr) indicates that a theme is candidate for inclusion in training (RCM Des4).

Measure	Preliminary description	Ready-made solution (a)	Process solution (b)
1	Evaluate and if necessary improve CCTV coverage in cargo hold and display relevant camera(s) on screen automatically, in relevant locations		X
2	Evaluate need for system upgrade to allow for remote activation of drenchers from bridge		X
3	Evaluate work practices and formal procedures/guidelines for drencher activation responsibility and modify to ensure harmonization		X
4	Evaluate need for system design modification to immediately show relevant drencher zone		X
5	Evaluate and if necessary modify practices regarding choice of location for activating CO_2		X
6 (tr)	Procedure to ensure that dangerous goods are taken into account before activating drencher system	X	
7	Evaluate operating instructions for drenchers and CO_2 system, update if necessary		X
8	Evaluate combination of electrical/remote and manual handling of fire systems (fire dampers, drencher sections, drencher pump), request modification if necessary		X
9 (tr)	Introduce standard protocol for two-way radio communication	X	
10 (tr)	Introduce (radio) communication practices that actively construct and maintain shared situation awareness	X	

5.6.1.2 *Impact on safety*

RCM Des3 consists of an array of measures 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 measures are divided into two categories. Category (a) (measures 6, 9, 10) are measures that that are fully developed and 'ready-to-use' when handed over to the ship operator. Category (b) (measures 1-5, 7) are measures that describe a process which the operator must run internally in order to adapt the measure to the organizational context. The benefit an delimitation of the measure are discussed in Table 2.

Table 2. Benefit and limitation of measures for efficient extinguishing system activation

Measure	Benefit	Limitation
1	Better CCTV coverage and automatic display of camera nearby activated fire detector may reduce the need for runner to undertake manual confirmation, and several minutes may be saved.	
2	Possibility to activate drenchers from bridge may save time and reduce the need for communication.	Less communication across locations may hamper the development and maintenance of shared situation awareness.
3	Reduction of ambiguity will reduce reason for hesitation towards activation.	
4	Immediately showing of relevant drencher zone on alarm panel may reduce time spent before activation. In addition, acknowledgement of this need may expedite requests to support implementation of RCM Des1.	
5	Remote activation of CO_2 may save time, in some cases several minutes.	Remote activation may hamper situation awareness, as activation from CO_2 room provides additional information from the human sensory apparatus.
6 (tr)	Uncertainty related to the appearance of dangerous good in areas with drencher systems, and to how this shall be dealt with in case of drencher activation can delay the activation process – this delay can be eliminated/reduced through clearer procedures.	
7	Ensuring that operating instructions do not give rise to confusion and hesitation, which has been the case in historic accidents, may save time in the activation process.	Procedures can never be exhaustive, and there is always a trade-off between brevity/clarity and thoroughness. Complex situations may cause need for more thorough descriptions, which may have been sacrificed and not as readily available.
8	Many of our informants have expressed a wish for better opportunities for remote management of fire systems, with the argument that this will save time. But also the opposite viewpoint have been stated, that such systems are better handled decentralized. The optimal solution must be evaluated for each ship context, and this evaluation may result in requests (wishes) from crew to modify systems. Either modification involves more or less remote management, the argument will be increased efficiency and time saved.	There is no guarantee that evaluations from the crew will lead to actions/changes, and the crew may also be aware of this – and it may affect their motivation to adopt/enact the proposed evaluation.
9 (tr)	Increase communication efficiency, reduce risk of misunderstanding, in turn leading to saved time.	
10 (tr)	Improve the shared situation awareness, leading to better decisions and time saved.	

All category (b) measures are all limited by the commitment of the ship operator and crew to invest in the process of further developing and implementing the measures in an adapted fashion. This is the main limitation of RCM Des3.

5.6.1.3 Planned method of evaluation

RCM Des3 will be demonstrated and evaluated on board ro-ro passenger ship and vehicle carrier in 2021-2022.

(a) type measures will be demonstrated during one or more fire drill(s), after having been implemented during the training module that will be developed as RCM Des4. Evaluation parameters may be in the form of qualitative/quantitative self-assessment (facilitated by LASH FIRE researchers) on value/improvement of measures.

(b) type measures will be subject to operator/crew-internal evaluation through means of query/workshop, followed by researcher-led qualitative evaluation of the internally produced material in cooperation with responsible operator representatives.

5.6.2 RCM Des4: Training module for activation of extinguishing systems

Main author of the chapter: Jaime Bleye Vicario, SAS.

5.6.2.1 Technical description

The training module (RCM Des4) will be designed to address the following challenges/situations:

- Hands-on activation of the fire extinguishing systems are not part of the Table A-VI/3 of the STCW Course "*Advanced firefighting*". Model course 2.03 [13];
- SOLAS II-2/19.3.2 [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 are not part of the compulsory fire drills;
- According to MSC.1/Circ.1430/Rev.2 [14], the manual activation of the deluge (or so-called drencher) systems are allowed and every crew member should be aware of the procedure. In reality there is a "blame culture" for activation and due to the lack of training and familiarity; and
- According to Chapter 5 "Fixed gas fire-extinguishing systems" of the International Code for Fire Safety Systems (FSS Code) Point 2.2.2. [15] 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 CO_2 control room (Figure 13) which is considered as a protected space with locked access. They are not familiar with activation and the efficacy of the carbon dioxide as firefighting agent.

Figure 13. Release box for control of activation of the CO_2 system.

5.6.2.2 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.

RCM Des4 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.

5.6.2.3 Planned method of evaluation

RCM Des4 will be developed with a TRL of 5, i.e., validated in a relevant environment (onshore maritime fire training facilities). More specifically in the Jovellanos Maritime Safety Training Centre belonging to SASEMAR located in Gijon, Spain. The fire training facilities to train on the implementation of activation routines and design guidelines in the activation of fixed (drencher and carbon dioxide) systems will be a container prepared to simulate the procedure on the efficient activation of the system considering the human factors involved from the detection until extinguishing (cf. Figure 14).

SASEMAR will define the scope of the course, course objective and entry standards providing the training facilities and equipment. Training outcomes will be reached matching the competence required for the minimum knowledge, understanding and proficiency required for certification.

Figure 14. Container prepared to simulate the procedure on the efficient activation of the system.

5.7 Action 7-C: Firefighting resource management centre

5.7.1 RCM Des5: Integrated solutions for fire resource management, combining relevant sources of information, including drone and camera monitoring system

Main author of the chapter: Martin Rasmussen Skogstad, NSR.

5.7.1.1 Technical description

RCM Des5 is connected to the development of a FRMC in Action 7-C. The FRMC is defined as both the technical systems and the wider context in which fire is managed, including socio-technical factors such as Human-Machine Interface (HMI), communication, and cooperation. One of the aspects of the FRMC will be a Digital Fire Central that integrates solutions for fire resource management, combining relevant sources of information, including drone and camera monitoring system.

A bolt-on solution was identified as the preferred option for the Digital Fire Central. A bolt-on solution would allow of a customizable solution that adheres to current rules and regulation, thus being a key enabler in addressing the needs of existing installations and having the potential to provide benefits to the sailing fleet.

The ultimate goal is to create the best possible situation for personnel in a fire situation. RCM Des5 contributes to that through making fire relevant information and controls available in one system. The integrated information includes both information that is current used in firefighting and information from new sources (e.g., drones).

Iterations of the prototypes of the FRMC and Digital Fire Central (Figure 15. Overview of the FRMC and Digital Fire Panel interface.) are currently being tested and developed so the final list of information sources and controls is not ready. Prototypes and discussions have included:

- Fire detection:
    - Heat and smoke detectors;
    - Closed-Circuit Television (CCTV);
    - IR camera systems;
    - Smart alarm systems; and
    - Drones.
- Fire suppression and extinguishing:
    - Additional relevant information and controls;
    - Power connectors;
    - Water levels, Bilge and Ballast;
    - Ventilation;
    - Fire curtains;
    - Doors;
    - Cargo information; and
    - Localization of personnel and passengers.
- Technical alarms.

Figure 15. Overview of the FRMC and Digital Fire Panel interface.

5.7.1.2 Impact on safety

The integration of fire relevant information and controls in one system is believed to have an impact on safety as it could:

- Reduce time spent on gathering information from several different systems;
- Improve quality of decisions as more of the available information is used;
- Improve quality of decisions as new information sources are used; and
- Further standardize relevant information.

In other words, improved technical design for effective management of critical operations in case of fire.

Possible negative effects could be that one central system for fire relevant information and controls will potentially cause more delays if it freezes/fails than current systems. There will be alternative or backup ways available, but additional delays could occur.

5.7.1.3 Planned method of evaluation

The following tests, demos and validations planned in WP07 will contribute to the development and evaluation of the FRMC, including the Digital Fire Central and RCM Des5:

- Lab test and validation of alarm system interface prototype (2021-2022);
- Onshore testing of training module on the use of fixed fire extinguishing systems (drencher and carbon dioxide) (2021-2022);
- Onboard demonstration of drencher and CO_2 activation procedures (2021-2022);
- Onboard demonstration of guidelines for drencher room design, by real ship implementation (2021-2022);
- Onboard test FRMC drone (2021-2022);
- Onshore lab demonstration of FRMC simulator prototype design (2022);
- Onshore lab validation test FRMC prototype (2022); and
- Onshore demonstration of FRMC prototype (2022).

5.7.2 RCM Des6: Guidelines for organizing the response in case of a fire emergency

Main author of the chapter: Martin Inge Standal, NSR.

5.7.2.1 Technical description

Formal fire safety work is mainly focused on functional construction, legislative compliance, and technical fire installations, which mean that large parts of the factors for successful fire emergency response are less visible. These invisible aspects are often connected to the crew's knowledge, experience, ability to adjust, cooperate, and apply creativity, which are features important for resilience/adjusting to a fire-situation.

Handling a fire situation is a combination of knowledge of the local situation (e.g., the ship with its physical and sociotechnical aspects) and knowledge of fire and firefighting. After detection of fire on board ships, quick and appropriate fire emergency response is a necessary ingredient to successful fire management, preventing loss of life and damage to ship and cargo. The primary goal is to safeguard life and health, and secondary to avoid the loss of ship and cargo. Thus, if possible, fire emergency response should be performed by extinguishing the fire with minimal risk to the health of crew and passengers.

RCM Des6 presents generic guidelines for fire emergency response, including fire dynamics, search and rescue, and evacuation in the world of ro-ro ships. This guideline will provide best practices for execution, work flow and processes in a fire emergency situation.

When any critical situation arises on board, the main objective is to protect human life, then assets. That means safety-concerns for the crew comes before damaging of cargo or ship. However, if at minimum risk the ship and cargo can be saved, this should be sought. Both for obvious economic reasons but also because it is safer for crew and passengers to stay on board the vessel as long as possible. That is the main objectives the decision makers during a fire on board a vessel is facing.

The objectives of RCM Des6 are to provide guidelines that can assist the decision making process from fire detection to extinguishment or evacuation and thus help reduce the risk of life caused by fire. Furthermore, the guideline will also aim to reduce the risk of damage caused by fire to the ship and the environment. This is done by providing guidance on how to contain, control and suppress fire in the compartment of origin and to provide guidance on adequate and readily accessible means of escape for passengers and crew.

Operators should use the guidelines to create specific protocols and procedures based on local conditions (e.g., ship type, functional or technical system) and should adjust these approaches in particular situations where doing so would maintain equivalent or better level of safety.

In the event of a fire, initial actions should be taken in accordance with the shipboard emergency plan. The guidance is for shipboard use where master and crew have to respond to a fire without external assistance (e.g., from land-based firefighting services).

The guidance should be integrated into the contingency plan for shipboard emergencies, and should be adapted specifically to the individual ship and the equipment on board. This guide provides a general overview that will assist considerations regarding, among other things, procedures, chronological order, also based on the type of ship, location of fire, and type of fire control room system. It is intended to be used for the preparation and development of a module structure of an integrated system of shipboard emergency plans.

5.7.2.2 Impact on safety

The main impacts of safety from RCM Des6 are through:

- Assisting companies in translating the requirements of the regulations and good practice into action and integrating the guidelines into existing emergency guidelines or safety management centres; and
- Developing harmonized fire emergency plans which will enhance the acceptance and understanding of the personnel in a fire emergency situation.

5.7.2.3 Planned method of evaluation

The following tests, demos and validations planned in WP07 will contribute to the development and evaluation of the FRMC, including the Digital Fire Central and RCM Des6:

- Lab test and validation of alarm system interface prototype (2021-2022);
- Onshore testing of training module on the use of fixed fire extinguishing systems (drencher and carbon dioxide) (2021-2022);
- Onboard demonstration of drencher and CO_2 activation procedures (2021-2022);
- Onboard demonstration of guidelines for drencher room design, by real ship implementation (2021-2022);
- Onboard test FRMC drone (2021-2022);
- Onshore lab demonstration of FRMC simulator prototype design (2022);
- Onshore lab validation test FRMC prototype (2022); and
- Onshore demonstration of FRMC prototype (2022).

Ignition Prevention

5.8 Action 8-A: Automatic screening and management of cargo fire hazards

5.8.1 RCM Pre1a: Cargo scanning and identification and tracking system by the means of a called Vehicle Hot Spot Detector system

Main author of the chapter: Robert Rylander, RISE.

5.8.1.1 Technical description

In LASH FIRE, a system originally used for increased tunnel safety called Vehicle Hot Spot Detector (VHD) will be the starting point for the development. Based on this system, LASH FIRE adds the scope of identifying the reefer-compressor unit that is placed on the trailer either on the wall facing the truck or a more modern solution.

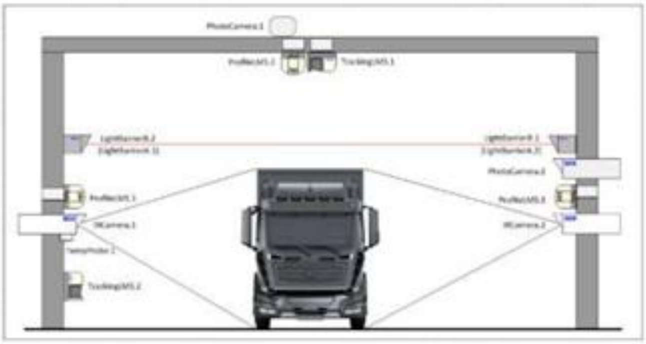


Figure 16. VHD system implemented as a gate.

Figure 16 illustrates the original VHD portal and arrangement of sensors (without the additional IR-sensor looking straight down from an elevated position in the arch over the objects lane). RCM Pre1a uses multiple sensors (Figure 17), IR cameras, Light Detection And Ranging (LiDAR) for profiling length, width, depth and volumetric measurements. It also uses cameras for registration plate recognition as well as capture “as is” photos and video of the object. It also has Light barriers, for indication if the object is too high (air draft) and possess a danger to infrastructure.

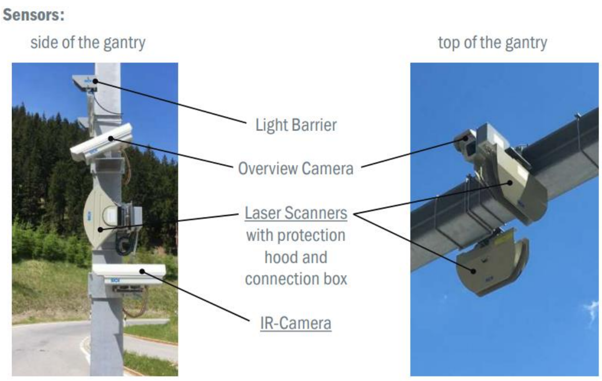


Figure 17. VHD sensors.

The profiling or outline of the object is done by an array of LiDARs, the 2D images are then stitched together using software to a 3D representation of the object. The motion of the object is tracked by a LiDAR placed in line, prior or after the portal.

A combination of the 3D model and the data collected with the IR light camera can be used to create a representation of the object and segment out the areas of interest or specific components. In VHD system, vehicle specific segments, or objects like wheels, parts of the drive train such as turbo and exhausts, can be subject to other software algorithms that can use pre-defined values or historical data to determine anomalies such as overheated breaks on a set of wheels, as illustrated in Figure 18.

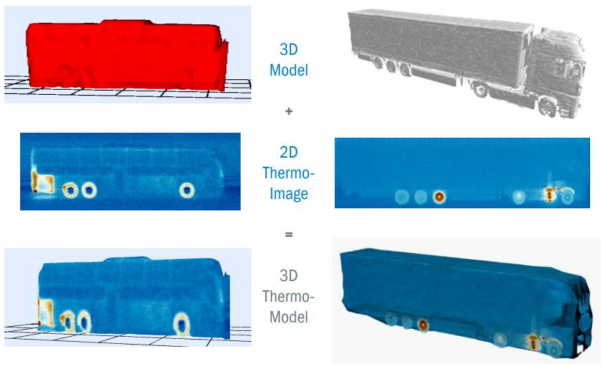


Figure 18. Example of 2D to 3D conversion and IR sensor fusion of sensor data.

A software can also be used to segment out the different compartments of the vehicle such as engine, passenger compartment, cargo hold and areas. Below (Figure 19) is an illustration of how the sensors data and how algorithms maps (dotted) different sections of the object and presented in a user-friendly HMI.

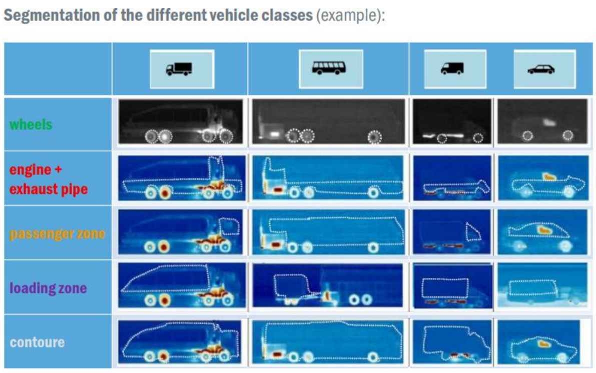


Figure 19. VHD Temperature and segments in 2D.

In LASH FIRE, a vertical IR-sensor is placed look down to enhance the field of view for the system that significantly increases the possibility to detect hotspots in the void between the back of the truck and front the trailer. This area is to be segmented especially for LASH FIRE functionality.

For the time being, different implementation strategies as solution for LASH FIRE are foreseen:

- Single point or gate:

  RCM Pre1a can be implemented as a stand-alone system at a single point. This will give a good understanding of the status of the cargo/trailer/vehicle as it passes the gate. The value of the information/system decreases over time and is correlated to where or how far from the ship e.g., how much prior the cargo/trailer/vehicle rolls on board the ship.

- Full VHD mesh:

This covers the object from gate to gate, monitoring the object as it enters the terminal, during loading, voyage and as it leaves the destination. This will allow the operator(s) to minimize the risk of an undetected hot spot, that could lead to a larger fire. Such system is costly to retrofit into old structures like terminals and especially ships.

- Hybrid solutions:

It is possible to set up a hybrid solution, where a full VHD system scrutinize the object at a strategic location and lower automatic object coverage is considered fine at a level where we are today. And perhaps the ship has its own array of sensors. If a system allows data exchange or the operator can monitor all systems in parallel, together terminal and ship systems enhance the safety level.

5.8.1.2 Impact on safety

As of today, little or no activity is done to assess the status of the cargo/trailer/vehicle as they enter the terminal area. While the object(s) sit at the terminal, little or no activity is performed to assess the status of the object at the yard.

During loading, the stevedore(s) and shore personnel should assess the object they are about to handle. As the object enters the ship, if the ship's crew is/are present, they should assess the object. During the voyage, ro-ro spaces should be monitored/patrolled by ship's crew. All actions above require the person(s) to be present (at all times to have full coverage over time), trained to look for known issues and vigilant to detect unknown issues.

IR technology detects heat signature faster than traditional fire detectors, it also gives a direction and with sensor fusion with camera/LiDAR can give a precise position of the hot spot.

5.8.1.3 Planned method of evaluation

Tests in a terminal (ashore) are planned to be conducted and if possible on board ships. Detection from a refer trailer will be tested by manually adding hotspots in different locations on the refrigeration unit. This will be run by the VHD gate at Stena Terminal at Majnabbe, Sweden to compare with normal traffic of trailers and reefer-trailers, to find normal refrigeration unit heat signature to be able to set warning and alarm levels for RCM Pre1a.

5.8.2 RCM Pre1b: Automatic screening and management of cargo fire hazards by means of Automated Guided Vehicles

Main author of the chapter: Robert Rylander, RISE.

5.8.2.1 Technical description

Based on ground-based drone, a concept system is being prototyped able to identify/detect heat signature from the undercarriage of an object (vehicle/trailer/cargo-carrier…). In Figure 20, the Automated Guided Vehicle (AGV) (RCM Pre1b) is passing under an object, in this case a vehicle and cargo; passing by in relative low speeds, depending on the sensor array, which must cover the whole undercarriage of the vehicle.

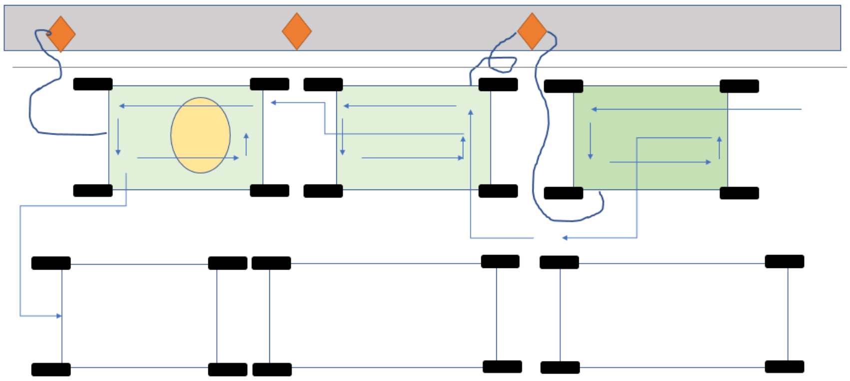


Figure 20. AGV screens undercarriage of vehicles.

Figure 21 describes RCM Pre1b architecture and sensor array. In the prototyping phase of LASHFIRE, only one IR sensor is looking upwards from the AGV.

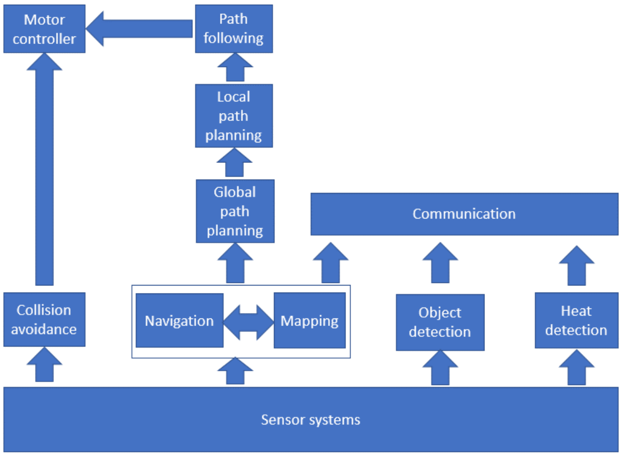


Figure 21. AGV path and mission control concept.

An example showing a temperature of the undercarriage of a hybrid vehicle is provided in Figure 22, as the battery bank is stressed and temperature rises.

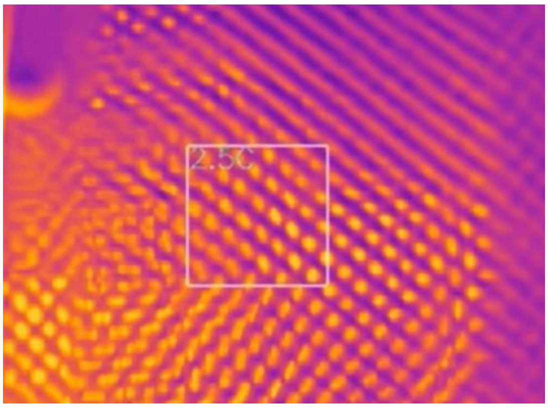


Figure 22. IR sensor showing 2.5°C (ambient temperature = 0°C).

For the time being, different implementation strategies as solution for LASH FIRE are foreseen:

- Single AGV:

Single AGV that patrols a designated area of the deck with the goal to monitor a specific area/object(s). Ro-Ro spaces have many lane meters, a single AGV might cover the whole deck but will probably need to focus on a specific area/cargo(s)/vehicle(s).

- Swarm of AGVs:

Swarm technology allows efficient covering of larger areas with AGVs that exchange data of planned route and share a common strategy.

- System of systems:

RCM Pre1b can be implemented as a component, covering the cargo decks during transit, focusing on movements of cargo/trailers/vehicles. The system can exchange data with onboard systems giving its location and sensor readings in a live stream.

- Added values:

RCM Pre1b could act as a firefighting team member and scout for hot spots, though this will add complexity to the design of RCM Pre1b.

5.8.2.2 Impact on safety

During the voyage, ro-ro space should be monitored/patrolled by ship's crew. All patrols are carried out by crew. They should have been trained to look for known issues and vigilant to detect unknown issues.

An automated system offers support to staff and crew in all the above mentioned realities, it will not replace the human, but support with both detection, early response and in case of an full blown incident, a better situational awareness via the sensors live stream of video and IR information about personnel activities and the fire development.

IR technology detects heat signature faster than traditional fire detectors, it also gives a direction and with sensor fusion with camera/LiDAR can give a precise position of the hot spot.

It can also be used to find persons/personnel that should be there and maybe a higher priority, those who should not.

5.8.2.3 Planned method of evaluation

Tests on land are planned to be conducted first and if possible on board ships. All functions can be tested and demonstrated ashore. RCM Pre1b will be located underneath different types of vehicles (e.g., Internal Combustion Engine Vehicles (ICEVs), Hybrid Electric Vehicles (HEVs) and Battery Electric Vehicles (BEVs)). Vehicles will have different "status"; for example: running on ICE, hybrid, battery, idling, charging. Different configurations and arrangements will be tested: singe vehicle and row(s) of vehicles, cluttered deck (charge cables, etc.).

5.8.3 RCM Pre2: Stowage planning tool with optimization algorithm for cargo distribution

Main author of the chapter: Francisco Rodero, CIM.

5.8.3.1 Technical description

As a summary definition, the Stowage Planning Tool (SPT) (RCM Pre2) is a software that supports cargo distribution in roro spaces including fire cargo hazard management.

The ship layout, the cargo to be loaded and additional criteria or configuration parameters will be taken as inputs, together with a cargo fire hazard database in order to perform a cargo distribution aiming at reducing the overall risk from the fire ignition prevention perspective.

The reduction will be addressed by means of a risk assessment based on historical information compiled in the already existing fire cargo hazard database.

RCM Pre2 will be designed to be run as plug-in that can be used by third-party components (i.e., current software from the operators): the tool will work as an external component from the existing operator's software point of view (Figure 23). In this case, the tool developed in LASH FIRE will receive a suggested stowage plan (SW) and will feedback with a fire risk score that will be managed accordingly by the decision-making processes from the operators. Optionally, the tool could make some changes in the distribution depending on the constraints defined for each unit.

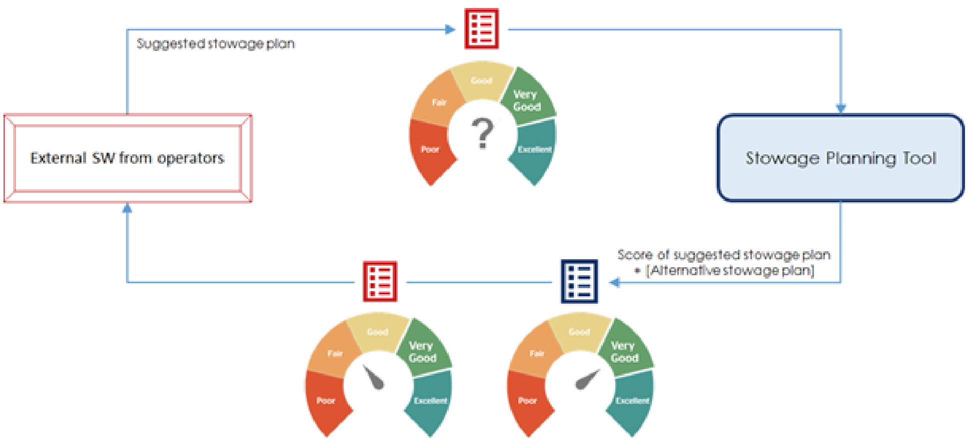


Figure 23. Overview of the interaction of the Stowage Planning Tool with external SW.

Risk assessment of a cargo unit is based on historical data about previous incidents or any documented reports where valuable information about ignition prevention can be found. Depending on the cargo type, a level of criticality is set and suggestions and recommendations are given to the algorithm in order to find a spot where International Maritime Dangerous Goods (IMDG) rules are satisfied and it is, historically, safe.

All technical components or elements such as inputs, outputs, configuration and, of course, technical details of how the algorithm will work and what are the different steps taken will be fully described in LASH FIRE deliverable D08.4, "Stowage planning optimization and visualization aid" [16], also including all relevant information managed in each step.

Although the algorithm is the core component of RCM Pre2, it is important to remark that it has no direct interaction with human users. For this purpose, a visual interface will be provided (visualization aid) where different user profiles (load office, tug master, deck crew...) have access to different features supporting the stowage process as defined in LASH FIRE deliverable D08.3, "Development of fire hazard mapping visualization tool with fire hazard matching integrated" [17].

The below image (Figure 24) depicts the main components of the software:

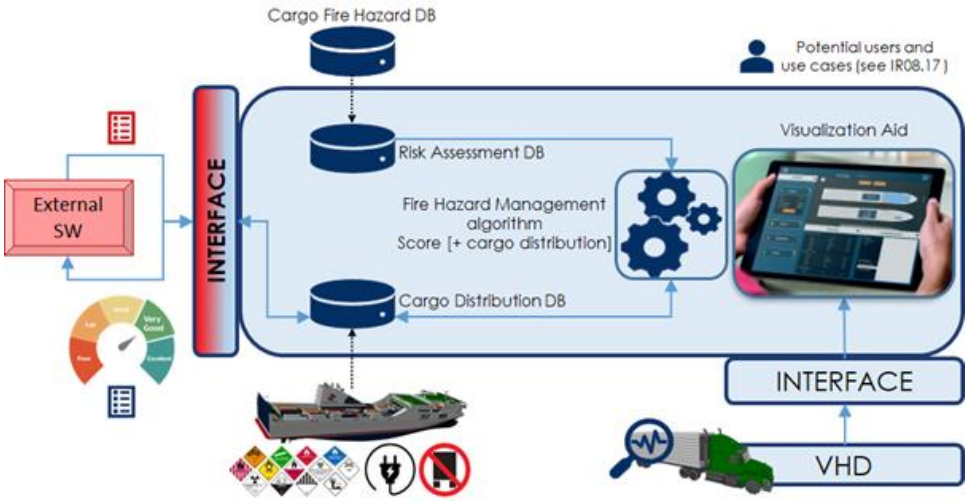


Figure 24. Overview of the interaction of the Stowage Planning Tool with external SW.

5.8.3.2 Impact on safety

The main objective of RCM Pre2 is to provide operators with a cargo distribution that not only takes into consideration IMDG rules but also adds fine tuning of the final placement of cargo unit after a risk assessment for each cargo unit.

From the safety point of view, benefits are clear enough. Placement of cargo is taking advantage of generated knowledge by means of a risk assessment which considers safety beyond current IMDG rules. Criticality for a given cargo unit is set during the generation of the cargo distribution but is also updated during the stowage process itself through the so-called real-time loop. An arc of sensors will be physically installed just before entering the vessel (RCM Pre1b) and, depending on what it detects scanning the cargo, criticality can be adjusted. If so, a recalculation of the cargo distribution may be triggered to consider the new situation.

Then, fire hazard management applied before and during the stowage process has a direct impact on safety since most critical cargo units are specially processed (or removed).

A limitation when operating the software as stand-alone application will be the integration with third-party stability calculation components since own implementation is out of the scope of the project.

5.8.3.3 Planned method of evaluation

Unit and integration tests during the development phase will be performed as well as functional tests after implementation are also expected to be realized in-situ (real environment). Unit and integration tests are intended to ensure quality of programming and to check that code is bug and error free. They are executed at “lab-level” since they can be automated in night batch-mode without any user interaction.

Functional testing aims at verifying that RCM Pre2 satisfies all requirements. They require more human intervention since they involve different profiles (end-user types) and here, the visualization component plays an important role displaying the outputs of RCM Pre2 and allowing user interaction.

During the final stage of the project, in-situ tests are expected to take place in order to assess the benefits of such a tool in a real environment and check the goodness of the results previously obtained.

Although contributions from operators are continuously included during design (specification and requirements) and development (scenario creation and analysis of first results), they are also relevant after these tests since they can provide a very valuable feedback to generate conclusions and to define improvements and further steps.

5.9 Action 8-B: Guidelines and solutions for safe electrical connections

5.9.1 RCM Pre3: Develop guidelines for safe electrical power connections in ro-ro spaces for reefer units

Main author of the chapter: Vasudev Ramachandra, RISE.

5.9.1.1 Technical description

Most of the loads that demand and consume power on the decks are ro-ro cargo and are mainly reefer units. With an increase in electric mobility, electric and hybrid cars that need charging during the voyage are also increasing as electrical loads on the deck. 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 Artificial Intelligence (AI) 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. RCM Pre3 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;
- Insulation; and
- Temperature.

5.9.1.2 Impact on safety

From historical data of near-miss cases, it is evident that human intervention has been of importance in preventing electrical faults related catastrophes on board. However, most of these interventions have not been deliberate but more of a coincidence. Noticing of smoke or sparks and hence proceeding to manually inspect and disconnect a reefer has been a relatively common occurrence among the near-miss cases.

With the implementation of RCM Pre3, the objective is to not leave anything to chance but to have everything monitored continuously. While this is true, it is predicted that false alarms will be of concern. The safety system cannot be designed highly conservatively as disconnecting reefers for insignificant faults might lead to loss of goods unnecessarily whereas designing a non-conservative system might allow faults through that might lead to a fire. A workaround is to design a conservative system but to not have an automatic disconnection of the load under contention. The proposal is that when the system encounters a fault or predicts one, a flag is raised which will then be evaluated by the crew who will decide if there is a need for disconnection of the said load. This demands certain regular operational procedures to be devised for the crew to follow.

5.9.1.3 Planned method of evaluation

The planned method of evaluating RCM Pre3 is by initially setting up a test bed where RCM Pre3 can be benched under various possible conditions. The testing is broadly planned in two phases.

The first will be to assemble the hardware including all sensors, computer units, etc. and to measure reference data on a normally operating reefer unit. Development of the AI system will then take place with the collected data as the reference data set.

The second phase would essentially test the hardware along with the AI. The reefer unit will forcefully be introduced with faults so the monitoring system can be evaluated for its accuracy in detecting and predicting the introduced faults.

5.9.2 RCM Pre4: Develop guidelines for safe electrical power connections in ro-ro spaces for charging of electric vehicles

Main author of the chapter: Vasudev Ramachandra, RISE.

5.9.2.1 Technical description

Monitoring of chargers and Electric Vehicles (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 ferry, 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 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, RCM Pre4 is to predict possible fires or extreme electrical conditions by the use of 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.

The computer unit can not only be used to run the AI but also can be used to optimize the measurement of data. For instance, for reefers, until a first insulation fault is registered, the frequency of requesting/receiving data from the sensors can be low. Upon the first fault, the fault locator will indicate the specific distribution box connected to which is the faulty load. The system can then be optimized to increase the frequency of measurements of currents and voltages only for those loads connected to the particular distribution box. These values will then be used to predict the future state of the load.

5.9.2.2 Impact on safety

The primary objective of RCM Pre4 is to monitor the EV and the charging unit in the ro-ro spaces while considering both as black boxes. With numerous charging standards, charger unit providers and even more EV manufacturers, this generic solution shall provide an overall monitoring capability that is designed to mitigate any negative consequence originating from electrical faults. RCM Pre4 shall also introduce AI to predict these negative consequences based on measured anomalies. This shall reduce the dependence on manual inspection at every fault. This shall also reduce the number of false alarms raised.

5.9.2.3 Planned method of evaluation

The planned method of evaluating RCM Pre4 is by initially setting up a test bed where the RCM Pre4 can be benched under various possible conditions. The testing is broadly planned in two phases.

The first will be to assemble the hardware including all sensors, computer units, etc. and to measure reference data on a normally operating charger-EV system. Development of the AI system will then take place with the collected data as the reference data set.

The second phase would essentially test the hardware along with the AI. The charger-EV system will forcefully be introduced with faults so the monitoring system can be evaluated for its accuracy in detecting and predicting the introduced faults.

5.10 Action 8-C: Fire requirements for new ro-ro space materials

5.10.1 RCM Pre5: Proposal for requirements of surface materials in ro-ro spaces, with reference to suitable test method and material property performance criteria

Main author of the chapter: Anna Sandinge, RISE.

5.10.1.1 Technical description

The usage of combustible materials, such as composite materials, increase in maritime applications. These materials, both newly developed as well as the usage of products from other sectors is increasing in the design of ro-ro spaces. However, there are no defined fire requirements for these materials. The need for requirements of surface materials in ro-ro spaces is obvious and a proposal of such requirements, with reference to suitable test method and material property performance criteria will be developed.

The main benefit from this will be development of new material solutions for use in ro-ro spaces. The work will also give knowledge on material properties, the fire hazard, and the safety level. Further, the establishment of test methods for performance validation of material properties will be provided.

5.10.1.2 Impact on safety

New materials and usage of already existing materials from other sectors in ro-ro spaces will have an impact on the fire safety. In case of fire, the combustible materials will burn and contribute to fire development on board. However, evaluating the fire performance of these materials and define requirements and guidelines will keep the fire safety at a high level.

5.10.1.3 Planned method of evaluation

The development of RCM Pre5 can be divided into three main steps.

1. Relevant materials will be identified. The materials can both used in ro-ro spaces today and in other applications, in other transportation vehicles, such as trains and aircraft.
2. A selection of these materials will be tested and evaluated with reaction-to-fire testing methods, with focus on the ignition phase and flame spread.
3. A proposal of fire requirements will be developed.

Detection

5.11 Action 9-A: Detection on weather deck

5.11.1 RCM Det1, Det8 & Det2: Flame wavelength detectors, thermal imaging (infrared) cameras, and deck mounted linear heat detection by fibre optic cables

Main author of the chapter: David Schmidt, RISE.

5.11.1.1 Technical description

According to SOLAS II-2/20.4.1 [2], fire detection is required for all ro-ro spaces. However, due to the absence of deckhead and other places for mounting of detectors at a weather deck, it is currently accepted to have weather decks unprotected by the fire alarm system.

To be able to detect fires on weather decks, two different methods have been considered, namely optical detectors overlooking a wide area from a long distance and deck mounted linear detectors monitoring the temperatures beneath the cargo items. For both methods, the placement of the detection device requires good planning, but a strategic placement is particularly critical for optical devices (e.g., flame detectors and IR cameras), because their line of sight has to be free, otherwise they cannot provide enough coverage for the weather deck.

5.11.1.1.1 RCM Det1: Flame wavelength detectors

Flame detectors are optical detectors and work with mainly two different technologies. The first one is ultraviolet (UV) flame detection which looks for UV radiation from flames, and the second one is infrared (IR) flame detection which looks for fluctuating IR radiation from flames in one or several wavelength bands.

During this study, only IR flame detectors were tested (Figure 25), as these detectors have the advantage of overlooking a large area using a single device. In the conducted study, all the detectors had approximately the same field of view and were tested following the general requirements of EN 54-10:2001 [18] and IEC60092-504 [19], while optimizing the balance between early flame detection and nuisance alarms required the adjustment of software settings and alarm thresholds on each given device.

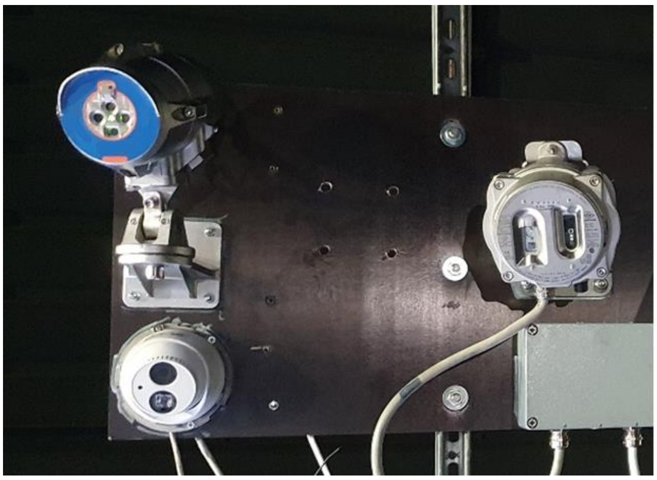


Figure 25. Flame wavelength detectors tested in the lab-scale experiments.

5.11.1.1.2 RCM Det8: Thermal imaging (infrared) cameras

Thermal imaging cameras are digital cameras where each pixel in the image sensor is detecting light in the IR spectrum. All objects emit IR radiation depending on their temperature and this principle is used for the camera to estimate the temperature of the objects within the field of view.

The information is presented as a video image where the temperatures are colour coded with a defined palette (Figure 26). Increased temperatures in parts of the image may be caused by flames, a developing fire, or a hot surface that may or may not represent a fire hazard. Subsequently, fire alarms may be triggered by a set of criteria based on the perceived temperatures.

The conducted tests show that the alarm threshold setting of the detector is a key factor defining the performance of the detector. Correspondingly, there is a trade-off between early detection and frequency of nuisance alarms that could be expected. Flame detection using IR thermal cameras is a relatively new concept and is not included in EN 54-10:2001 [18] for standard testing.

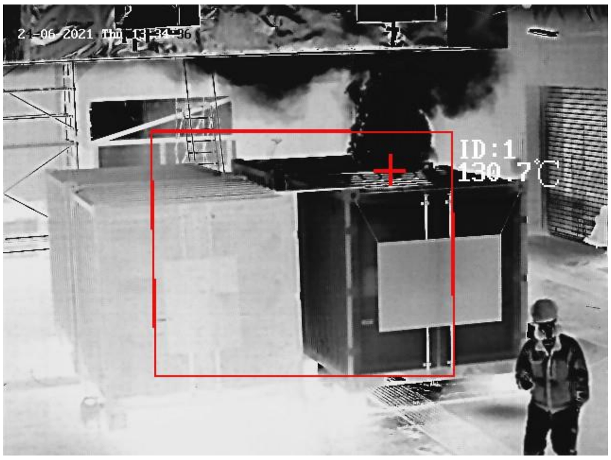


Figure 26. IR image from a camera during lab scale test. An alarm is triggered, and the recorded maximum temperatures are presented.

5.11.1.1.3 RCM Det2: Deck mounted linear heat detection by fibre optic cables

The linear heat detector tested in this study is a fibre optic cable that detects temperature changes along the cable connected to a central unit. The measurements are done by sending laser pulses from the central unit through the cable and via analysing the light reflected to the central unit. This involves analysing the wavelength and intensity of the reflected light over time which in turn provides information about temperature changes along the cable as the light is scattered by such temperature changes. This detection system is robust and can be used in the harshest of environmental conditions, e.g. under extreme temperatures or in presence of radiation or dust. Potentially, fibre optic linear heat detection can be fixed on weather decks to be able to detect fires starting closer to the deck floor, for example, in batteries in EVs.

The deck mounted linear heat detector will not be sufficient by itself to detect all fires on a weather deck but may be relevant to get early warnings on overheating vehicles, a signature that is not easily detected by detectors from above as is the case for optical detectors.

5.11.1.2 Impact on safety

Weather decks are not obliged to be covered by any fire detection system in practice because there are limitations related to the fixing of the detectors on such decks. Smoke on a weather deck will be diluted due to open air and wind circumstances and this makes the smoke hard to detect. With smoke detection excluded, the alternative is heat or flame detection. In this case, due to the missing bulkhead for traditional point heat detectors, it is most practical to use optical devices or to implement deck-mounted solutions.

Optical devices such as flame detectors, thermal imaging cameras, and video flame detectors have the benefit of covering a large area using a single device. Correspondingly, one or more detectors could be mounted on the upper deck structure to cover the weather deck. The downside of such detectors is that they need free line of sight to the area of fire development, otherwise they will not be able to detect the fire. Nevertheless, 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 areas (for example, roof of a container when there is a fire inside) that could help detect the fire development more efficiently. Moreover, optical devices might falsely detect a fire sometimes due to light reflections on shiny surfaces. Similarly, since thermal imaging cameras could detect fires based on hot areas, there could be false detections due to hot exhaust pipes or similar permissible hot areas. Depending on the detection technology used, there are different techniques and algorithms to be used for avoiding false detections of fire from sources such as arc welding or reflected sunlight. In particular, detection threshold values can be adjusted on the detector devices, so that the maximum detection distance and sensitivity to early detection is balanced accordingly.

Deck mounted linear heat detection can give an improved detection when a fire is close to the deck surface (for example, fire starting from a battery pack on an EV) but these detectors are evaluated only for use as a complement to other detection devices. Moreover, deck mounted linear heat detectors need mechanical protection to prevent the fibre optics from getting damaged.

5.11.1.3 Planned method of evaluation

Laboratory-scale tests were performed in two sessions where different scenarios of fire were simulated between a configuration of four steel containers, considering open and concealed fires with different fuels and wind conditions. The corresponding evaluations from the lab-scale tests provide insight as to which type of detectors are best suited for detection of fires on weather decks. Moreover, outputs from the lab-scale tests will be input to the large-scale validation of selected weather deck solutions. In this regard, the technologies listed above are the three solutions found to be suitable for the detection of fire on weather decks, albeit with different pros and cons.

The large-scale validation is planned to be performed on board. The plan is to use, as far as possible, the same setup as in the lab-scale tests, although large-scale tests will have more limitations regarding heat, flames, and duration of the fire tests.

5.12 Action 9-B: Detection in closed and open ro-ro spaces

5.12.1 RCM Det3, Det7 & Det4: Video detection, fibre optic linear heat detection, and adaptive detection threshold settings

Main author of the chapter: David Schmidt, RISE.

5.12.1.1 Technical description

5.12.1.1.1 RCM Det3: Video detection

Video detection uses a camera to detect flame or smoke using video analytics. There are two principal types for video fire detectors: Video Flame Detection (VFD) and Video Smoke Detection (VSD). The camera can be either an already existing surveillance camera system (CCTV) with video detection as an add-on feature (Figure 27), or a separate detector equipped with a camera. Flame or smoke characteristics are interpreted in the field of view to identify visual features of flame or smoke. These characteristics consider textures, shape, size, flicker pattern, motion, energy, transparency or colours and are analysed using video algorithms.

Figure 27. Image from a camera video clip that is post-processed by the video flame and smoke detection software. The flame inside the container is recognized by the software and marked with a grey outline and smoke is recognized and marked with a blue outline and purple dots.

5.12.1.1.2 RCM Det7: Fibre optic linear heat detection

The linear heat detector tested in this study is a fibre optic cable that detects temperature changes along the cable connected to a central unit. The measurements are done by sending laser pulses from the central unit through the cable and via analysing the light reflected to the central unit. This involves analysing the wavelength and intensity of the reflected light over time which in turn provides information about temperature changes along the cable as the light is scattered by such temperature changes. The electronic system is based on a cable with embedded temperature sensors that can communicate with a central device through a serial bus. Both systems can measure the temperature at addressable intervals throughout the length of the detection cable. This detection system is robust and can be used in the harshest of environmental conditions, e.g. under extreme temperatures or in presence of radiation or dust.

5.12.1.1.3 RCM Det4: Adaptive detection threshold settings

Existing detection system are in most cases de-activated during loading and unloading in order to avoid false alarms. By analysing the existing normal scenario, both during sea and at dock for loading/unloading, the sensitivity to existing detectors could be adapted to suit the environment. This could remove the need for disabling detection during loading/unloading and the space would be protected. The algorithms/sensitivity would be changed in the fire alarm system based on the input from the normal scenario. This could also help the system to detect a fire in an earlier stage. This would be applicable for existing smoke, heat and gas detectors based on EN 54-10:2001 [18].

5.12.1.2 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.

VFDs are considered with limitations for open and closed ro-ro decks due to the need for flames to reach over the vehicles/cargo while there is a limited space between vehicle roof and deck head in the ro-ro space. VSDs have greater potential for fire detection but they are affected by similar limitations regarding the space above the vehicles which affects the coverage area of the VSDs. Overall, video detection could be a supplementary solution for complementing the existing CCTV cameras.

The linear heat detection proposed for open and closed ro-ro spaces are cables mounted in deckhead (Figure 28) 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.

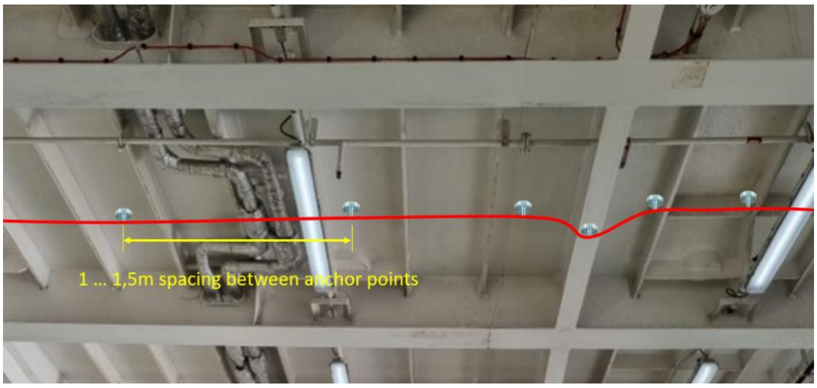


Figure 28. Linear heat detection cable routing in deckhead.

5.12.1.3 Planned method of evaluation

Laboratory-scale tests were performed in two sessions where different scenarios of fire were simulated between a configuration of four steel containers, considering open and concealed fires with different fuels and wind conditions. Evaluations from lab-scale tests provide insights as to which detectors are best suited for detection of fires in open and closed ro-ro spaces. Outputs from the lab-scale tests will be input to large-scale validations of the selected solutions. Technologies listed above are the three solutions discovered to be suitable for detection of fires on open and closed ro-ro spaces, albeit with different pros and cons.

The large-scale validation is planned to be performed on board. The plan is to use, as far as possible, the same setup as in the lab-scale tests, although large-scale tests will have more limitations regarding heat, flames, and duration of the fire tests.

For the evaluation of the various detection algorithms and threshold settings, the plan is to use the raw values from the existing detectors to find the optimal threshold settings for the detectors in the project.

5.13 Action 9-C: Technologies for visual fire confirmation and localization

5.13.1 RCM Det5 & Det6: Video detection and thermal imaging (infrared) cameras

Main author of the chapter: David Schmidt, RISE.

5.13.1.1 Technical description

5.13.1.1.1 RCM Det5: Video detection

A variety of VFDs or VSDs utilize a camera together with their flame/smoke detection algorithm. The camera could either consist of an integrated camera supplied with the detector itself or an existing CCTV system which could be employed by a fire/smoke detection algorithm using add-on software. By using the camera, the operator has the possibility to get a visual confirmation regarding the location of the fire identified by the detector, displayed on a dedicated screen. Some detector models also store video footage of fires on a memory card, recording some given period before and after the detection of the fire, which could be used for investigation at a later stage.

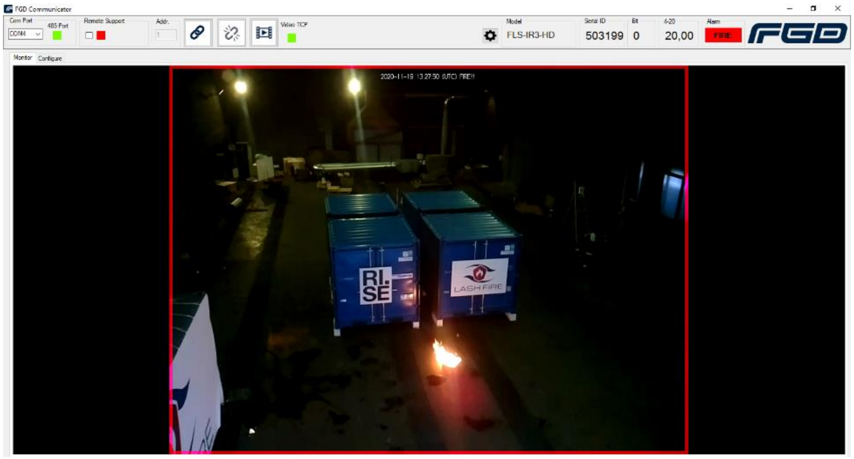


Figure 29. Example of flame detection with a camera.

5.13.1.1.2 RCM Det6: Thermal imaging (infrared) cameras

The IR detectors, much like VDFs and VSFs, can be equipped with a camera providing a visual confirmation of the fire development. In addition to flame and smoke detection, an IR thermal camera can give real time temperature monitoring for the area affected by fire. This could give the operator an overview before any alarm thresholds are reached. The visual confirmation could either be shown in black and white with the temperatures represented by different shades of black, or in colour with the temperatures represented by different colours (Figure 30 and Figure 31). Accordingly, IR thermal cameras can measure temperatures on surfaces in large areas and from a long distance. Moreover, they can see relatively well through smoke, and may be able to monitor the situation even after the fire has developed and filled the space with smoke.

Figure 30. Example of how a visual confirmation could be obtained regarding a fire inside a closed container that using an IR thermal camera during a lab-scale test. This image is captured by the IR camera, showing that the roof of the container is hot as it is marked with a red colour, denoting high temperatures. The fire was not detected by any of the flame detectors as there were no visible flames outside the container.

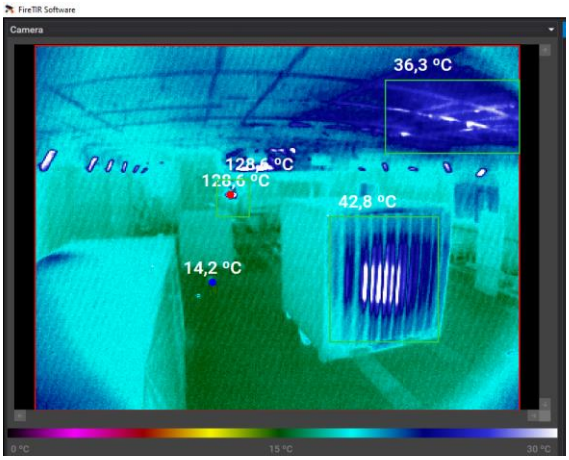


Figure 31. Example of image captured by an IR thermal camera during a test with flame reflections from a flame outside the field of view of the camera. The maximum temperatures in three different zones are shown in the image. The reflections from the corrugated steel container wall at 5 m from the fire show a maximum temperature of 42.8 °C, while the aluminium scaffolding approximately 25 m away from the fire shows 128.6 °C. The hot gases near the ceiling and the heated ceiling show 36.3 °C. The minimum temperature is shown on the concrete floor at 14.2 °C.

5.13.1.2 Impact on safety

One of the benefits of video fire detection is the use of the camera which can provide further details of fire development immediately after the detection of fire. With the help of the camera, the operators can get a visual confirmation on a screen at the fire management station to get a clear view on where the fire is located before confirmation by a runner. During a fire emergency, time management is of critical importance, and as the visual confirmation is provided earlier to the operator, they could act more quickly, starting the fire fighting procedure earlier. Some units also allow the possibility to record the events on a memory card or a hard drive which could be used later to review the fire development and locate the fire source as part of a fire investigation or hazard analysis. Storage on memory card is also beneficial if not connected to a monitor/CCTV system to have the possibility of live streaming. One limitation for the systems is that to make use of the visual confirmation, additional equipment is needed to show the visual picture in addition to the warning of the fire system. The system also needs to be installed with a good field of view over the protected area, although the available field of view may later be obscured by objects or smoke. Another limitation for the system is the need for a Personal Computer (PC) and a display, requiring extra space at the control station if not possible to connect to any existing PC.

5.13.1.3 Planned method of evaluation

IR thermal cameras and flame detectors are to be evaluated during a large-scale validation for weather decks on board a ro-ro ship. The detectors shall be mounted on board in a suitable position with a good coverage. Detectors will also be tested over an extended period to test them for nuisance alarms and environmental durability performance during normal operations. Input from this evaluation will be used to find the optimal detection thresholds settings for the system. After an extended period in normal operation, fire tests will be performed on board in order to evaluate the response from the detectors. Recordings from existing CCTV cameras will also be used for evaluation.

Extinguishment

5.14 Action 10-A: Local application fire-extinguishing systems

5.14.1 RCM Ext1a & Ext1b: Dry pipe sprinkler and automatic deluge water spray systems for ro-ro spaces on vehicle carriers

Main author of the chapter: Magnus Arvidson, RISE.

5.14.1.1 Technical description

Two automatic water based fire protection system solutions were developed. The systems should be used as a supplement to the fixed installed carbon dioxide system used in ro-ro spaces on vehicle carriers:

- RCM Ext1a: A dry pipe sprinkler system. Note: This is per definition an automatic system; and
- RCM Ext1b: An automatic deluge water spray system utilizing open nozzles.

The overall approach is that early and automatic activation will allow time to properly discharge the fixed installed carbon dioxide 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 carbon dioxide system.

For the dry pipe sprinkler system, individual sprinklers are activated by the heat from the fire (Figure 32). For the deluge water spray system, a fire detection system is required for fire detection and activation, but the system could also be remotely manually activated.

Figure 32. The discharge of water from automatic sprinklers (in another project than LASH FIRE).

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. RCM Ext1a or Ext1b 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 is 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.

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

The differences between the system solutions are discussed in more detail below.

A third system solution (RCM Ext2), an automatic deluge system using open rotating Compressed Air Foam Systems (CAFS) nozzles was considered in Action 10-A. **RCM Ext2 was disregarded for further evaluation as it was proven to be more expensive to install and maintain serviceable than the two solutions discussed above. Furthermore, it was not proven that CAFS offered any improved fire protection performance in the fire intermediate-scale tests conducted in the LASH FIRE project. This solution is therefore not further discussed in this document.**

5.14.1.1.1 RCM Ext1a: Dry pipe sprinkler 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 seconds to 60 seconds 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.

The total water demand is lower than that of a deluge water spray system, which results in a lower pump demand, a lower required power demand, and a lower drainage demand.

5.14.1.1.2 RCM Ext1b: Automatic deluge water spray system

A deluge water spray system has a fixed pipe system connected to a water supply and is equipped with open water spray nozzles designed to provide a specific water discharge and distribution over the protected surfaces or area. Automatic activation requires a separate fire detection system that is installed in the deluge section protection areas. An electrical signal from the control panel of the fire detection system should open the correct deluge valve and start the sprinkler pump. Manual operation of a specific deluge valve is possible and is made electronically and remote controlled from another location, but physical operation of the deluge valve is also possible. There is a time delay from the operation of the deluge valve until water is discharged from the water spray nozzles. The design and installation guidelines developed in the project stipulates a maximum water delivery time of 60 seconds.

Deluge systems should be designed for the simultaneous activation of the two (or four) adjacent deluge sections with the greatest hydraulic demand at a minimum water discharge density. This results in a total water demand that is higher than that of a dry pipe system, as per the discussion above. Another drawback compared to a dry pipe system is that a large number or deluge valves are required.

5.14.1.2 Impact on safety

The main benefits of RCM Ext1a and Ext1b 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).

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 require that the drainage system is 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 [20]. It is assumed that this guideline is implemented.

5.14.1.3 Planned method of evaluation

The performance objective of both RCM Ext1a and Ext1b is fire control, to gain time to discharge the fixed-installed carbon dioxide system and limit fire damage. The preliminary design of the systems was based on a literature review, where field experience for similar fire hazards (parking garage fires in the UK and fires on ro-ro ships) and fire tests (by RISE, in the IMPRO project and in the FIRESAFE II project) was documented, refer to LASH FIRE deliverable D10.1, “Description of the development of local application fire-extinguishing systems and selected solutions” [21].

In addition to this data, large scale validation tests were conducted in late September 2021. These tests proved that the preliminary system design worked. The water-based systems were able to control the fires and prevent them from escalating during the 30 minute application of water. The tests are documented in LASH FIRE report D10.1 [21].

5.15 Action 10-B: Weather deck fixed fire-extinguishing systems

5.15.1 RCM Ext3 & Ext4: Autonomous fire monitor (water only) and remotely-controlled Compressed Air Foam fire monitor systems for the protection of weather decks

Main author of the chapter: Magnus Arvidson, RISE.

5.15.1.1 Technical description

Two different fire monitor systems concepts for the protection of weather decks were developed:

- A fire monitor system that discharges water only.
- A fire monitor system that discharges compressed air foam (CAF).

Both solutions 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 duration time is needed. If the CAFS runs out of foam, the system should be able to discharge water at the same rate as a fire monitor system that discharges water only. CAFS will typically improve the fire suppression performance for flammable liquid spill fires and may also improve the performance for ordinary combustibles. But another benefit is that foam would stick on vertical and horizontal surfaces (as the outer sides of vehicles or cargo) and provide a radiation shield that will prevent or delay fire spread.

The differences between the solutions are discussed in more detail below.

Independent on the type of fire monitor system (water only or CAFS), the fire monitors can be controlled in three different ways:

- **Manually remote-controlled fire monitors:** The primary feature is that the fire monitors are controlled by an operator positioned at safe location and not at the actual fire monitor. Modern systems come with a variety of options for remote control. These may include a joystick connected by a cable to the monitor’s Programmable Logic Controller (PLC), a wireless radio remote control, or an app for smartphones or tablets, connected via Wi-Fi to the PLC, or via computer connected via a local- or wide-area network. Remote control devices often include a variety of additional control features, including the opening/closing of the valve supplying water and/or foam, a record and playback function, programmable stow position, an indication of the monitor and nozzle tip's current, real-time positions, and the control of other peripheral devices, etc.

- **Semi-autonomous fire monitor system:** A semi-autonomous monitor system is a monitor system that requires human interaction for the activation and control, similar to a remote-controlled system. But it has a record and play function built into the system's controller(s), whereby an operator can record, in real-time, all monitor movements--including monitor rotation, inclinations and nozzle spray angle adjustments, as well as the variable speeds and pauses of such movements--and play them back at any time.
- **Autonomous fire monitor system:** An autonomous monitor system as used herein is a system comprising a fire detection system, a monitor and electronic hardware and software enabling the system to automatically and autonomously detect the presence and position of a fire and dynamically guide the monitor to achieve fire suppression, without any human intervention. However, it should be empathized 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.

5.15.1.1.1 RCM Ext3: Autonomous fire monitor system (water only)

A low installation cost of a system is essential. Therefore, the RCM Ext3 concept is based on small sized 2" fire monitors (Figure 33), lightweight DN125 (5") or DN150 (6") pipes, and small dimensions valves and actuators, keeping material and installation costs to a minimum.

Figure 33. Fire monitor.

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.

5.15.1.1.2 RCM Ext4: Remotely-controlled CAF fire monitor system

The principal layout of RCM Ext4 is similar to that of RCM Ext3. But the generation of CAF require a foam concentrate tank, a foam proportioning and injection component, a mixing chamber or device, an air compressor, piping between these individual components, and a control system ensuring suitable mixing of the water, foam concentrate and air. Note that finished foam is distributed in the piping to the fire monitors, i.e., there is one single distribution pipe on each side of the vessel to which the individual fire monitors are attached.

There are no dedicated CAF monitors. However, most CAFS use a smooth bore type nozzle or straight piece of pipe, to maintain the quality of the foam that is discharging through the nozzle. A separate jet or water spray nozzle can be used in combination with CAF, if desired.

At similar pressures at the inlet of a fire monitor, the throw of foam is virtually similar to that using water only according to manufacturers of CAFS.

5.15.1.2 Impact on safety

Fire monitors, whether remote controlled, semi-autonomous 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 Action 10-B.

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 require that the drainage system is properly designed and that the scuppers is 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 [20].

5.15.1.3 Planned method of evaluation

Large scale validation fire tests are planned for spring 2022.

The fire detection performance was proven during outdoor tests in 2020. The objective of the tests was to determine the capability and effectiveness of a fully autonomous system, i.e., to determine whether a fixed, autonomous monitor system is able, within an area roughly comparable to a weather deck, to: 1) quickly detect multiple, separately-placed fires; 2) determine the fires' three-dimensional positions; and 3) effectively guide the water streams of the monitors towards the fires.

It was concluded that fire detection occurred in less than 10 seconds, irrespective of the position of the fire test source. Rain and fog were simulated using a fire hose stream of water directed into the air flow of the snow cannon. Fire detection ability was not influenced. The system was able to accurately determine the three-dimensional size and position of each of the fires and aim the water streams of the monitors to the fire location. The monitor is oscillating over the fire to provide water over a larger area than that represented by the actual test fire. When the specific fire test source was turned off, and another ignited the water streams were redirected towards that new fire location.

The flame detectors were positioned vertically 5 meters above the surface of the ground and orientated towards the midpoint of the test area. The vertical height represents a clearance of 1 meter above cargo. The data that was collected during the tests indicate that the precision of the detectors would improve using a higher elevation.

For the tests with two systems (two individually operated monitors), the water streams from both monitors were directed towards the fire. The water flow rates and pressures used (1 200 l/min at 5 bar) resulted in a throw sufficient to reach the corners of the test area, i.e., approximately 40 meters.

The system also tested in simulated wind conditions. The reach of the solid water stream was not influenced by the generated wind using a shorter throw, about 20 to 30 meters, but break-up of the stream was observed. Using a longer throw, the generated wind reduced the reach and break-up of the stream was observed. The use of a fog or cone spray pattern during the wind simulation proved ineffective due to the wind's effect. It should be emphasized that the tests conditions were limited to influence by wind over a small area of the water streams. In an actual case, wind will influence the whole water stream. To reduce the effect of wind conditions under actual conditions, it is suggested that any location of a weather deck should be accessible by at least two monitors positioned at opposite sides of the deck. With this approach, it is likely that a fire anywhere on a deck would be relatively close to a monitor, which would improve fire suppression performance.

It was also concluded that the performance and function is dependent on the accuracy of the relative position, distances and angles of the fire detectors and monitors.

5.16 Action 10-C: Updated performance of alternative fixed fire-fighting systems

5.16.1 RCM 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

Main author of the chapter: Magnus Arvidson, RISE.

5.16.1.1 Technical description

Resolution A.123 (V) was published in 1967, but concerns were raised in the 1990's whether its guidelines for the installation of fixed water spray fire-fighting systems offered sufficient protection of vehicle, special category and ro-ro spaces in the light of modern vehicles and new types of cargo. A desire to install 'alternative' (equivalent) water based fire-fighting systems led to the development of MSC/Circ.914 and later MSC.1/Circ.1272. The latter document permitted alternative systems to be automatically activated, a feature that (if used) was expected to improve system performance. However, an inadequacy of the fire test procedures of MSC.1/Circ.1272, as adopted in MSC.1/Circ.1430 [14], is that the performance requirements of alternative systems only equal those of a system designed per Resolution A.123 (V). It has also been argued that the fire test scenarios of the fire test procedures do not reflect the fires that may occur in modern vehicles or in cargo trailers transporting high hazard (non-dangerous goods) cargo. The objective of Action 10-C is to develop relevant and realistic fire test procedures for alternative water based fire-fighting systems, where the performance acceptance criteria is based on the performance of the prescriptive system alternatives given in MSC.1/Circ.1430 [14].

It should be emphasized that SOLAS II-2/20.6.1.2 [2] requires that: "*Vehicle spaces and ro-ro spaces not capable of being sealed and special category spaces shall be fitted with a fixed water-based fire-fighting system for ro-ro spaces and special category spaces […] which shall protect all parts of any deck and vehicle platform in such spaces.*" The guidelines and fire tests of MSC.1/Circ.1430 (as amended) [14] are intended for the design and approval of fixed water-based fire-fighting systems for open and closed ro-ro spaces and special category spaces as defined in SOLAS [2]. These systems could either be designed and installed in accordance with the prescriptive requirements or in accordance with the performance-based requirements in MSC.1/Circ.1430 [14] (Figure 34). In other words, there will always be a fixed water based fire-fighting system in the spaces, whether it be a 'prescriptive' design or a 'performance-based' design.

Figure 34. Mock-up in the Appendix of MSC.1/Circ.1430. Photos by RISE Fire Research AS.

Deluge systems can be applied in open ro-ro spaces when the actual wind condition is taken into consideration, for example through the use of high velocity nozzles. Systems using automatic sprinklers or nozzles are only permitted for closed ro-ro and special category spaces or other spaces where wind conditions are not likely to affect system performance.

The approach suggested for this report is that RCM Ext5 is either:

- A wet or dry pipe system designed per the revised fire test procedures intended to be developed in Action 10-C, and thus implied that the system has the same level of performance as a wet or dry pipe system per the prescriptive design.
- A deluge water spray system design per the revised fire test procedures intended to be developed in Action 10-C, and thus implied that the system has the same level of performance as a deluge water spray system per the prescriptive design.

5.16.1.1.1 An alternative wet or dry pipe system

Here it is assumed that either a wet pipe system using an antifreeze or that a dry pipe system is used, as freezing conditions may be a concern that need to be dealt with. From a performance perspective, a wet pipe system discharges water earlier than a dry pipe system, but the fact that the area of operation is larger for a dry pipe system will to a certain degree compensate for the longer delay time of a dry pipe system.

It is likely that the increased complexity of a dry pipe system translates to a somewhat lower system reliability that should be reflected in the analysis.

5.16.1.1.2 An alternative deluge water spray system

As a conservative approach, it is assumed that the system is manually activated. This is probably a fair approach as a fully automatic deluge water spray system is non desired due to the large quantities of water that is discharged when a whole deluge section is activated. It is, however, assumed that a fire is detected at its early stage by a fire detection system, or visually, and that the system is activated as soon as fire has been confirmed.

5.16.1.2 Impact on safety

It is assumed that the automatic activation of a wet pipe system using an antifreeze or a dry pipe system as well as the manual activation of a deluge water spray system, will control the fire i.e., prevent it from involving multiple vehicles, prevent it from spreading to adjacent spaces and limit structural damage. As mentioned, it is implied that the level of performance of these alternative systems is similar to that of a system per the prescriptive requirements in MSC.1/Circ. 1430 [14].

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 require that the drainage system is properly designed and that the scuppers is 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 [20].

5.16.1.3 Planned method of evaluation

Large scale validation tests are planned for spring 2022. These tests will be conducted with a traditional dry pipe and a deluge water spray system to establish the performance using realistic fire test scenarios, to set the performance acceptance criteria for the testing of alternative systems.

Containment

5.17 Action 11-A: Division of ro-ro spaces

5.17.1 RCM Cont1b1 & Cont1b2: A-30 fire integrity or extinguishing system simultaneously activated above and below sub-dividing deck

Main author of the chapter: Franz Evegren, RISE.

5.17.1.1 Technical description

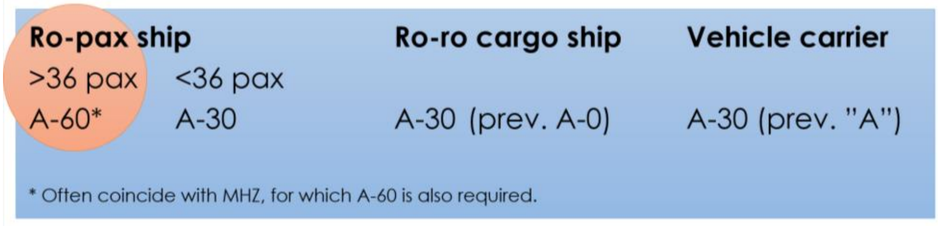


Figure 35. Fire integrity requirements for ro-ro spaces.

As summarized in Figure 35, the fire integrity of decks separating special category spaces or ro-ro spaces from other cargo or accommodation spaces on ro-ro passenger ships is required to be A-60 if the ship carries more than 36 passengers and A-30 if it carries up to 36 passengers. For ro-ro cargo ships and vehicle carriers, A-30 is required. However, special category spaces and ro-ro spaces can also be designed with several internal decks, sub-dividing the spaces horizontally, for which no fire integrity requirements apply (cf. Figure 36). Without thermal fire insulation, fire simulations show that a fire can spread between such sub-spaces within 8 minutes. Fire spread within 10 minutes through a steel deck has also been confirmed by tests. RCM Cont1b1 and Cont1b2 therefore addresses the fire integrity of such internal decks, sub-dividing special category spaces or ro-ro spaces.

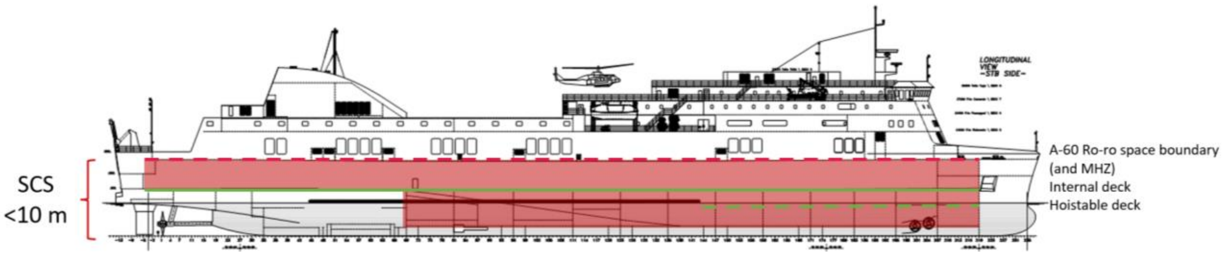


Figure 36. Example of onboard fire integrity of ro-ro spaces

According to the study done in the WP11 and reported in the LASH FIRE deliverable D11.1, "Development, theoretical evaluation and preliminary assessment of requirements for horizontal division of ro-ro spaces" [22], a realistic fire within ro-ro space could be represented by the engineering hydrocarbon time-temperature curve. Experiments performed by exposing this engineering curve to different systems composed by fire insulation and steel plates, have shown that the addition of fire insulation increase the fire integrity.

During the tests, two types of thermal insulation have been used. One of those thermal insulation has shown a very low performance at high temperatures reached by the engineering hydrocarbon time-temperature curve. Therefore, outcomes of those experimental tests with this thermal insulation can be considered, at first glance, as similar as outcomes of tests would have been performed without thermal insulation.

The addition of A-30 insulation increases the fire integrity by 110% (around 11 minutes) and the addition of A-60 increases it by 300% (around 20 minutes) compared to no insulation where fire integrity is 5 minutes (Table 3).

Table 3. Results of thermal insulation tests

Class of thermal insulation	Fire integrity based on HC curve Time (min)
A-30 (Low performance thermal insulation)	5
A-60 (rockwool)	20
A-30 (rockwool)	11

To create horizontal subdivisions containing heat and smoke in case of fire, two means of fire protection have been studied, namely A-30 fire integrity (RCM Cont1b1) and an extended use of the required fixed fire-extinguishing system (RCM Cont1b2). The proposed requirement consists in that either thermal insulation should be provided to prevent fire spread through an internal deck (RCM Cont1b1), OR a fixed fire-extinguishing system should be activated both above and below the given deck (RCM Cont1b2).

The thermal insulation should be of class A-30. Ramps and doors between decks should be made of steel and of a design being as tight as practical. If this is for some reason not possible to achieve, e.g., due to the design of ramps, hoistability of the deck, lashing holes, etc., the alternative with a fixed fire-extinguishing system should be selected. The fixed fire-extinguishing system should comply with the requirements in SOLAS II-2/20.6.1 [2] and cover the applicable area above and below the given deck. The activation above and below the deck should be simultaneous and automatic in the sense that activation occurs on both decks at the same time and that one part (above or below the deck) cannot be manually disconnected. Hence, the sprinkler areas above and below the given deck should belong to the same section of the extinguishing system.

5.17.1.2 Impact on safety

The main impact on safety consists in reduction of heat transfer between internal decks within a ro-ro space or special category space. It will imply a reduced probability for fire spread, and a significantly increased time until it occurs if it would happen. It will also imply a reduced need for boundary cooling, which will in turn also relieve resources to prioritize other tasks during the pressed fire situation. The potential for an uncontrollable fire scenario is hence reduced.

It will imply a cost if insulation is to be added, or if an additional extinguishing system needs to be added. However, for most ship designs, an extinguishing system is already required, and the simultaneous activation of the system would only require a redesign of the valves or activation principle. However, it could also imply a need for a larger pump, if the new section (above and below the given deck) becomes dimensioning/the largest. The drainage capacity MAY also be affected.

If the insulation option is applied (RCM Cont1b1), there may be a limitation in function by ramps and doors between decks, which shall be made of steel and of a design being as tight as practical. Hence, they will pose a weakness in the fire integrity.

If the extinguishing system alternative is applied (RCM Cont1b2), it is dependent on successful activation, hence the reliability is lower. Therefore, the use of insulation should be the first option if it can be applied without too many weaknesses in fire integrity.

5.17.1.3 Planned method of evaluation

These measures are mature and of a high TRL, already implemented onboard just in a different form. Hence, no testing or demonstration is considered necessary.

5.17.2 RCM Cont3a, Cont3b, Cont3c & Cont3d: Vertical subdivision of a ro-ro space with a solid curtain

Main author of the chapter: Pascal Boulet, LUL.

5.17.2.1 Technical description

To create vertical subdivisions in the ro-ro space for containment of heat and smoke in the case of fire, two means of fire protection have been studied, including 'active' and 'passive' means. Active means of fire protection are those requiring a certain amount of motion and response to operate, while passive means of fire protection are those that are integral parts of the structural design, such as fire-resistant walls and doors. In the present project for the subdivision of ro-ro spaces, water curtains and solid curtains are the active means studied. Both systems were studied experimentally by LUL in a reduced-scale deck setup with a scale of 1 to 12.5. The selected system is now evaluated in real scale by RISE and STENA.

Water curtains were not selected in the end, because of a series of drawbacks:

- Smoke containment is not completely achieved;
- The activation induces a mixing of smoke layer and smoke-free layer resulting in a loss of visibility and in access difficulty;
- Some unexpected effects of turbulent mixing could even promote the fire itself; and
- Supplementary cost due to doubling the water spraying systems (drenchers and water mist system) seems unreasonable.

Solid fabric curtains were studied in the same setup as the water curtain. They are supposed to be rolled down by a dedicated fixed system, under manual or automatic control. They can adequately block both smoke and thermal radiation as they are solid and opaque. In order to protect against flame spread across the subdivisions, the curtains should be made of a material which withstand flames. The most preferable alternative would be to use a curtain with a fabric classified for fire protection curtains. Although it is not possible to achieve E-classification due to the lack of side guides, which is not a practical solution for such wide curtain. Depending on the fabric chosen the integrity to withstand direct contact with fire varies between 30 minutes to 2 hours. Moreover, the curtains preferentially need to be dropped to the floor level to provide adequate containment of smoke and heat, otherwise the smoke and heat can escape from below, but also the fire heat release rate may increase slightly if the side openings are open (particularly with liquid pool fires). The solution workshop with the two LASH FIRE's advisory groups (MAAG and MOAG) held in September, 1st 2021 finally led to a compromise, with a curtain partially rolled down to the top of the vehicles, in order to provide at least a partial containment, even not perfect. Another recommendation that cannot be satisfied is the closure of side openings (as this solution studied in Action 11-C is now rejected).

The curtain is expected to stop – or delay the propagation of – smoke and radiation until the fire gets too close to the curtains and compromises them. These curtains should be used with the following requirements:

- The curtains must preferentially be allowed to drop to the floor level, or at least to the top of the cargos and vehicles. Note that a space left under the curtain which would induce supplementary costs through a loss of space for loading cargos however (not recommended by MAAG and MOAG). A solid curtain solution requires at least an 100 mm wide free zone underneath;
- The curtains must be made of fire-resistant materials;
- The curtains are recommended to be used in parallel with other active fire protection systems such as deluge system. This is because in the absence of active fire suppression, the heat and smoke trapped by the curtain could help the fire to grow faster. This is due to the fact that solid curtains do not provide cooling effects like water curtains do; and
- The curtains should be rolled-up when not needed (to let ventilation work correctly and to increase visibility in the deck for spotting the fires early on). Consequently, a fixed system must be designed to allow them to roll down or up.

RCM Cont3 was sub-divided into four different concepts based on implementation and options for closure to be evaluated further.

5.17.2.1.1 RCM Cont3a: Solid curtain, horizontal mounting, fully rolled down

RCM Cont3a (Figure 37) is to mount the curtain in the same direction as the lanes and loading of the cargo on board. The main benefit for this type of mounting is the limited impact on loading plan combined with the better effect for curtains reaching all the way down to deck.

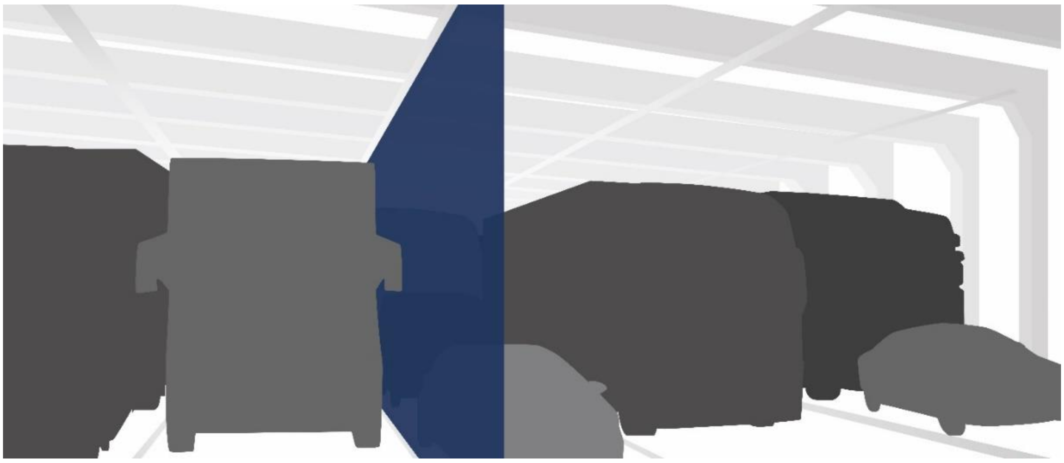


Figure 37. Solid curtain, horizontal mounting.

5.17.2.1.2 RCM Cont3b: Solid curtain, vertical mounting, fully rolled down

RCM Cont3b (Figure 38) uses a curtain which is vertical mounted, and the curtain is rolled down all the way to deck. To do so the curtain requires a break between the cargo transversally which could have an impact on the loading of the cargo.

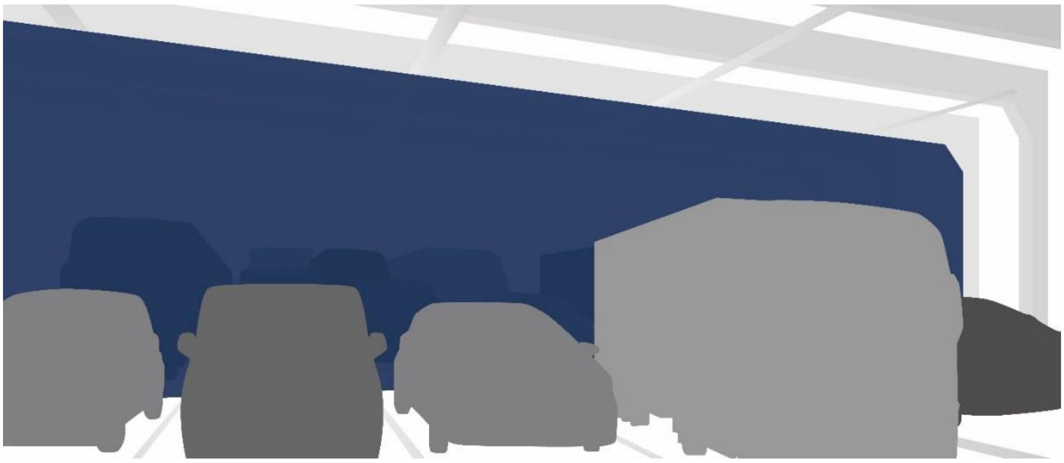


Figure 38. Solid curtain, vertical mounting, fully rolled down.

5.17.2.1.3 RCM Cont3c: Solid curtain, vertical mounting, partly rolled down

RCM Cont3c has the same principle as RCM Cont3b but with one major difference, the curtain is not brought all the way down to deck. There are two versions of partly rolled down curtain evaluated in RCM Cont3. Both have the same principle to bring the curtain down in a straight line to the top of cargo but one on the top of high cargo such as trucks (Figure 39) and the other on top of low cargo/cars (Figure 40).

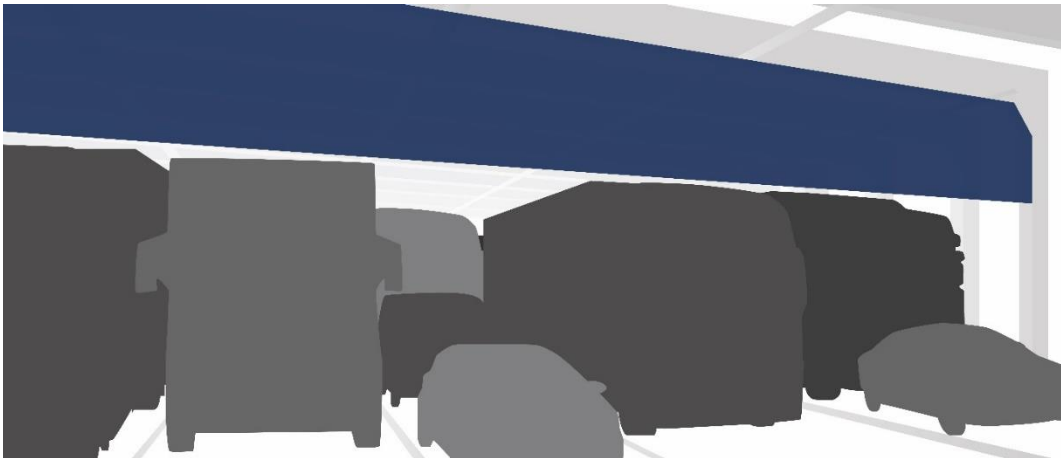


Figure 39. Solid curtain, vertical mounting, partly rolled down to top of high cargo/trucks.

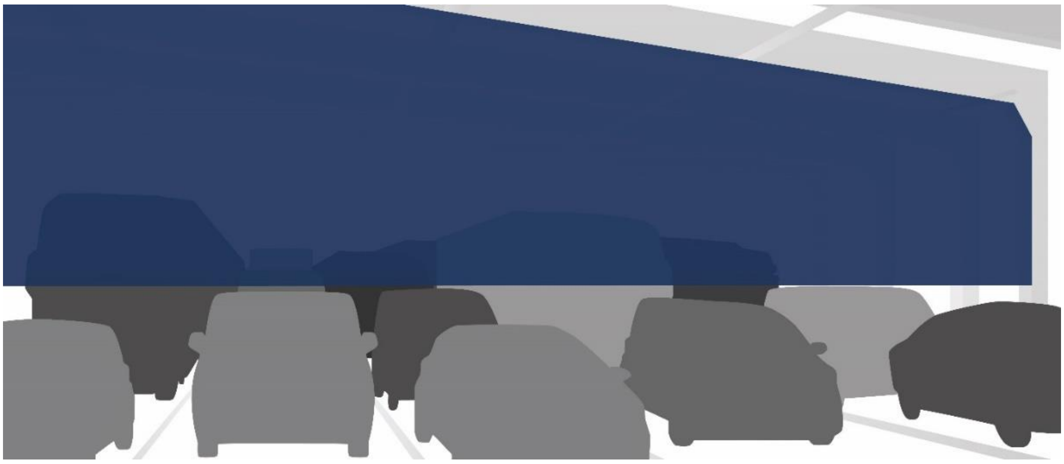


Figure 40. Solid curtain, vertical mounting ,partly rolled down to top of cars.

5.17.2.1.4 RCM Cont3d: Solid stripped curtain, vertical mounting, fully/partly rolled down

RCM Cont3d has the same principle as RCM Cont3c but the main difference is that the curtain is striped allowing it to roll down at different height along the transverse direction of the ro-ro space (Figure 41).

Figure 41. Solid striped curtain, partly rolled down to top of cargo of different heights.

5.17.2.2 Impact on safety

Smoke, heat (radiation and transport by hot gases) and fire to some extent should be contained in a given space between two curtains. At least their propagation will be delayed, especially if the drenchers are activated simultaneously. This would result in a gain of time for evacuation, or firefighting. For closed decks, the containment could decrease the oxygen supply and penalize the fire development (in the case of curtains totally rolled down to the floor).

Damages could be limited to the surroundings of the fire zone. The area outside the contained space will be protected from soot deposit (if the fire is finally suppressed).

These benefits should be only partially observed if the curtain is not totally rolled down. Instead of containment, a delay before propagation is rather expected.

One possible weakness would be to accumulate heat and flames in a limited space due to the containment, which should even favour the fire increase to some extent. This is why simultaneous drencher activation is mandatory, to cool down the space contained between curtains.

A second drawback could be enhanced exhausts of smoke by the side openings, open ro-ro decks, within the contained space. Requirements on safety distances discussed within the frame of Action 11-C should be taken into consideration.

5.17.2.2.1 RCM Cont3a: Solid curtain, horizontal mounting, fully rolled down

The identified benefits are:

- Natural divisions with aspect to loading/lanes;
- Possibility to drop down to floor without special requirements on loading; and
- Reduction of oxygen supply to fire.

The identified drawbacks are:

- Requires a very wide curtain;
- Cassette could limit required loading height;
- Deluge sectioning not designed horizontal; and
- Cannot prevent fire spread along the ship.

5.17.2.2.2 RCM Cont3b: Solid curtain, vertical mounting, fully rolled down

The identified benefits are:

- Can divide area in line with existing drencher sectioning;
- Good reduction of oxygen supply to fire (only for closed ro-ro spaces);
- Comprehensive heat radiation damping;
- Block smoke between zones; and
- Can prevent fire spread along whole ship.

The identified drawbacks are:

- Requires free break, 100 mm, between cargo to reach deck (loss of cargo space);
- Might need special requirements in loading plan to achieve break; and
- Flames, and smoke, can spread at side openings between curtain and bulkhead.

5.17.2.2.3 RCM Cont3c: Solid curtain, vertical mounting, partly rolled down

The identified benefits are:

- Can divide area in line with drencher sectioning;
- Possibility to drop down without special requirements on loading; and
- Can prevent fire spread along whole ship.

The identified drawbacks are:

- Drencher might push smoke under the curtain;
- Less reduction of oxygen supply to fire due to opening underneath curtain; and
- Less reduction of heat radiation between zones (compared to fully rolled down curtain).

5.17.2.2.4 RCM Cont3d: Solid stripped curtain, vertical mounting, fully/partly rolled down

The identified benefits are:

- Can divide area in line with drencher sectioning;
- Possibility to drop down without special requirements on loading;
- Comprehensive heat radiation damping;
- Block smoke between zones; and
- Can prevent fire spread along whole ship.

The identified drawbacks are:

- Drencher might push smoke under the curtain;
- Less reduction of oxygen supply to fire due to leakages between stripes;
- Less reduction of heat radiation between zones (compared to fully rolled down curtain); and
- Flames and smoke can spread between stripes.

5.17.2.3 Planned method of evaluation

Reduced-scale testing was done for the solid curtain, showing the ability of a solid curtain to contain smoke. The result of the reduced-scale testing will be described in the LASH FIRE deliverable D11.2, "Development of means for sub-division of ro-ro spaces" [23].

RISE plans real scale evaluation in cooperation with STENA. A demonstration of the system operation is scheduled on a real ship of the STENA fleet (spring 2022). This demonstration will map practical obstacles to install a solid curtain on board. Fire Dynamics Simulator (FDS) evaluations to be performed comparing the effect of the different solid curtain concepts. There will also be a fire performance test performed in lab scale for further evaluation of the effect of different closing scenarios for a solid curtain. Performance test will be performed during 2022 and discussions are ongoing with supplier.

5.18 Action 11-B: Ensuring safe evacuation

5.18.1 RCM Cont5: Alternative disembarkation path through "dedicated side door"

Main author of the chapter: Davood Zeinali, LUL.

5.18.1.1 Technical description

The objective of RCM Cont5 is to implement an evacuation strategy that allows the abandonment of at least 1.28 persons per second from either side of the upper deck of the ro-ro passenger ships and ro-ro cargo ships. This flux of people can be achieved by the installation of 2 slides of 2 lanes on either side of the ship (because each lane can evacuate 0.69 persons per second [24]), or the installation of 12 escape chutes on each side of the ship (because each chute can evacuate 0.11 persons per second [25]). Alternatively, the desired flux of people requires the use of 6 lifeboats (as each lifeboat can evacuate 0.25 persons per second [2]) although the simultaneous launching of the lifeboats might be more difficult to realize than the use of slides or chutes. Correspondingly, RCM Cont5 is applicable to new ships but also existing ships which have the space required to accommodate the aforementioned devices.

5.18.1.2 Impact on safety

Based on evacuation simulations, the time taken by all the passengers to abandon the ship was shown to improve by 12 to 18 min if the evacuation was done using the optimized means of abandonment (i.e., using a people flux ranging from 0.99 to 1.28 persons per second from either side of the upper deck). This is most easily achievable using slides, but escape chutes might be a viable option too.

The existing slides used for ships are meant for evacuation at sea and are considered as a Life-Saving Appliance (LSA). However, for evacuation at a port, new slides are needed that are deployable on the ground (e.g., slides of aeroplanes). The embarkation ramp is usually considered safer and more practical to use at the port. Therefore, the use of slides may be limited to only highly urgent situations or for evacuation at sea. In such cases, the crew members must be adequately familiar with the equipment involved, otherwise there could be miscommunication on the deployment or the use of the slides, leading to evacuation delays or failure. The existing escape chutes for ships are also LSA meant for evacuation at sea. This is achieved by using a so-called lifecraft system, much like a lifeboat that connects to the chutes. However, for evacuation at a port, new chutes are needed that are deployable on the ground (e.g., escape chutes of buildings or those of offshore oil platforms). The embarkation ramp is usually considered safer and more practical to use at the port. Therefore, the use of escape chutes may be limited to only highly urgent situations or for evacuation at sea. In such cases, the crew members must be adequately familiar with the equipment involved, otherwise there could be miscommunication on the deployment or the use of the chutes, leading to evacuation delays or failure. Moreover, the chutes require some space on the upper deck of the ship. In the case of chutes to be used for a port, only the chute itself is required (≈ 0.8 m diameter), but in the case of chutes to be used at sea, the required lifecraft system occupies additional space (packed size ≈ 16 m x 2.7 m x 2.6 m for a system with 4 chutes). Particularly in the latter case, the area dedicated to the device might hinder the nearby traffic of passengers to some extent if the device is poorly positioned (e.g., near narrow passageways). Moreover, the chutes themselves might catch fire if the container of the device is not well maintained or protected, which could create a fire hazard near that area.

5.18.1.3 Planned method of evaluation

The evaluation was completed for the proposed solution of abandonment with an optimized flux of people, namely using the evacuation model AMERIGO that quantified the gain in terms of improved evacuation time of up to 18 min. Moreover, the number of slides required to meet the optimized flux of people has been determined based on the experimental data of an evacuation drill performed by Airbus on the aeroplane A380 in Hamburg [24], providing an estimation of the flux of people offered by each slide (i.e., 0.69 persons per second). For the use of escape chutes, the flux of people is available from the capacity of the marine evacuation system [25] (i.e., 812 persons in 30 min using 4 escape chutes, meaning 0.11 persons per second per chute).

5.19 Action 11-C: Safe design with ro-ro space openings

5.19.1 RCM Cont9: Ship manoeuvring/operation to limit the effect of fire at least in critical areas

Main author of the chapter: Tuula Hakkarainen, VTT.

5.19.1.1 Technical description

Simulations of fires in open ro-ro spaces of two generic ships were performed using FDS software to study heat transfer and smoke spread from ro-ro space side and end openings to critical areas, such as embarkation stations and LSAs. Stena Flavia (the generic ro-ro passenger ship) and Magnolia Seaways (the generic ro-ro cargo ship) were utilized in studying heat transfer and smoke spread from side and end openings, respectively. The studied fire scenarios included a heavy goods vehicle (HGV) fire in different locations, and wind direction and speed were varied.

The main purpose of the heat transfer and smoke spread simulations were to determine safety distances from ro-ro space openings to critical areas. However, the results were useful for showing that manoeuvring can be used to direct smoke away from critical areas if conditions are favourable. The analysis of the simulation results has provided high-level general guidance to support the development of ship-specific manoeuvring instructions for a ro-ro space fire. The goal of manoeuvring is to direct smoke away from critical areas (such as assembly stations, LSA stowage areas and external evacuation routes) in case of a ro-ro space fire to enhance safe evacuation.

The following recommended actions to support the selection of a beneficial course were defined on the basis of the simulations:

- Locate the opening(s) where the smoke is coming from;
- Identify the side of the ship (port or starboard) from where evacuation can be done;
- Define the beneficial change of course so that the critical areas on the side selected for evacuation have the least impact from fire products (smoke, radiant heat flux, etc.);
- Recommendations for choosing a suitable direction for apparent wind:
    - Smoke from side opening(s):
        - The side selected for evacuation is manoeuvred to face the wind perpendicular to it (i.e., portside wind or starboard side wind). If this is not possible:
            - Fire location aft from the critical areas: select headwind; or
            - Fire location forward from the critical areas: select tailwind.
    - Smoke from end opening(s):
        - Smoke emerging aft from the critical areas: select from headwind to side wind; or
        - Smoke emerging forward from the critical areas: select from tailwind to side wind.
    - The best wind direction will push the smoke directly away from the ship, and the smoke will not travel across any parts of the ship.
- Manoeuvre the ship to the course identified beneficial.

It is noted that ship-specific instructions and procedures need to be developed on the basis of the recommendations given above.

The recommended actions above are based on simulations of fires in open ro-ro spaces of a ro-ro passenger ship and a ro-ro cargo ship, since the main goal was to study heat transfer and smoke spread from ro-ro space side and end openings to critical areas. However, similar considerations can be made for fires in closed ro-ro spaces or on weather decks, and to some extent for vehicle carriers. The basic idea is to locate where the smoke comes from, identify the side of the ship from where evacuation can be done, choose a suitable direction for apparent wind to direct smoke away from the areas to be protected, and manoeuvre the ship accordingly. Figure 42 shows a schematic example of manoeuvring considerations described above.

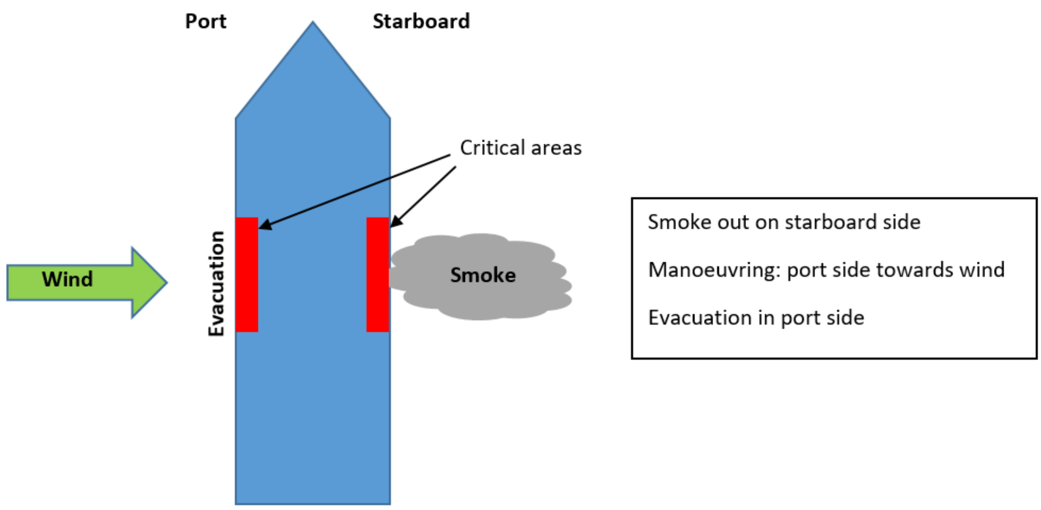


Figure 42. A schematic example of manoeuvring considerations.

5.19.1.2 Impact on safety

Successful manoeuvring/operation of the ship in a beneficial direction to avoid smoke spread to critical areas ensures that at least a part of the embarkation stations and LSAs can safely be used for evacuation in case of a ro-ro space fire. The goal is to direct smoke away from critical areas (such as assembly stations, LSA stowage areas and external evacuation routes) in case of a ro-ro space fire to enhance safe evacuation.

It is noted that RCM Cont9 requires careful consideration of the best direction, since beneficial directions for different critical areas can be contradictory. Ship-specific instructions and procedures need to be developed on the basis of the recommendations given above.

RCM Cont9 can be used with the following conditions:

- The ship is manoeuvrable, i.e., no blackout;
- The change of the ship's course does not endanger safe evacuation in rough seas; and
- Wind speed and direction are favourable to support the desired outcome after manoeuvring. (Very low-speed wind will not be efficient in pushing the smoke away.)

5.19.1.3 Planned method of evaluation

The ship operator partners of LASH FIRE will test the above-presented recommended actions by developing ship-specific instructions and procedures to support the selection of a beneficial course in case of a ro-ro space fire. The testing was performed as a desktop study to evaluate if ship-specific instructions can be developed on the basis of the list of recommended actions. The target schedule for the testing is by the end of 2021.

5.19.2 RCM Cont10: Safety distances between side and end openings and critical areas

Main author of the chapter: Tuula Hakkarainen, VTT.

5.19.2.1 Technical description

Simulations of fires in open ro-ro spaces of two generic ships were performed using FDS software to study heat transfer and smoke spread from ro-ro space side and end openings to critical areas, such as embarkation stations and LSAs. Stena Flavia (the generic ro-ro passenger ship) and Magnolia Seaways (the generic ro-ro cargo ship) were utilized in studying heat transfer and smoke spread from side and end openings, respectively. The studied fire scenarios included a heavy goods vehicle (HGV) fire in different locations, and wind direction and speed were varied. Separate criteria were established for human and material safety.

The obtained simulation results are dependent on the assumptions made about the environmental conditions and operational procedures. Based on the simulation results, potential risk control measures to establish safe design with ro-ro space openings were identified and discussed.

The simulations showed that implementing safety distances between ro-ro space openings and critical areas is an effective way to ensure safety of the critical areas.

It is noted that the definition of proper safety distances is challenging, requiring further research work. The obtained results and the proposed safety distances are dependent on the assumptions made about the environmental conditions and operational procedures. However, the goal is that in the future, it would be possible to use either prescriptive values defined in IMO regulations or ship-specific values based on approved calculation or simulation methods in ship design. The possibility to use ship-specific safety distance values would be a significant step towards alternative design of ships.

The prescriptive safety distance values could be, for example, as proposed in MSC.1/Circ.1615 [3], based on FIRESAFE II study [26].

The ship-specific safety distances could be based for example on the analytical calculation method currently under development in Action 11-C of the LASH FIRE project. In this work, the analytical formulas of the FIRESAFE II study are updated and further developed, which brings added value to the assessment of safety distances. The simulation results of Action 11-C are used for “calibrating” the analytical model. The input needed for the calculations include e.g., ship geometry including the arrangements and dimensions of the openings, locations and heat release rate of the design fire, assumed wind conditions, and radiant heat flux criteria.

5.19.2.2 Impact on safety

Implementing safety distances has been found to be an effective and reliable method for controlling the risks due to heat transfer and smoke spread. When the distance from openings to critical areas (such as embarkation stations and LSAs) is sufficient, the critical areas remain safe in case of fire and the safety of evacuation is supported.

In new ships, the safety distances can be implemented by means of novel ship designs. For existing ships, the safety distances can possibly be established by closing some openings which may lead to additional weight. It is noted, however, that openings are required for natural ventilation of open ro-ro spaces.

The definition of safety distances is not straightforward. Computational results obtained and safety distances proposed are dependent on the assumptions made about the environmental conditions and operational procedures.

5.19.2.3 Planned method of evaluation

The fire tests for the evaluation of critical conditions for materials and simulated heat flux levels at different distances from the openings took place in autumn 2021 - winter 2022.

Critical conditions for LSA materials will be verified by small-scale tests using the cone calorimeter method. Tests will be performed to determine minimum heat fluxes for ignition for the materials of interest.

The simulated heat flux levels will be validated by comparison with large-scale fire tests using the SP FIRE 105 method. The measuring methods include heat flux gauges and plate thermometers.

The results of the evaluation will be reported in the LASH FIRE deliverable D11.4, "Description of development and assessment of safe ro-ro space openings" (May 2022) [27].

5.20 Action 11-D: Ro-ro space ventilation and smoke extraction

5.20.1 RCM Cont11: Guidance on calculation of side openings in ro-ro spaces

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

5.20.1.1 Technical description

RCM Cont11 consists of forming a guidance of how calculate the side opening in ro-ro spaces. This solution is closely linked to RCM Cont12, which aims to reduce the openings in ro-ro spaces.

The current definitions of ro-ro spaces are as follows:

- *Open ro-ro spaces are those ro-ro spaces that are either open at both ends or have an opening at one end, and are provided with adequate natural ventilation effective over their entire length through* ***permanent openings distributed in the side plating or deckhead or from above, having a total area of at least 10% of the total area of the space sides***. (SOLAS II-2/3.35) [2].
- *Closed ro-ro spaces are ro-ro spaces which are neither open ro-ro spaces nor weather decks.* (SOLAS II-2/3.12) [2].
- *Weather deck is a deck which is completely exposed to the weather from above and from at least two sides*. (SOLAS II-2/3.50) [2].

The part of the definition describing permanent openings and the area of these, marked with bold in the text above, is open to interpretation. There is currently no internationally accepted best practise for what to include in the calculation of the opening percentage. This might cause differences in how the calculations are made for ships. Therefore, the solution is to implement the following guidance of how to calculate the side openings in ro-ro spaces:

- The calculation should only consider the area of the long sides of the ro-ro space.

This means that it is only the long sides of a ro-ro space that should be considered when calculating the opening percentage. The ceiling and ends should not be considered in the calculations. This approach is in line with the method used by the Swedish Transport Agency. Figure 43 shows a top view of two schematic ro-ro spaces. The red line is marking the sides that should be used in the calculation.

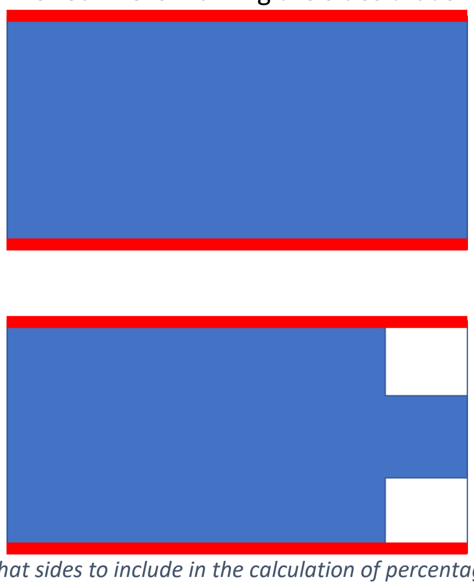


Figure 43 Example of what sides to include in the calculation of percentage for open ro-ro space.

RCM Cont11 covers closed and open ro-ro spaces on ro-ro passenger and ro-ro cargo ships. It addresses new ships.

5.20.1.2 Impact on safety

The proposed guidance will provide clarification to the definition of ro-ro spaces and make the definition easier to interpret. This guidance is closely linked with RCM Cont12 and is part of the work to lessen the adverse effects of a fire in open and closed ro-ro spaces by improving the requirements of opening percentage and configuration in the ro-ro spaces. The impact by side openings on fire development is investigated in RCM Cont12.

Providing a guidance for how to perform the calculations might make the design of ro-ro ships less flexible.

5.20.1.3 Planned method of evaluation

As this solution is a guidance, and not a technical system to be implemented onboard, there are no tests planned to evaluate or validate the solution. Rather, the solution is a result of the work being made for RCM Cont12, where FDS simulations and model scale tests will be used to evaluate opening percentage and configuration in ro-ro spaces.

5.20.2 RCM Cont12: Configuration of side openings in ro-ro spaces

Main author of the chapter: Anna Olofsson, RISE.

5.20.2.1 Technical description

Ventilation is needed in both open and closed ro-ro space to provide healthy atmosphere and to avoid stagnation of gases that can create a harmful/flammable atmosphere. Open ro-ro spaces require natural ventilation by permanent side openings, while closed ro-ro spaces require mechanical ventilation. However, closed ro-ro spaces with mechanical ventilation are also permitted to have permanent openings (< 10% of the total area of the space sides, see definitions further below).

The initial intention of RCM Cont12 was to reduce the allowed opening percentage in open ro-ro spaces and provide recommendations for optimal configuration of openings to decrease the fire development (compared to current definition of open ro-ro spaces), while maintaining an adequate level of natural ventilation.

Results from the FDS simulations using Stena Flavia as the generic ship, shows that adequate level of natural ventilation could not be demonstrated if the opening percentage of the side openings were reduced for open ro-ro spaces. Thus, the opening percentage will not be investigated further. RCM Cont12 will only consider configuration of side openings in open ro-ro spaces. The proposed solution is visualised in the figures below (Figure 44, Figure 45 and Figure 46).

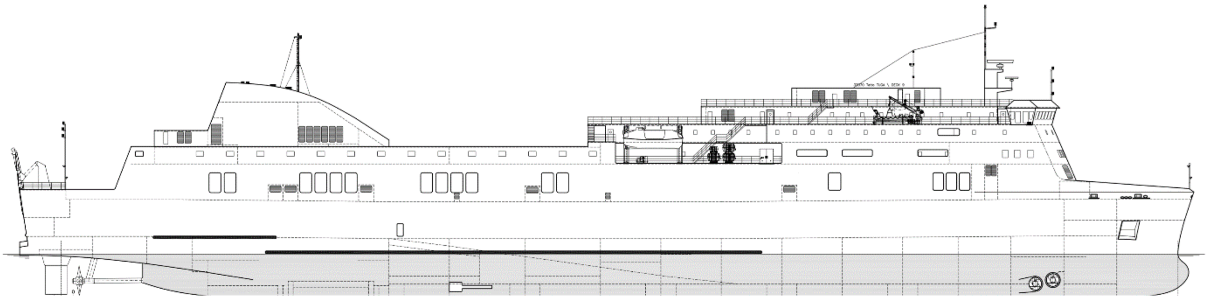


Figure 44. Example of existing configuration of side openings in an open ro-ro space.

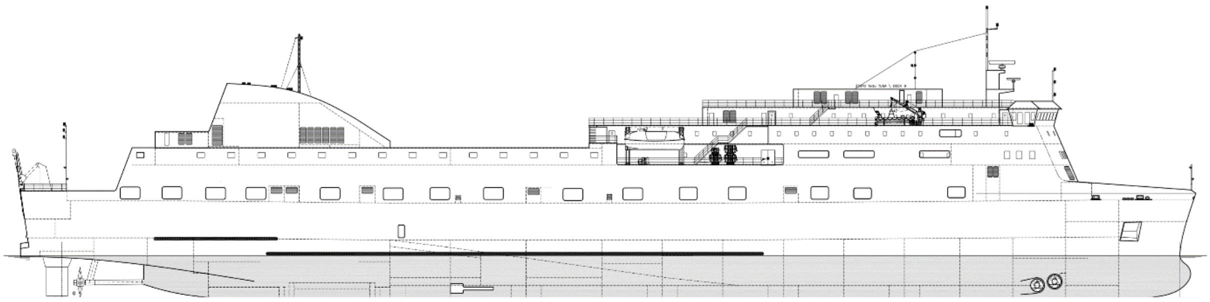


Figure 45. Example of changed configuration of side openings in an open ro-ro space (placed low, evenly distributed).

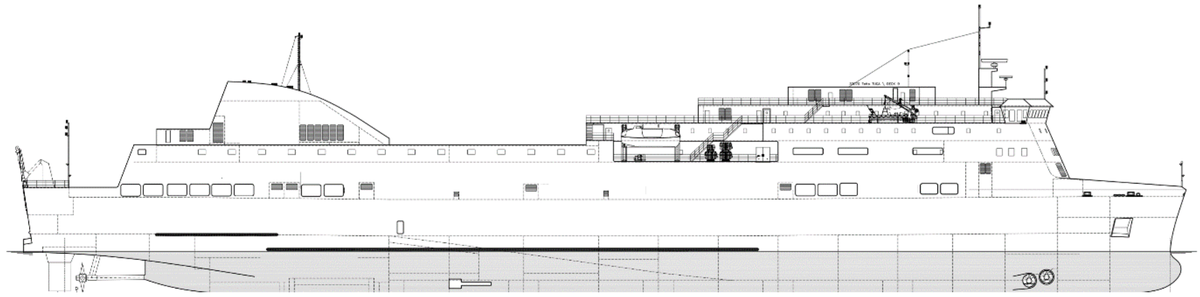


Figure 46. Example of changed configuration of side openings in an open ro-ro space (placed low, compactly distributed).

RCM Cont12 covers open ro-ro spaces on ro-ro passenger and cargo ships. It addresses new ships only.

RCM Cont12 will potentially act as input on the current definitions of open and closed ro-ro spaces in SOLAS [2]:

- An open ro-ro space is "*either open at both ends or [has] an opening at one end and [is] provided with adequate natural ventilation effective over [its] entire length through permanent openings distributed in the side plating or deckhead or from above, having a total area of at least 10% of the total area of the space sides*"; and
- *A closed ro-ro space is any vehicle or ro-ro space which is neither open nor a weather deck.*

5.20.2.2 Impact on safety

Having openings in a ro-ro space means that a fire will be provided with oxygen. The ventilation (natural or mechanical) is crucial to the growth, intensity and burning time of fires in ro-ro spaces. The openings in a ro-ro space can feed a fire with oxygen from the outside and the fire can go on for days if there are enough fuel. Fuel is normally not a problem since the space is filled with vehicles with fuel in their tanks and other rolled on cargo.

The benefits of the configuration of side openings in ro-ro spaces would be to decrease the oxygen supply and thus making the fire development less severe and possibility to self-extinguish.

The negative effects could be that the configuration of side openings in ro-ro spaces could:

- Make the natural ventilation inadequate for the "every-day use" in an open ro-ro space;
- Lead to heat and smoke are trapped more in the space compared to if the openings remain as of today; and
- Cause unburnt gases which could ignite when feeding the space with oxygen again, e.g., by opening a door.

5.20.2.3 Planned method of evaluation

RCM Cont12 was evaluated using FDS simulations during autumn 2021 (October-December), and will be evaluated using model scale test during spring 2022 (February-March). Potentially, a large-scale validation of dilution measuring on board will be done in the spring 2022.

RISE will finish the comparable study between openings and mechanical ventilation with regards to mixing of air:

- Here it shall be compared what % openings (in an open ro-ro space) give the same mixing of air as 6/10 ACPH (Air Changes Per Hour) in a closed ro-ro space. This will at first-hand be studied in FDS using Stena Flavia as generic ship.

Regarding the opening configurations providing the ability to influence the harmful effects of a fire:

- This was studied by RISE with model scale tests during week 8-10, 2022. Studying effects on fire development, heat release rate, temperature in the space and possible visibility in the space with different opening size, shape, location etc.

5.20.3 RCM Cont13: Tactical guidelines for manual intervention

Main author of the chapter: Stina Andersson, RISE.

5.20.3.1 Technical description

RCM Cont13 consists of forming tactical guidelines for how to use the ventilation system in case of fire in a ro-ro ship. The guidelines will be developed later in the project (to be reported in LASH FIRE deliverable D11.5, "Elucidation and guidelines for ro-ro space ventilation in case of fire" [28]).

The guidelines would be an active method of controlling the smoke with the intention of releasing heat or fire gases to the outside of the ship.

Possible new equipment will be proposed in the guideline; reversible fans is a solution further described in RCM Cont14 and will give input to this guideline. As will the results provided in LASH FIRE deliverable D11.4 [27].

The design of the ventilation system varies between ships. A guideline must therefore be general enough to be usable for all types of ro-ro ships. At the same time, it must be detailed enough to provide concrete guidance that is easy to use and understand for the crew. If the guidelines are made too narrow it might make them unsuitable for ships with certain ventilations system designs.

5.20.3.2 Impact on safety

The benefit of such guidelines for use of ventilation would be to:

- Facilitate fire and rescue operations in the ro-ro space;
- Prevent accumulation of hot gases from the fire in the ro-ro space;
- Prevent spread of smoke; and
- Prevent spread of fire to adjacent spaces by reducing the temperature and pressure in the ro-ro space.

The proposed guidelines will facilitate firefighting operations onboard by providing guidance on how to use the ventilation in case of a fire. The guidelines will provide predefined "how-to" scenarios on how to use the ventilation system to allow access for the fire team into the ro-ro space.

5.20.3.3 Planned method of evaluation

A field study on Stena Jutlantica was made in November 2021. Interviews were made with onboard personnel. The interviews showed that the personnel were positive towards a tactical guideline for how to use the ventilation during a fire.

The guidelines were evaluated by simulations (FDS) and by model scale tests that were performed during spring 2022 (February-March). Potentially, RISE will also perform a large-scale ventilation study onboard.

5.20.4 RCM Cont14: SOLAS requirement of reversible fans

Main author of the chapter: Anna Olofsson, RISE.

5.20.4.1 Technical description

RCM Cont14 is to install reversible fans in closed ro-ro spaces. This means that the fans that are installed in a ro-ro space to fulfil the ventilation requirement in SOLAS II-2/20 [2] should be able to operate in both supply and exhaust mode, i.e., be reversible. The reversible fans should be the fans that are used in the every-day ventilation system on board and be able to operate in the required capacity range.

Having reversible fans in closed ro-ro spaces would improve the manual firefighting operations by creating a possibility to control the spread of smoke in the ro-ro space, hence improving the visibility for the crew. Using the reversible fans to facilitate manual firefighting operations is only suggested for fires less than 5 MW (corresponding to a vehicle fire). For larger fires it is assumed that the drencher is activated and that manual firefighting operations are normally not performed.

The fans and ducts should withstand temperatures relating to the temperatures that can be expected of the gases from a fire (cf. for example EN 12101-3:2015 [29]). To be able to operate the fans also in case of fire, the installation needs to be safely installed with fire resisting cables and components. Exhaust outlets need to be located so the exhausted smoke does not impact the passage in case of evacuation/abandonment of ship or impact the use of LSA.

RCM Cont14 is proposed for new ships and for ro-ro passenger and cargo ships.

5.20.4.2 Impact on safety

The benefit of reversible fans is that it improves the manual firefighting by creating a possibility for the crew to operate the mechanical ventilation fans in a favourable direction in case of fire in a ro-ro space. The reversible fans are only suggested to be used as part of manual firefighting tactics for smaller fires where a manual firefighting operation is possible, and the drencher is not yet activated. RCM Cont14 will be a part of the guidelines for smoke and heat exhaust management [28], an active method of controlling the smoke with the intention of releasing heat or fire gases out of the ship. The purpose of such guidelines for smoke and heat management would be to:

- Facilitate fire and rescue operations in the ro-ro space;
- Prevent accumulation of hot gases from the fire;
- Prevent spread of smoke; and
- Prevent spread of fire by reducing the temperature and pressure in the ro-ro space.

Critical aspects:

Forced ventilation may improve visibility conditions for firefighters, but at the same time the supply of fresh air will mean adverse effects in terms of increased temperature and fire spread.

By using active fire ventilation, and thereby change the conditions in the gas flow the impact of pressure, heat and gases will be reduced, and air will most probably flow into the ro-ro space which can have unwanted consequences. This aspect is more related to the fire ventilation itself and not directly the requirement of reversible fans. Supply of fresh air can increase the fire and thereby increase the risk of fire growth and the spread of fire gases. In addition to this, using the ventilation as part of the firefighting tactics might increase the risk of fire spread to the surrounding cargo. Using fans might also increase the external spread of smoke and impact the evacuation/abandonment of the ship, compared to having the fans shut off.

It is important to gain experience and for the crew to be properly trained and familiarized with the reversible fans and procedures to be able to make a decision on how to use the ventilation during a fire.

5.20.4.3 Planned method of evaluation

RISE has conducted Computational Fluid Dynamics (CFD) simulations, using FDS, in order to study the effect of having reversible fans instead of fans that can only operate in one direction, i.e., exhaust air or supply air. The simulations studied gas temperature, visibility, and smoke layer height in the ro-ro space in different fire scenarios and different operational modes on the mechanical fans. As an example, in one scenario the fire was located close to a supply fan and in the other scenario the fire was located close to an exhaust fan. The scenarios are to be compared. RISE studied the scenarios mainly with a fixed heat release rate to find a steady state of the smoke behaviour. Simulations were finished by the end of year 2021.

In addition to simulations, RISE has conducted model scale test to verify some of the simulation results. These tests were run during week 8-10, 2022.

6 Conclusion

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

This deliverable provides a compilation of the selected solutions at an intermediate stage of the project, including the actual or foreseen impact on fire safety and the related testing and demonstrations plan. It shall not be understood or used as a final outcome of the LASH FIRE project.

A total of 44 solutions were preliminary selected by the LASH FIRE's D&D WPs (Table 4). The list of solutions is covering the entire "fire protection chain", it comprises both preventive and mitigating risk controls, as well as both engineering, inherent and procedural risk controls.

As next steps, those solutions will be assessed by WP03, WP04 and WP05 through:

- Ship integration feasibility evaluation;
- Cost assessment;
- Cost-effectiveness assessment; and
- Other assessments.

Meanwhile, the D&D WPs will continue and refine the on-going developments, conduct the validation and the demonstration of solutions.

The next critical milestone (iMS01) will be to select and define the RCOs for the purpose of the quantitative cost-effectiveness assessment (step 4 of Formal Safety Assessment, reported in the LASH FIRE deliverable D04.6, "Cost-effectiveness assessment report" [30]). A workshop at consortium level will be organized and RCOs will be selected on the basis of the preliminary and qualitative assessments of the 44 solutions performed by WP03, WP04 and WP05.

This deliverable 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 1:

> "LASH FIRE will strengthen the **independent** fire protection of ro-ro ships by developing and validating effective **operative and design** solutions addressing **current and future** challenges in **all stages of a fire**".

Table 4. Summary of solutions

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
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

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)
	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
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

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)
	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
		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

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)
	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 = New ships, Ex = Existing ships.
(4) Attributes as defined in MSC-MEPC.2/Circ.12/Rev.2 [1].

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8 Indexes

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