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Consolidation of performance assessment and solutions' impact on safety

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Abstract

There have been a number of fires on board ro-ro ships with severe consequences the last decades, several which have started in a ro-ro space. To prevent and mitigate future fire accidents, cost-effective solutions to improve ships' abilities to independently handle a fire starting in a ro-ro space are needed.

Within the LASH FIRE project, innovative solutions aimed at strengthening the independent fire protection of ro-ro ships have been developed and demonstrated. These solutions are developed to strengthen all parts of the fire protection chain, from ignition prevention all the way to evacuation. This deliverable, D04.10, presents an overview of the testing and demonstration of the solutions. Through this deliverable, external parties, such as industry actors, will have a compilation of the evaluation and its outcome for the different solutions that have been developed and demonstrated within LASH FIRE.



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1 Executive summary

1.1 Problem definition

Every day, more than 5000 ro-ro ships carry both cargo and passengers across our waters. Most trips are carried out without issues. However, there have been several fires on board ro-ro ships with severe consequences the last decades, many of which have started in a ro-ro space [1, 2, 3]. The frequency and severity of fires onboard ro-ro ships marks a need to enhance fire safety onboard, preferably by improving ships' abilities to independently handle a fire starting in a ro-ro space in a cost-efficient way.

1.2 Method

To improve the situation, innovative solutions aimed at strengthening the independent fire protection of ro-ro ships have been developed and demonstrated within the LASH FIRE project. These solutions are developed to strengthen all parts of the fire protection chain, from ignition prevention all the way to evacuation. The solutions are developed by six Development and Demonstration Work Packages (D&D WPs) within LASH FIRE. A technical description as well as a qualitative assessment of their foreseen impact on safety is presented in the LASH FIRE report Deliverable D04.09 "Preliminary impact of solutions and related testing and demonstrations plan" [4]. The deliverable was issued in April 2022 and included information about the testing and demonstrations planned for each solution. This report, D04.10, will present the outcome of the testing and demonstration of the solutions. It acts as an extension of D04.09 and readers are encouraged to read these two reports together.

1.3 Results and achievements

This deliverable provides a compilation of the selected solutions, their method of evaluation and the performance assessment. It is to be understood as a brief overview of the development and demonstration work conducted within the LASH FIRE project.

1.4 Contribution to LASH FIRE objectives

This deliverable will contribute to 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"*.

It will also contribute 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

This deliverable is a summarizing report. It will provide external parties with information about the safety impact of the solutions that have been shown through the testing and demonstration work carried out by D&D WPs in LASH FIRE. In doing so, this deliverable will help to disseminate the work and result of all D&D WPs in LASH FIRE.

2 List of symbols and abbreviations

AGV	Automated Guided Vehicles
AI	Artificial Intelligence
APV	Alternatively Powered Vehicle
CAF	Compressed Air Foam
CFD	Computational Fluid Dynamics
D&D	Development and Demonstration
DFC	Digital Fire Central
DG	Dangerous Goods
EV	Electric Vehicle
FDS	Fire Dynamics Simulator
FSA	Formal Safety Assessment
FSS	Fire Safety Systems Code
FTP	Fire Test Procedures Code
GA	General Arrangement
HRR	Heat Release Rate
IMDG Code	International Maritime Dangerous Goods Code
IMO	International Maritime Organisation
LFVHD	LASH FIRE Vehicle Hot Spot Detector
MSC	Maritime Safety Committee
OOW	Officer On the Watch
RCM	Risk Control Measure
RCO	Risk Control Option
SOLAS	Safety of Life at Sea
SPT	Stowage Planning Tool
SWOT	Strengths, Weaknesses, Opportunities and Threats
TRL	Technology Readiness Level ¹
UHF	Ultra High Frequency
VFD	Video Flame Detection

¹ LASH FIRE use the definition according to H2020 - Work program 2018-2020:
https://ec.europa.eu/research/participants/data/ref/h2020/other/wp/2018-2020/annexes/h2020-wp1820-annex-g-trl_en.pdf

VSD Video Smoke Detection
WP Work Package

3 Terminology

The Formal Safety Assessment (FSA) guidelines from the International Maritime Organisation (IMO) [5] gives the following definitions for the terms Risk Control Measure (RCM) and Risk Control Option (RCO):

Risk control measure A means of controlling a single element of risk

Risk control option A combination of risk control measures

It should be noted that a risk control measure developed in LASH FIRE may control more than one single element of risk. In LASH FIRE, the terms "Risk Control Measure" and "solution" are used as equivalent. Within this report, both "RCM" and "solution" are used.

4 Introduction

Main author of the chapter: Stina Andersson, RISE

LASH FIRE is a European Union-funded research project with the aim to enhance the independent fire protection of ro-ro ships. Six areas of improvement have been identified: Effective Manual Operations, Inherently Safe Design, Ignition Prevention, Detection, Extinguishment and Containment. These areas are addressed by the work in Development & Demonstration Work Packages (D&D WPs), one D&D WP per area. Within each D&D WPs, several challenges for fires originating inside ro-ro spaces have been identified. These challenges are called Actions. The D&D WPs together with the associated Actions are summarised in 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
	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. List of the six Development & Demonstration Work Packages and their associated Actions.

Within each Action, solutions have been developed with the purpose to improve ro-ro ship's ability to handle a fire originating inside a ro-ro space by addressing the challenge at hand. The developed solutions can be both technical and operational in nature and cover the whole fire protection chain: ignition, detection, 1st response, decision, extinguishment, containment and evacuation. To see the performance of the solutions and understand how the solutions impacts the onboard safety, evaluation of the solutions were carried out within the LASH FIRE project. The solutions and the planned methods of evaluation have been presented in the LASH FIRE report D04.9 "Preliminary impact of solutions and related testing and demonstrations plan" [4]. D04.9 was issued in April 2022 and provided an intermediate compilation of the actual or foreseen safety impact of the solutions. This report, D04.10, is a continuation of D04.9 and will present the result of the evaluation of the solutions. While D04.9 presented how the solutions would be evaluated, D04.10 will present how the evaluation of the solutions actually went. Readers are encouraged to read D04.9 and D04.10 in conjunction.

D04.10 aims at giving an overview of the D&D work carried out in LASH FIRE. For a more detailed description of each solution and its shown performance, please refer to D&D WPs deliverables.

5 List of solutions

Main author of the chapter: Stina Andersson, RISE

This section presents each Action, its goal, and the solutions (RCMs) developed and demonstrated within the Action. For each solution, a description of the problem that the solution addresses is given, followed by information about the method(s) of evaluation of the solution. Finally, a summary of the showed performance of the solution is presented. A detailed technical description of each solution is presented in D04.9 [4]. For a detailed description of the evaluation and performance for a specific solution, the reader is referred to D&D WPs deliverables.

An overview of all developed and demonstrated solutions, together with the applicable ship types and ro-ro spaces, is presented in ANNEX A: Summary of solutions and their method(s) of evaluation.



Effective Manual Operations

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

The goal of Action 6-A is to *“Develop a methodology that allows the manual screening of cargo and the implementation of effective fire patrol procedures and routines”*.

5.1.1 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 Problem definition and description of solution

The fire patrols frequency and procedures can vary significantly from one shipping operator procedure to another. IMO regulations regarding fire patrols are quite vague. SOLAS II-2 regulation 7 [6] states that *“for ships carrying more than 36 passengers an efficient patrol shall be maintained and that each member shall be provided with a two-way portable apparatus”* providing little information about procedures and the most effective equipment a fire patrol should carry. The assisting equipment for fire patrols should be better defined besides the minimum requirements stated at SOLAS II-2. Op1 is describing the most efficient methods (routes, frequency, gear, and equipment) to be followed by fire patrol members considering the human factor as a complex multi-dimensional issue that affects maritime safety, involving the entire spectrum of human activities performed by ships' crews. The human element, in particular fatigue, is widely perceived as a contributing factor in marine casualties. The result of fatigue is impaired performance and diminished alertness. Fatigue is a problem for all 24-hour a day in the marine industry, even more for ro-ro short sea shipping reaching different ports a day. Boring and repetitive fire patrol working consistently heavy workload will cause physically and mentally fatigue.

Op1 is considering all these aspects and proposing sufficient rest periods between fire patrols without decreasing frequency and efficacy.

5.1.1.2 Method(s) of evaluation

Op1 has been validated and demonstrated on board a ro-pax vessel with a Technology Readiness Level (TRL) of 6 & 7. On board tests on the efficacy of new assisting equipment and procedures for fire patrolling were carried out by SAS on 10 July 2021 on board the ro-pax “BAHAMA MAMA” belonged to BALEARIA in route from the port of Malaga to Melilla (Spain) at 01:00 Local Time. 1.5h after departure, 25 different locations were inspected during 37 minutes in duration starting (as Op1 was

proposing) with the screening of fire hazards that may occur in the cargo space where high risk cargo is stowed.

5.1.1.3 Performance assessment

On board tests following the fire patrol team through the route has shown the following conclusions:

Electrical failures are seen as the main ignition risk on board. Many fires are caused by electrical failures; these are overheated components or cables that may produce smouldering fires (no flame). Some of them produce too little smoke or soot to be detected by automatic means (smoke detectors). If the fire patrol pass through the cargo space and manually detect either by smell or with the help of an IR camera, it is expected to have an impact on the possibility of ignition by electrical cause.

Other fire origin can be unknown. It can even be intentionally provoked and spontaneous fires on conventional vehicles are rare to occur. The only way to detect such incidents is by visual confirmation. By implementing efficient fire patrol procedures, the risk of ignition will be lower.

Electric vehicles, (**EVs**) are a new challenge in the maritime shipping. The connection of the car battery to an onboard charging system may contribute to overcharge, provoking a thermal runaway despite the inner safety measures of the battery management system. Increased safety awareness of fire patrols by monitoring the condition of the battery may contribute to reduce the risk of ignition.

Vehicles using other energies than gasoline or diesel will be referred to as Alternatively Powered Vehicle (**APV**) i.e., vehicles that include other liquid fuels like ethanol, LNG, LPG, compressed gas like CNG, hydrogen fuel cells. Safety solutions to protect the fuel or energy storage from fires are similar within the different groups and their failure nodes are also similar. By implementing efficient fire patrol procedures, it is expected to have a risk reduction in chances of ignition.

Reefers have always been seen as a potential source of ignition in the ro-ro industry; crew should make connection with own cables. Fire patrol will monitor and check connections after departure. Reefer units are generally not allowed to operate on their own diesel generator power supply (excepting weather deck and in some cases in ro-ro open spaces) and should be connected to the ship's grid. By reviewing the belts and mechanical parts of the system, fire patrols can reduce the risk of ignition on reefers.

Ro-ro ships are carrying **Dangerous Goods (DG)** complying with IMDG Code. DG can generate reactions and provoke fires. Even though accessibility is a problem for an efficient fire patrol inspection, it is expected that by implementing efficient fire patrol procedures, the risk of DG reaction will be reduced.

Accessibility within ro-ro spaces between cargo is very limited. Sometimes less than 15 cm making the first response very difficult. Fire patrol procedures will not improve accessibility, but the use of IR cameras can detect risk from a distance (10-15 meters)

Fire patrol **frequency** varies from different ships. An interval of one hour between fire patrol is taken as reference with a length of 35 minutes in total. If frequency is more than one per hour and the total length of the fire patrol route is shorter than 30 minutes, frequency can be increased.

Another task or priority of the fire patrol member can result in that fire patrol will be required but not present. Some systems, like the check point reader, can guarantee that fire patrol is physically present at the location.

SOLAS Chapter II-2 only states the use of a two-way radio apparatus for the fire patrol member. By defining a more comprehensive gear and equipment (ultra high frequency radio with hands free press to talk bottoms and IR camera), early detection can be improved.

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

Main author of the chapter: Jaime Bleye, SAS

5.1.2.1 *Problem definition and description of solution*

The main aim of the manual screening of cargo is the identification of fire risks at the ramp during the loading process. Currently, there are no specific IMO regulations related to the manual screening of cargo fire hazards. Only ship operators' procedures exist. 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 IMDG cargo) leaving little time for inspections. Because of this, 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 (1h as standard) during the fire patrol routine. Op2 proposes a previous screening of cargo fire hazards at the terminal preceding the automatic and the manual screening at the ramp.

There is a need of 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 vans or recreational vehicles like Christmas trees or heaters.
- Stowaways' activities.
- Other obvious fire hazards.

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

5.1.2.2 *Method of evaluation*

Op2 has been validated and demonstrated on board a ro-pax vessel with a TRL of 6 & 7. Initial on-board testing was performed using the BALEARIA ro-pax "BAHAMA MAMA" in the Port of Melilla (Spain) on 10 July 2021. During the previous screening of cargo, we (SAS) assessed how the police of the port detected a petrol leak in an old Opel Astra car. The cargo was rejected by the chief officer. Some faulty electrical connections on reefers were also identified. Another on board test was carried out on board MALEARIA ro-pax "ABEL MATUTES" between Barcelona and Palma (Spain) in May 2022.

5.1.2.3 *Performance assessment*

According to statistics, around 60% of the fires in ro-ro spaces are electrical fires. **Electrical failures** in reefers, standard trailers and trucks, and also in recreational vans with homemade installations are seen as the main ignition risk on board. By screening hazards before loading, it is expected to have a risk reduction of ignition.

Reefer units are generally not allowed to operate on their own diesel generator power supply (excepting weather deck and in some cases in ro-ro open spaces) and should be connected to the ship's grid. Reviewing the belts and mechanical parts of the system before loading can reduce the risk of ignition. Shipping operators cannot efficiently control the conditions that reefer units are loading. So that, it is expected that by increasing the awareness and vigilance of these units at dock before loading will also reduce the risk of ignition.

The main conclusions and points after the on-board visits are:

- Screening of cargo fire hazards at port should begin before the loading process.
- Loading process is carried very fast and the identification of hazards is very tricky (only related to the most obvious). Can also be identified during lashing by Able seamen or stevedores.
- Once the ship has berthed and the ramp is down at port, one crew member can start a tour through the parking lot where vehicles are parked.
- The vehicles to be inspected: reefer units, cars or APV, and recreational vehicles.
- Main hazards to be identified are general status, substandard electrical connections, suspicious noise/smell, presence of ignition sources, self-reactions of DGs, leakages, status/level of portable tanks.
- Operator should wear high visibility vest, radio in communication with ship/chief officer and IR camera.
- Screening should not be performed during a dynamic situation, when vehicles are in motion and driving through the dock, due to the dangerous situation. Truck drivers have a blind spot.
- Screening should not provoke delays.
- A total identification of fire hazards is not possible at this stage. Even if the stipulated measures for identification are totally performed the system may have gaps.
- One operator can do the screening of cargo hazard before loading but it should be established. It can be performed by a crew member or an operator from the land side, like a stevedore.
- Conditions are different in every port. In some ports (ship visit "ABEL MATUTES", May 2022, Spain) the trucks do not stay at port so the work cannot be performed in a static situation.

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

The goal of Action 6-B is to *"Set a standard for quick manual fire confirmation, localization and assessment"*.

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

Main author of the chapter: Jaime Bleye, SAS

5.2.1.1 Problem definition and description of solution

Op3 is required due to the following reasons:

- 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. Figure 2 show a drencher section plan on the bridge.



Figure 4. Framing marks on bulkhead. Difficult to read.

Op3 is addressing:

The identification of signage and marking mismatches between the different marking and signage systems on the vessel and different fire management system interfaces.

Every single vessel should identify signage and marking mismatches between the different marking and signage systems on the vessel and different fire management system interfaces available used in the bridge or engine room. This can be done by preparing an exhaustive list of the vessel's different fire management system interfaces (such as alarm panel, integrated fire management system, CCTV, drencher panel, or any other printed instruction) and relevant marking/signs (such as painted markings on deck/bulkhead, sections, zones and localities, drencher station valves etc.) to check whether marking and signs coincide with the information displayed in every interface previously identified.

The alignment of marking and signage systems in vessels with the different fire management system interfaces.

The signs and markings in the system have to coincide with the information provided by the different fire management system interfaces available (including any printed instruction and verbal terminology) in the vessel. For instance, the section numbering indicated inside the space should be the same as the section valve identification and section identification at the safety centre or continuously manned control station. Signs and marks proposed need to easily identifiable and interpretable signs and use established vocabularies and symbols as described by ISO 24409-01:2020.

5.2.1.2 Method(s) of evaluation

Op3 has been validated and demonstrated on board a ro-pax vessel with a TRL of 6 & 7. Initial on-board testing was performed using the BALEARIA ro-pax "BAHAMA MAMA" in the Port of Melilla (Spain) on 10 July 2021. Mismatches between the colouring code of the drencher sections and the section plan located at the bridge were identified and suggestions were made by Action 6-B. Figure 5 show coloured valves in drencher room.



Figure 5. Coloured valves in drencher room.

In addition to this, Action 6-B proposed solutions were tested and applied on Stena Baltica during an onboard visit in Norvik, on April 4 2022. The visit was arranged by the Stena project manager fire safety, which provided support onboard to the NTNU Social Research team. The visit started with the observation of the visibility conditions of fully loaded cargo deck during ship arrival. It continued with a comprehensive ship familiarization round with a safety focus carried out by the safety officer. The weekly “Fire and Abandon Ship” drill was observed, both, from the bridge and the affected deck. Finally, the application of guidelines and suitable solutions were discussed with several crew members, namely, the captain, watch officer, two watchmen and the safety officer.

5.2.1.3 Performance assessment

On board trials performed under the umbrella of Action 6-B have raised the following conclusions:

Signage and markings represent an important resource for wayfinding and localisation in case of fire, but manual confirmation is also affected by the surrounding environment, for instance cargo deck environment (tight passages, smoke, etc.).

Consistency between signage and markings and information in the bridge represent an important resource for wayfinding and localisation in case of fire in closed spaces. Consistency between signage and markings and information in the bridge and readable and identifiable signage and markings can reduce misunderstandings and errors when identifying and traveling to detection point. Yet, other factors such as physical condition of the runner or familiarity with the ship can also have an effect on the fire confirmation and localization.

The signage and markings onboard and its consistency with information in the bridge may contribute to some extent to an inadequate fire confirmation. Other factors such as lack of familiarity with the ship or stress among others can also play an important role.

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

Main author of the chapter: Jaime Bleye, SAS

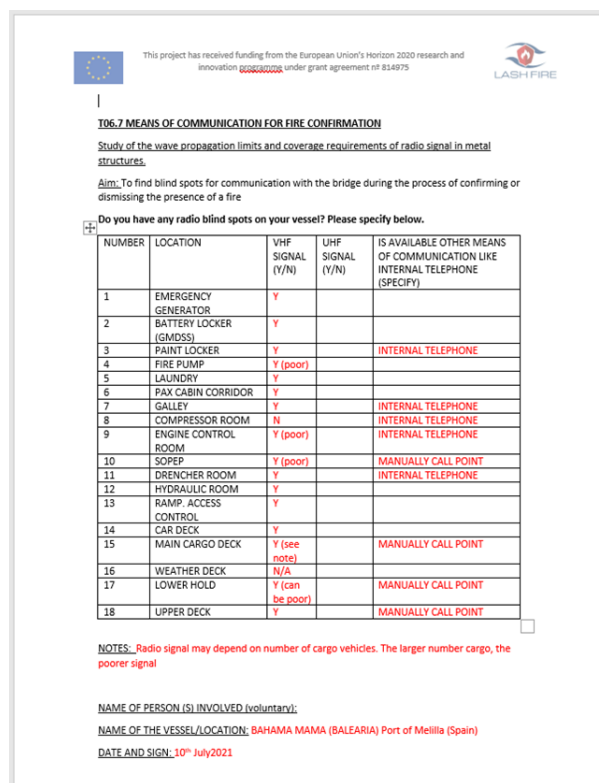
5.2.2.1 Problem definition and description of solution

Op4 is required due to the following reasons:

- Manual fire confirmation and localization is rarely examined, systematized and trained for (lack of scientific literature, standards, company procedures and/or description of routines)
- Runner's lack of familiarization with the vessel
- Poor communication with bridge (radio shadows, dead spots lack of a common language, etc.)

5.2.2.2 Method(s) of evaluation

Op4 has been validated and demonstrated on board a ro-pax vessel with a TRL of 6 & 7. On board testing were performed using the BALEARIA ro-pax “BAHAMA MAMA” in the Port of Melilla (Spain) on 10 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 6 show a questionnaire to find blind spots of communication and alternative means of communication.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement nr 814975

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 July 2021

Figure 6. Questionnaire to find blind spots of communication and alternative means of communication.

5.2.2.3 Performance assessment

First response might be performed by the first crew member that discover the fire in the initial stage. This way, fire confirmation and localization or runner is directly linked with an efficient first response. By **training the role of the runner** and acquiring a better understanding of the task, the time for an efficient manual confirmation can be reduced.

Op4 is improving:

Definition of the 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 [7].

Definition of the task: Manual confirmation and localization of fire 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.

Requirement: Regarding the conditions for the performance of the task, the runner has to be familiarized with the activity and the vessel by completing company's familiarization routines and participating in several trials including events where manual fire confirmation and localization related activities have been trained. Furthermore, the manual confirmation and localization of fire has to be carried out by an experienced crew member that reports him/herself confident to perform the task and is assessed as capable by the person sending him/her.

Finally, the runners should wear a portable radio, safety torch, IR camera and long-sleeved clothes.

Clear communication will drastically reduce misunderstandings and late decisions from the operational point of view. Practical measures to ensure a clear communication between bridge and runner.

Requirement: Standardize language and terminology used by adopting the use of IMO Standard Marine Communication Phrases in vessels with English as working language.

Requirement: Every vessel has to identify potential blind spots for communication and radio shadows.

Suggestion: Study of wave propagation limits and coverage requirements of radio signal in metal structures can be adapted to local conditions and/or used to identify potential blind spots for communication and radio shadows.

Requirement: Use of communication equipment with coverage. Not less than the 85% of the vessel area should have radio coverage with full cargo. This implies finding solutions to eliminate radio blind spots and shadows and providing alternative means of communication or solutions for areas without coverage in case of few acceptable radio blind spots and shadows in non-significant locations. Solutions can comprise repeaters, a user-friendly combination of different technologies, use of ultra high frequency (UHF) radio transmitters, etc.

A description of the practical measures to ensure familiarization with the task.

Requirement: Design and perform realistic fire drills involving manual fire confirmation and localization activities by including subevents in which concerned crew get familiarized with scenarios that they may encounter once they are sent for confirmation: typical signs of an incident, typical personal safety risks and default actions depending on situation; and potential challenges to manual fire confirmation and localization are trained.

Requirement: Include the assessment of the task in drill debriefs and HSE meetings.

Requirement: Practice the use of IMO Standard Marine Communication Phrases during trials.

Suggestion for all vessels with fire patrols: Fire patrols should practice the use of IMO Standard Marine Communication Phrases in non-emergency situations as well.

5.3 Action 6-C: Efficient first response

The goal of Action 6-C is to *“Develop and validate smart technical solutions and tactics as well as to evaluate new equipment for quick first response and effective fighting of fires in their initial stage”*.

5.3.1 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 Problem definition and description of solution

The concept of **“first response”** is not well recognised among crew members and is not mentioned in any relevant part of SOLAS or in any other resolution of the IMO Maritime Safety Committee (MSC). For shipping operators’ procedures, there is no difference between first response and manual firefighting, being different tiers and concepts in the firefighting chain. A first response will be performed with no specific fire gear at the first stage of the fire. A typical first response action is the use of a handheld device or portable fire extinguishers and will be probably performed by only one person (probably the fire patrol member). On the other hand, a manual firefighting action is an organized activity, advanced from the equipment point of view and strategy and will include a fire team and all type of fire equipment like fire hoses and breathing apparatus. Crew on board must have a clear idea about the procedure to follow when they 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 the time for an efficient first response.

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
 - ✓ By shouting 3 times “FIRE, FIRE, FIRE” ensuring that another crew member has received the message that has to be transmitted to the Officer On the Watch (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/ro-pax industry.
- Investigate method/equipment to extend the usability of fire extinguisher to less accessible fire seats such as high places on top of truck cabins.
- 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.

5.3.1.2 Method(s) of evaluation

The efficacy of Op5 has been tested through a training module on the effective first response, gear and equipment, developed in the Maritime Safety Training Centre “Jovellanos” that belongs to SASEMAR – SAS. Figure 7 show the training schedule for first response and manual firefighting on APV.

   	
COURSE: FIRST RESPONSE AND MANUAL FIREFIGHTING TRAINING ON APV FDATES: 18th TO 19th OCTOBER 2022	
TUESDAY 18th	
08:00-08:30	Safety introduction. Healthy working environment- classroom.
08:30-09:00	Objectives of the training. Pre-briefing start meeting.
09:00-09:30	Donning of PPE
09:30-09:45	Equipment familiarization
09:45 -10:30	DRILL0. Dry tests
10:30-11:00	BLEVE demo
11:00-11:30	Coffee/snack break (fireground)
11:30-13:00	DRILL 1. Pressurized LPG jet fires. Defensive strategy.
13:00-15:00	DRILL2. EV Free burn safety awareness and firefighting procedures.
15:00-15:30	Lunch at restaurant
15:30-16:30	Debriefing and conclusions.
MIÉRCOLES 19 / WEDNESDAY 19th	
08:00-09:00	Pre- briefing start meeting. Development of APV fires in ro-ro spaces going into training session. Objectives of the training. Classroom
09:00-09:30	Hose deployment and size selection. BA donning. Communication test.
09:30-10:00	Coffee/snack break (fireground)
10:00-12:30	DRILL 3. (a) First response & (b) Firefighting methods
12:30-14:30	DRILL 4. Indoor EV manual firefighting methods in combination with or without drencher system and ventilation. Post extinguishing methods (cooling device, fire blanket).
14:30-15:00	DRILL 5 Post extinguishing treatment (boundary cool down and healthy working environment. Procedures for safe undressing)
15:00-15:30	Lunch at restaurant
15:30-16:30	Debriefing and conclusions

HC/FRAPV/REV01/1022

Figure 7. Training schedule for first response and manual firefighting on APV. The training module was performed at SAS facilities in Spain in October 2022 in collaboration with STL.

5.3.1.3 Performance assessment

The pilot training module performed at SASEMAR fire training ground with 8 STENA LINES crewmembers has raised the following conclusions:

Fire patrol might not detect a fire; therefore, no first response will be performed. By stating the role of the designated people who might act as first responders gaining awareness on the task.

The absence of communication and report to OOW when discovering a fire is considered a communication failure that will drastically affect the confirmation of the fire.

By establishing written clear instructions establishing the right gear and equipment of the role of the designated first responder, the risk of late decision will be reduced.

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

Main author of the chapter: Jaime Bleye, SAS

5.3.2.1 *Problem definition and description of solution*

Localization of first responders is a key factor for the decision-making process on the event of an emergency. There is no other way at this stage than the information processed via radio, but this system may content mistakes.

The aim of Op6 was 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 vessels. Besides the core geo-positioning technology, the aim is also to develop a ship indoor information system and an application-based platform of a ro-ro indoor navigation and indoor fire intelligence system.

For the above purpose, Op6 capitalizes upon the technology ecosystem of Anyplace, which is a Wi-Fi localization, navigation, crowdsourcing, and indoor modelling platform. Wi-Fi technology is not widely available on ro-ro vessels and interactions within LASH FIRE have shown that dense telecommunications deployments, which are necessary to provide multiple reference points for the task of localization, will not be available on ro-ro vessels in the years to come. This led to the design and development of an innovative geo-positioning technology with “zero” infrastructure. Particularly, the aim was to offer similar benefits to Wi-Fi localization (i.e., room-level accuracy to about 2–10 m and low installation and maintenance cost) without relying on Wi-Fi access points as reference points but rather use static elements of indoor spaces as reference points (e.g., deck patterns, bulkhead patterns, hoses, fixed installations, signs, control buttons) and their spatial.

5.3.2.2 *Method(s) of evaluation*

Op6 was 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, Op6 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 ground-breaking indoor localization technologies on ro-ro vessels 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 vessels.

5.3.2.3 *Performance assessment*

The on-board trials were carried out by the University of Cyprus on board Stena Flavia. First responders were equipped with smartphones featuring a heat camera that allow continuously monitoring in an unobtrusive way hazardous condition on vessel and communicate this information seamlessly to the bridge. This device and technology will reduce the risk of radio equipment failure and will help in the decision-making process of a fire emergency.

5.4 Action 6-D: Effective and efficient manual firefighting

The goal of Action 6-D is to *“Develop guidelines and a training module for firefighting of alternative fuel vehicles in ro-ro spaces, based on evaluation and full-scale demonstration of new equipment”*.

5.4.1 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 *Problem definition and description of solution*

APV represent other hazards than vehicles with traditional fuel (e.g. gasoline, diesel) with internal combustion engine. Alternatively powered vehicles (APV) include battery, hybrid, fuel cell and gas-powered vehicles. In the event of fire, gas tanks can give rise to a strong jet flame or explode if they do not work properly or if they are handled incorrectly (for example, if the thermal fuse is cooled). Lithium-ion batteries can produce flammable and toxic gases during thermal runaway and new metals in chassis such as magnesium can cause fires that are flammable and difficult to extinguish.

The new type of dangers introduced by APV require new routines, tactics, equipment and training to ensure the safety of crew and passengers on ro-ro vessels.

Op7 is addressing:

- 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 APV will help to build and sustain a safe workplace, protect the cargo on board and the sea environment.
- 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.

5.4.1.2 *Method(s) of evaluation*

Op7 has been 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 & 6. It was carried out 29 and 30 March 2022 with the schedule shown in Figure 8.

LASHFIRE T06.12 APV TESTS

DATES: 29th to 30th March 2022TUESDAY 29th

08:00-10:00	Set up meeting.
10:00-10:30	Coffee/snack break (main hall)
10:30-11:30	Fire ground arrangement for test 1
11:30-13:00	Test 4.1: Free burn test
13:00-13:30	Lunch
13:30-14:30	Conclusions
14:30-15:00	Dry tests

WEDNESDAY 30th

08:00-09:00	Set up meeting.
09:00-10:00	Fire ground arrangement for tests 2 & 3
10:00-10:30	Coffee/snack break (fireground)
10:30-12:00	Test 4.2: First response test & firefighting
12:00-12:30	Conclusions and preparation
12:30-13:30	Test 4.3: Manual firefighting test (indoor)
13:30-14:30	Lunch
14:30-15:00	Conclusions



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n° 814975

Figure 8. Large scale APV tests carried out at SAS facilities on March 2022. Schedule.

5.4.1.3 Performance assessment

These are the main conclusions after the large-scale fire tests carried out at SAS (Spain) using real Electric vehicles (EVs):

Defining the conditions for manual firefighting with APVs and the risks associated with this operation will reduce the risk of late decision.

Specific training on APV fires and drills will also reduce the risk of low experience and competence.

The use of new equipment (fog nail, boundary cooling device, smaller hoses, large fire blanket) that can face the new challenges with APVs will reduce the risk of equipment failure (see deliverable D06.8 [8]).



Inherently Safe Design

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

The goal of Action 7-A is to *“Re-design and develop guidelines for improved fire detection system interface design, promoting intuitive operations and quick decision-making”*.

5.5.1 Des1: User friendly alarm system interface design guidelines

Main author of the chapter: Staffan Bram, RISE

5.5.1.1 Problem definition and description of solution

Previous studies both within and preceding LASH FIRE (e.g. FIRESAFE II [7]) have shown that systems and environments used by the fire leader during an incident will often have shortcomings, such as clumsy user interfaces, poor integration of resources that are often used in combination, and issues related to the working environment (such as noise from concurrent alarms on the ship’s bridge). According to LASH FIRE research, issues like these can be attributed to the process of ship design and construction. When ships are designed, there is rarely any structured approach to end-user needs integration and human-centered design, methods that would strengthen the fit between design solutions and the practical demands of the ship’s safety organization. The guidelines developed under Des1 are meant to provide reference materials and guidance on activities to promote usability and ergonomics in the design of bridge safety center layout, and of the different resources relevant for this environment.

5.5.1.2 Method(s) of evaluation

The design guidelines of Des1 are targeted towards shipping companies and are developed in collaboration with two ro-pax newbuild projects, which allows for iterative evaluation and adjustments of their contents. The focus of these evaluations are primarily ease of use, practical applicability, and functionality to support interactions between project stakeholders (e.g. between different groups within the shipping company or with external agents such as design firms).

At the end of development, a workshop will also be conducted where shipping company representatives discuss the utility of our design guidance and potential future development towards implementation.

5.5.1.3 Performance assessment

Design guidance development is still ongoing and because of that, no firm evaluation results are available.

5.5.2 Des2: Alarm system interface prototype

Main author of the chapter: Staffan Bram, RISE

5.5.2.1 Problem definition and description of solution

[This is a reworking of texts from D07.6 [9]]

Current standards for fire centrals and fire plans on board are a long way behind the possibilities provided by current technological developments. Today, paper-based General Arrangement (GA) plans will often be used where every deck is shown in its entirety, displaying large amounts of information (not only that which is relevant for fire management), creating a cluttered overview of the ship. In addition, the static nature of paper-based plans means that information about the fire and the crew’s actions has to be noted and updated manually. This creates a significant workload for the operator and

thus invites potential mistakes. In addition, the process of locating the fire can be tedious, which means that valuable time is lost in fire response.

On vessels with digital systems, decentralization is a big issue. More often than not, systems are decoupled, meaning that different interfaces are provided for alarm positions, CCTV, fire doors, etc., all with their own interaction paradigms and graphical styles. Apart from providing operational inconsistency, this creates a lot of clutter on the ship's bridge and makes it difficult to gather the information necessary for leading the firefighting operation.

5.5.2.2 *Method(s) of evaluation*

The Digital Fire Central (DFC) was evaluated through an experimental session at a shipowner's headquarters, where officers designated the role of fire leader used the interface while working through a simulated fire scenario. The demonstration session included an introduction, familiarization with the DFC, performing the fire scenario, and a debriefing. During the debriefing, participants were queried on their reflections around User Interface graphical elements as well as the interface's envisioned utility in terms of situation overview, saliency of information, system feedback, orientation and localization, and potential impact on fire management work practices. Participants also completed a questionnaire rating the DFC on 8 different usability measures.

5.5.2.3 *Performance assessment*

[This text is a reworking of results presented in D07.6 [9]]

The results of the DFC demonstration show a lot of potential for an integrated system. Participants appreciated how easy it was to gain full understanding of the location, spread, and intensity of the fire, in addition to an understanding of what happened before they took their position at the fire control centre. A graphical visualisation of the fire on the fire plan, together with a visualisation of the historical development, was seen to save time and increase situational awareness. Usability of the system received high scores in the debriefing questionnaire. Participants also believed that this would make it easier to gauge the effectivity of used countermeasures. The integration of safety-relevant information about loaded goods (lorries, electric cars etc.) was also perceived as valuable. Being able to interact with the cargo on the fire plan to access information about dangerous goods was significantly more user friendly than looking up the information in a separate cargo manifest. Furthermore, the integration of emergency controls in one system shortened response times, and participants believed that this could eliminate misunderstandings between the operator and crewmembers, who otherwise would have to engage those systems on different locations.

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

The goal of Action 7-B is to *“Develop guidelines for efficient extinguishing system activation and inherently safe design”*.

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

Main author of the chapter: Torgeir Kolstø Haavik, NSR

5.6.1.1 *Problem definition and description of solution*

Quick activation of fixed fire extinguishing systems (drencher and CO₂ systems) is a precondition for successful handling of fires in ro-ro spaces. Historic fire incidents have taught us that the first minutes of a fire in ro-ro spaces are critical, and the response time is decisive for the outcome. Hence, the fact that it often takes 20 minutes before drencher systems are activated – after the decision is made – and generally longer for CO₂ systems, points towards a significant improvement potential. Reasons for late activation can be found both in procedures and design relating to the extinguishing systems, examples

being ambiguous instructions for system activation, or unclear communication between the fire commander and the engine control room. However, the arrangements and practices of procedures and design vary greatly between shipping companies and between ships, thus a solution to the problem must be context-sensitive, i.e. adapted to the specific conditions on each ship. Des3 is developed to help the crew identify and implement changes in procedures and design, through a reflection, evaluation and change process that can be undertaken in connection with existing fire drills.

5.6.1.2 Method(s) of evaluation

The solution was demonstrated onboard a ro-ro ship while docked in harbour. The demonstration was outlined as prebrief and debrief sessions with the crew, in connection with the arrangement of a tailor-made fire drill. Four researchers facilitated the demonstration, observed closely and documented the event through note-taking, photographing and video-filming. This documentation was used for an expert judgement by the researchers. In addition, the crew contributed to the evaluation through producing actual improvement suggestions through the demonstration. The improvement identification and suggestions being an outcome of the RCM implementation was a central source for evaluation of the solution.

5.6.1.3 Performance assessment

The demonstration resulted in explicit identification of improvement potentials relating to design issues. Two design improvement potentials were:

- Ambiguous drencher activation instruction – would benefit from re-writing,
- Difficult-to-read laminated formal drencher activation instructions – would benefit from re-design.

This outcome demonstrated the suitability of the RCM for identifying improvement potentials for activation procedures. In addition, the researchers facilitating the demonstration session observed that the RCM was possible to conduct as planned, and as such judged the solution/demonstration as contributing to risk reduction as assumed/calculated in the risk reduction estimation.

5.6.2 Des4: Training module for activation of extinguishment systems

Main author of the chapter: Torgeir Kolstø Haavik, NSR

5.6.2.1 Problem definition and description of solution

Although fire drills are arranged onboard at least every month, and usually more often, activation of drenchers and CO₂ systems are usually only simulated. Thus, the crew seldom or never get to practice actual activation in a situation that resembles a real fire. Particularly, this is the case for CO₂ systems, which cannot be activated onboard as part of drills due to the risk of asphyxiation. Historic maritime fire accidents have shown the importance of quick activation, and the potential catastrophic consequences of hesitation or erroneous activation, and more hands-on training of efficient activation is a means to improve the capability to undertake the activation process more rapidly. Des4 is a training course that is developed to let crew members practice hands-on activation of drenchers and CO₂ systems in a safe and forgiving environment. The course involves both a theoretical and a practical module, and includes a scenario involving communication and collaboration between the bridge and the personnel on the location from where fixed fire extinguishing systems are activated.

5.6.2.2 Method(s) of evaluation

The training course was demonstrated through the execution of the course in the training centre of Centro Jovellanos in Gijón, Spain. Ten participants from shipping companies took part, and contributed to the evaluation of the solution through a survey after the course. In the survey, they rated different

aspects of the course, the usefulness and the learning outcome on a Likert scale. In addition, researcher evaluation was part of the final evaluation of the RCM.

5.6.2.3 Performance assessment

The survey led to the following assessment of the training course:

1. *The course content was relevant for my job*
All course participants agreed (22%) or strongly agreed (78%) to this statement.
2. *I would feel more confident on activating extinguishing systems if I had more practical, hands-on training*
All participants agreed (70%) or strongly agreed (30%) to this statement.
3. *The course provided more comprehensive training on activation of fixed fire extinguishing systems than other courses I have participated to*
67% of the participants agreed or strongly agreed to this statement. 33% of the participants were neutral or disagreed.
4. *The theoretical part of the course provided knowledge that makes me better prepared for fire management*
68% of the participants agreed or strongly agreed. 33% of the participants were neutral or disagreed.
5. *The practical training on activation of fixed fire extinguish system provided knowledge that makes me better prepared for fire management*
77% of the participants agreed or strongly agreed. 23% of the participants were neutral or disagreed.
6. *The theoretical and practical part of the course complemented each other*
88% of the participants agreed or strongly agreed. 22% of the participants were neutral or disagreed.
7. *The course gave me an improved understanding of factors that may influence effective activation of fire extinguish systems*
All the participants agreed (89%) or strongly agreed (11%).

With respect to researcher evaluation, the demonstration – which was also a test of the assumed conditions/performance applied in the first iteration of the risk estimation – was conceived as successful, and as such confirmed the assumptions in the risk reduction estimate.

5.7 Action 7-C: Firefighting resource management centre

The goal of Action 7-C is to “Develop and validate a firefighting resource management centre (FRMC) with improved design for critical operations in case of fire, reducing the potential for human error, accelerating time sensitive tasks and providing more comprehensive and effective decision support”.

5.7.1 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

The separation between Des5 and Des6 (and the RCMs in Action 7-A) was a separation that made sense at the time it was made. As work progressed, focus areas and division of work has changed. Most notably the development and presentation of a digital fire central is included in Des2 (Action 7-A). The performance assessment and solutions impact on safety from Des5 will therefore focus on the drone part of the action.

5.7.1.1 Problem definition and description of solution

The drone system developed as part of Des5 is presented in detail in D07.7 [10]. It deals with the problems of:

1. Reducing the time until fires are detected by automating fire patrols,
2. Maintaining an overview in emergency situations by providing a bird's-eye view,
3. Speeding up search & rescue missions by rapidly taking off into the direction where the person is suspected missing and flying an automated search pattern.

5.7.1.2 Method(s) of evaluation

A drone system prototype was developed using open standards, hardware & software during the course of the project. The prototype was demonstrated on-board and evaluated in the field to gather data for a technical feasibility analysis as well as video material for an online questionnaire. The online questionnaire was used to interview experts and analyse the usefulness of a drone system on board. Furthermore, a legal feasibility analysis was performed. The results for the feasibility and usefulness analyses combined were the bases for a SWOT analysis.

5.7.1.3 Performance assessment

[This text is a citation from the D07.7 abstract [10, p. 1]]

“Technical feasibility is assessed positively overall using a purpose-designed drone-control software, in-field tests and a demonstration onboard of DFDS Petunia Seaways. The needs for further development, analysis and long-term tests are described. The legal feasibility assessment gives an overview of applicable maritime and airspace regulations within the EU. It concludes that the drone system should be seen complementary to existing fire safety systems and that operational authorization is best applied for in collaboration with a ship owner. Usefulness is assessed using responses from maritime experts to an online questionnaire on the targeted use cases. Results are positive with two major challenges identified: achieving a reasonable selling price and obtaining the ship operators’ and crews’ trust in the system. Finally, a SWOT analysis gives a concise summary of the performed assessments and can be used as input to the strategic business planning for a potential drone system provider.”

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

Main author of the chapter: Martin Rasmussen Skogstad, NSR

5.7.2.1 Problem definition and description of solution

In Des6 three tools have been developed to deal with three specific problems:

- A comprehensive and exhaustive understanding of the firefighting management system is lacking. To deal with this problem we created an analysis that intends to capture all aspects of firefighting management, uncover potential gaps while still being easy to use.
- Fire drills are not utilizing their potential to prepare crews for a fire. To deal with this problem we created a system for systematic and creative modification of fire drills.
- Valuable knowledge could be obtained through an improved debrief after fire drills.

5.7.2.2 Method(s) of evaluation

All three tools were included in a test (note: technically a demonstration) at Centro Jovellanos in January 2023. D07.11 will include the full results of this test/demonstration (due for review 15.03.23). The plan is presented in D07.8 [11].

The demonstration was analysed and evaluated with respect to three aspects:

1. From the research perspective, did the work/activities played out in the simulation meet the training objectives as identified in the safety assessment?
2. From the perspective of the participants, how was the usability of the process experienced?
3. From the research perspective, what is the learning value of the tools developed?

5.7.2.3 Performance assessment

Evaluation of the three aspects from previous section:

1. Our evaluation as researchers was that we were able to capture the planned training objectives. This far superseded what is normally included in a fire drill, enabling the discussion on the added benefits of more comprehensive and complex drills.
2. This was evaluated through both discussions and feedback after the test/demonstrations and through an online survey completed by the participants after. Most of the participants had very positive feedback in terms of usability of the tools tested, and were very positive towards increasing the comprehensiveness and complexity of fire drills.
3. Our evaluation (and the expressed opinions of the participants) were that the tools could increase learning from fire drills.

It is very difficult to set a value on the safety impact of the tested solutions from Des6. We believe that they have the potential to improve safety work both in terms of thinking systematically and creatively about safety in general and firefighting management in particular. The tools would also have a very low cost as they are mostly improvements to processes that are already conducted.

 Ignition Prevention

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

The goal of Action 8-A is to *“Develop and demonstrate a technical solution for automatic screening of cargo to identify fire hazards and develop, utilize and experimentally validate a digital logistics management tool featuring risk-based load planning”*.

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

Main author of the chapter: África Marrero, CIM

5.8.1.1 Problem definition and description of solution

Nowadays, all cargo except dangerous goods (DG) is loaded without consideration to the hazards they pose, which leaves much room for fire prevention. Means need to be provided for screening of the cargo and also an objective way of managing the cargo based on the hazards they pose. Planned loading is although demanding and it is not clear how for example AFVs should compare to DG. General guidelines are necessary for how the different new cargo should be managed and what additional means could be necessary for certain cargo. Pre1a, Pre1b and Pre2 RCMs in combination shall address this gap based on historical information compiled in a fire cargo hazard database and exploited in terms of a risk assessment.

The fire cargo hazard database is a database where almost 20 relevant data fields from each incident has been collected. The fields for each accident include: the date and location of the incident, the severity, what goods the vehicle was transporting (if any), what goods were transported by nearby vehicles or if the origin vehicle was connected (and charging) when the ignition occurred. For those reports, extra information has been gathered such as the type of vessel (ro-ro, ro-pax or car-carrier), the deck (which one and type) or if the vessel was loading, on passage, or unloading. In those cases, where dangerous goods were involved, their International Maritime Dangerous Goods (IMDG) Code was also included in the database.

At the end of the process of data recompilation, about 230 records of fire accident in the cargo have been obtained; existing duplicates have been considered only once and have been assigned to that source where more detailed and accurate information was found.

At present, during the voyage, deck is monitored/patrolled by the ship's crew. All patrols are carried out by crew. They are expected to be trained to look for known issues and remain vigilant to detect unknown issues. 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 in the yard.

Pre1a: To be able to remotely monitor and survey cargo and vehicles. This includes the use of sensor technology in combination with statistical and machine learning to analyse different parts of the objects that are of interest to segment and analyse for heat signature anomalies. LASH FIRE Vehicle Hot Spot Detector (LFVHD) monitors the object as it enters the terminal or during loading, voyage and as it leaves the destination. This allows the operator(s) to minimize the risk of an undetected hot spot, that could lead to a larger fire. The system design, number of sensors will vary depending on ship type, deck type, terminal type, infrastructure types at terminal.

5.8.1.2 *Method(s) of evaluation*

LFVHD was installed at Stena Line terminal Majnabbe, where the VHD (Vehicle Hot Spot Detector) system scan all lorries, trucks and trailers to extract data and validate the system operation. Planning for a test with Stena Line shore and terminal crew is in the making and planned to take place during February and March 2023.

The plan is to run this test by the LFVHD gate at Majnabbe and compare with normal traffic of trailers and reefer-trailers, to find normal reefer AC-unit heat signature to be able to set warning and alarm levels for the LFVHD system.

5.8.1.3 *Performance assessment*

Tests carried out at Stena's Gothenburg terminal show that it is easy to detect anomalies in vehicles entering the ship. The tests at the terminal show 3D images of the vehicles and the temperature signature of each part of the vehicle. When the LFVHD detects a high temperature, it displays an alarm that is easily recognizable to the terminal operator.

The importance of installing the arc of sensors (LFVHD) in the ships' composites is emphasized, to ensure a better recording of the cargo independently of the terminal. The information extracted from LFVHD is useful to know the status of the cargo and in case of fire to know the status of the cargo when entering the ship. In case the cargo is in bad condition and has high temperatures, LFVHD helps in decision making (to let the cargo into the ship or not) so that we are reducing the risk of ignition of this cargo on board the ship.

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

Main author of the chapter: África Marrero, CIM

5.8.2.1 *Problem definition and description of solution*

See problem definition under section 5.8.1.1.

Based on ground-based drone, a concept system is being prototyped which might be able to detect heat signature from the undercarriage of an object. Automated guided vehicles (AGV) assist in both detection and early response. These vehicles in the event of an incident provide better situational awareness through live transmission of what is happening. The AGV sends a video signal and infrared information from sensors about the activities of personnel and the development of fires. Thanks to the AGV it is possible to scan a large number of loads and vehicles and thus detect possible anomalies.

5.8.2.2 *Method(s) of evaluation*

The AGV has been tested in three major categories:

- License plate detection - to determine type of transport.
- Navigation - to locate itself, perform obstacle avoidance, and move around the environment.
- Thermal sensing - to detect anomalous heat signatures.

The functionality tests have been performed both in a lab environment and in a parking garage to simulate some of the conditions expected on a ship's deck. The tests and results for license plate detection have been detailed in D08.9, while navigation and thermal sensing are detailed in D08.10.

5.8.2.3 *Performance assessment*

More details of the evaluation can be found in D08.9 and D08.10 with an excerpt presented here. The thermal coverage and setup were evaluated through a 3D modeling approach that can be seen in

Figure 9. It was determined that one thermal camera of the type Leption 3.5 should be capable of covering the undercarriage of most vehicles at the target ground clearance. Furthermore, the capability of the thermal sensor was tested in a lab environment where it could separate the temperature of a heated object from the ambient temperature in Figure 10.

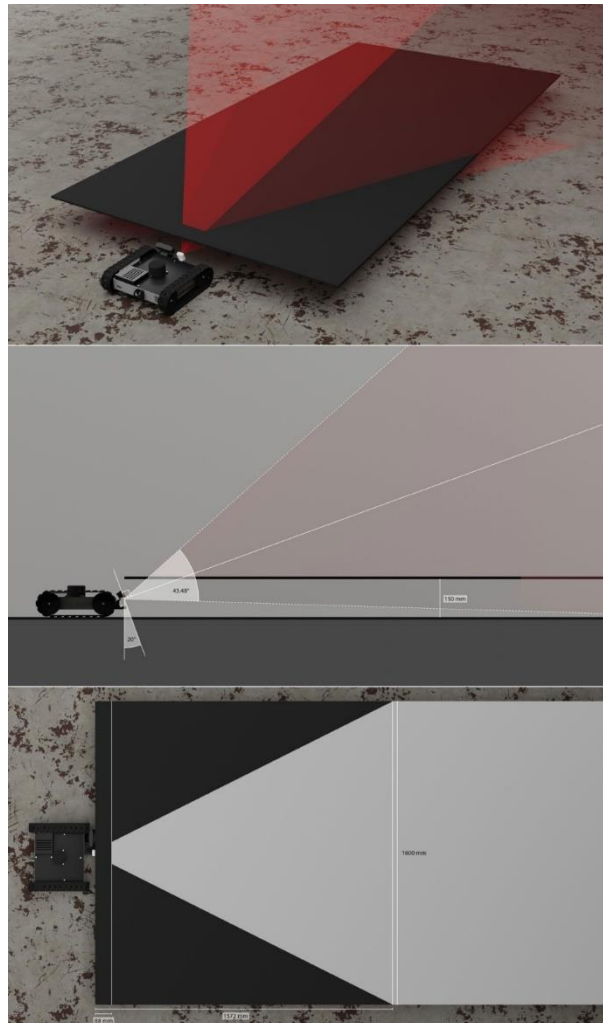


Figure 9. Coverage of a typical passenger vehicle's battery with the IR camera. Top: AGV approaches vehicle with a battery of 1.60m width and 15cm ground clearance. The red cone depicts the field of view (FOV) of the IR camera and how it intersects with the battery. Middle: The thermal sensor is mounted with a fixed angle of 20° on the AGV. It has a horizontal FOV of 57.1°, and a vertical FOV of 43.48°. Bottom: The intersection of the FOV cone with the battery shown in light grey. The full width of the battery is visible in the IR camera's frame at 157.2cm distance.

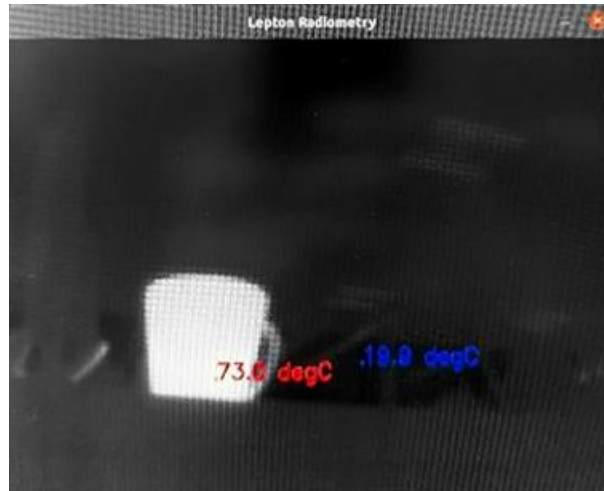


Figure 10. An example of the thermal sensor and its min and max temperature readouts. Here a cup filled with hot water is detected as 73 °C and a background object as 19.9 °C, representing the ambient temperature of the environment.

The navigation functionalities were demonstrated in a parking house as can be seen in Figure 11. The whole video can be found here: <https://youtu.be/YQ3OD3oGC38>. The AGV was able to navigate under a row of two cars, but issues were detected with the LiDAR used. It is common for 2D LiDARs to not be perfectly level in addition to uneven floors and drone chassi. These factors affect the detections from the LiDAR making it detect objects that does not exist by having a slight angle that makes it detect the undercarriage of a vehicle it is able to pass underneath. These are effects that need further attention in future work.

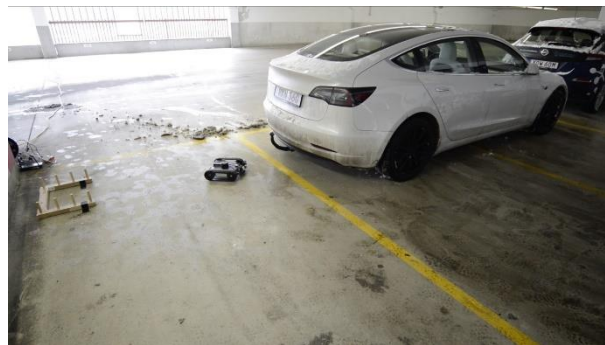


Figure 11. An example of the AGV navigating among vehicles in a parking house.

The license plate detection algorithm was tested on a smaller dataset with 108 images where 78 were correctly detected and classified, 28 were detected but not correctly classified and 2 were not detected at all. In Figure 12 a successful example is presented and an unsuccessful example can be found in Figure 13.



Figure 12. Correctly classified vehicle by OpenALPR. Image modified from [OpenALPR, 2017. Benchmarks. Available at: <https://github.com/openalpr/benchmarks> [Accessed 2023-03-14].



Figure 13. Failure to detect vehicle by OpenALPR. Image modified from [OpenALPR, 2017. Benchmarks. Available at: <https://github.com/openalpr/benchmarks> [Accessed 2023-03-14].

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

Main author of the chapter: África Marrero, CIM

5.8.3.1 Problem definition and description of solution

See problem definition under section 5.8.1.1.

The Stowage Planning Tool (SPT) is a software that supports cargo distribution in ro-ro spaces including fire hazard management. Placement of cargo can be carried out by taking advantage of generated knowledge by means of a risk assessment over the cargo units of the suggested stowage plan based on historical data coming from previous incidents.

The software calculates the risk score for a suggested stowage plan, being the output of the above-mentioned risk assessment. First, the intrinsic risk of the cargo units is calculated, which depends on the cargo types and the frequency and severity of reported incidents. Then, the score is updated for every single unit considering other units nearby; that is, the score can change depending on the specific location.

Since the score is a numerical value, the SPT basically tries combinations of placement for units (considering certain constraints) and, for each combination, the new resulting score value is calculated. The objective, then, is to provide the operators with an alternative stowage plan which, based on the risk assessment, has a lower score risk than the initially suggested and used as input together with other configuration parameters.

5.8.3.2 Method(s) of evaluation

To evaluate the SPT, laboratory tests and simulations have been planned to see how this software would affect the loading time of the vessel. In the next stages, demonstrations will be carried out with real users to validate the tool.

5.8.3.3 Performance assessment

The Stowage Planning Tool has proven in its laboratory tests to be robust and effective from the software engineering point of view.

Regarding the score feature, up to 14 tests have been defined to verify that the software is able to detect all the combinations (in terms of influence of nearby units over a specific one) that the risk assessment defines. These tests simulate different stowage plans for both ro-ro and ro-pax generic ships, where units are placed in various decks and cargo types are a mix of dangerous goods and other types that are relevant as per the risk assessment methodology. All tests have correctly evaluated the risk score of the whole ship and this has been verified in an automatic way using a reference database with expected results and comparing these expected results with the output of the software. Computational time required to run these tests can be measured in milliseconds.

The cargo distribution feature has been tested using the more complex of the previous tests. Using the previous feature as the function which value has to be minimized, the algorithm successfully returned a different cargo distribution with a lower risk in a reasonable computational time (just a couple of seconds using a virtual server).

It is difficult to predict the performance associated to the risk reduction (which is the main objective of the software) since the value of the optimal score is unknown. In other words, there is an intrinsic risk before loading the units which is equal to the sum of the initial risk scores (RS_0) for all the units but this value does not necessarily correspond to the optimal value.

The algorithm searches for a lower value for the risk score once the units have been placed in the decks (suggested stowage plan by the operators) which corresponds to the sum of the RS value for all the units. Also, RS value depends on the RS_0 value of the unit itself and all the nearby units in its area of influence, which at the same time, depends on physical distances that are configuration parameters, driving to an uncertainty respect to the optimal value.

As an example, the reference test includes 27 units with a total RS_0 value equal to 38 (which is not necessarily the optimal/minimum possible) and the placement of these units results on a total RS value of 46. After running the software, the output suggests a different distribution of the units where the total RS value is equal to 38,75.

More detailed information about the design, implementation, risk assessment methodology and testing can be found in D08.4.

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

The goal of Action 8-B is to “*Develop guidelines for safe electrical power connections in ro-ro spaces (refrigerated cargo units, charging of electrical vehicles, etc.), considering the design of electrical ship systems, equipment as well as operational procedures.*”.

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

Pre3 is presented together with Pre4 in section 5.9.2.

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

This section presents all solutions within Action 8-B, i.e., Pre3 and Pre4.

Main author of the chapter: Vasudev Ramachandra, RISE

5.9.2.1 *Problem definition and description of solution*

Statistics of electrical related fires and near miss cases on ro-ro and ro-pax ferries indicate a lack of early detection of anomalies. This is mainly due to human error which might fail to assess initial unexpected behavior on deck. While experiences and skills of personnel responsible on board contributes to preventing catastrophes, it is almost impossible to predict, detect a fire in its early stages or pinpoint the faulty reefer unit with the current measures in place. Even upon successfully ascertaining an anomaly, it is not possible to remotely disconnect a load. It requires a person to physically disconnect it, which in many cases might not be easy owing to smoke and heat from the fire. This opens a possibility for implementation of much safer fault monitoring systems on board for early detection of faults that lead to fires.

The proposed solutions (Pre3 and Pre4) are to predict possible fires or extreme electrical conditions using artificial intelligence (AI). With the knowledge of ideal behavior of electrical parameters of the load, in 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 a particular distribution box. These values will then be used to predict the future state of the load.

Pre3 “Develop guidelines for safe electrical power connections in ro-ro spaces for reefer units”:

Most of the loads that demand and consume power on the decks are ro-ro cargo and are mainly reefer units. With a rising popularity in electromobility, 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 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. This solution will also be open to implementation of communication architecture like reefer containers have today.

To effectively understand the behavior 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

The main benefits are:

- Early detection of anomalies during connection and operation of reefer units.
- Automatic disconnection of faulty unit if needed.

Pre4 “Develop guidelines for safe electrical power connections in ro-ro spaces for charging of EVs”:

The primary objective of this solution 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. The solution 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.

The main benefits are:

- Raising the knowledge of risks involved with alternative fueled vehicles and reefer units onboard ships by developing "Best practices".
- Early detection of anomalies during connection, charging of BEVs.
- Automatic disconnection of faulty unit if needed.

5.9.2.2 Method(s) of evaluation

The planned method of evaluating this solution is by initially setting up a test bed where the solution can be bench tested under various possible conditions. The testing is broadly planned in two phases.

The first phase is to assemble the hardware including all sensors, computer units, et cetera and to measure reference data on a normally operating reefer unit and 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 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.

For both solutions

- Preliminary test - Shore based test campaigns to collect data in a controlled environment.
- On board installation of the solution.

5.9.2.3 Performance assessment

With extreme delays in shipment of components leading to time constraints, the planned method of evaluation of first testing on shore and then onboard had to be modified. As different components were procured, they were tested and configured on shore and then tested as a part of the overall system onboard. A fully consolidated system, on which the risk reduction estimation is based on, is yet to be tested onboard as one full solution.

However, as components of the overall solution, the measurements and readings so far indicate very close similarities to the “expert judgement” which was considered for the risk reduction evaluation

(presented in D04.6 [12]). While several specific scenarios were considered for risk reduction evaluation, many of them cannot be tested on board due to possible dangerous outcomes. Forced electrical faults in reefer units, for instance, is suitable only under controlled environments on shore and since full fledged tests are not being conducted on shore anymore, these tests cannot be done onboard. In this regard, the reduction estimation shall depend on expert judgement but will be a more educated estimate based on all non-extreme measurements made with respect to the same reefers on board.

In a few cases of measurements on board so far, anomalies in certain reefers have been identified without having created it deliberately. Such measurements indicate that in case the anomaly was to be extreme, it would have still been detected by the solution, hence also supporting the previously made risk reduction estimation.

The evaluation shows that with the current solution, the entire spectrum of electrical parameters is constantly being monitored for every connected reefer unit thereby having a significant increase in the impact on safety.

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

The goal of Action 8-C is to *“Determine reaction to fire property requirements for non-regulated used new materials in surfaces of ro-ro spaces”*.

5.10.1 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: Vito Radolović, FLOW

5.10.1.1 Problem definition and description of solution

The usage of combustible materials, such as composite materials, has increased in maritime applications. Materials systems, both newly developed as well as the usage of products from other sectors is gaining popularity in the design of ro-ro spaces. However, there are no defined fire requirements for these materials. Such material systems include surface protection (fire retardant systems, intumescent coating systems, anti-skid coatings, low flame spread systems, etc.), insulation systems (ceramic fibre, spray-on insulation), non-regulated ro-ro space structural materials (composite material systems, plywood, etc.). 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.

New materials and usage of already existing materials from other sectors in ro-ro spaces will have an impact on the fire safety. There are several interesting solutions which are already well known in other industry sectors and which could be also widely used in the marine environment, in particular for ro-ro cargo spaces. Intumescent coatings, already widely used in offshore oil and gas industry for more than 20 years, could be one of the potential passive fire protection means as a replacement of the conventional insulation or to be used on critical points, such as gaps at ro-ro ramps/hatches, etc.

A step forward towards improving fire properties and reducing weight will be investigating new materials and technologies for structural application on ro-ro ships, as to replace conventional steel structure arrangement. Several composite components and combinations may be considered, including core type (known materials as PVC, PET, balsa, and other cores recently available on the market or under development), fibres (glass, carbon, basalt, hybrid, etc.) and composite products with improved fire properties such as multiaxial fabrics with integrated fire protection for structural parts with a fire-retardant surface layer.

In case of fire, the combustible materials will burn and contribute to fire development onboard. However, evaluating the fire performance of these materials and define requirements and guidelines will keep the fire safety at a high level.

The main benefits of the solution are:

- New material solutions for use in ro-ro spaces.
- Knowledge on material properties, the fire hazard and safety level.
- Establishment of fire test method for performance validation of material properties.

The objective of Action 8-C is to provide knowledge on material properties, fire risk and safety level for non-regulated material systems that are, or may be, used as surfaces within ro-ro spaces.

5.10.1.2 Method(s) of evaluation

A selection of relevant materials systems that can be used in ro-ro spaces (and other fields) were identified. Composite materials and related intumescent coating systems were selected for further evaluation.

Each selected material system will be tested according to IMO 2010 FTP Code, part 5 “*Surface flammability of bulkhead, ceiling and deck finish materials*” and IMO 2010 FTP Code, part 2 “*Smoke and toxicity test*”.

5.10.1.3 Performance assessment

Testing and evaluation of results are not performed at this stage but planned for April 2023. It is expected that in case of fire, the combustible materials will burn and contribute to fire development on board. Further, the usage of intumescent systems is expected to reduce the fire spread in the combustible material systems and in the development of fire.

As mentioned earlier that the objective of Action 8-C is to provide knowledge on material properties, fire risk and safety level for non-regulated material systems that are, or may be, used as surfaces within ro-ro spaces, therefore, no integration and cost assessment is performed.



Detection

5.11 Action 9-A: Detection on weather deck

The goal of Action 9-A is to *“Develop demonstrate and evaluate in full-scale means for quick and reliable detection on weather deck”*.

5.11.1 Det1: Flame wavelength detectors

Det1 is presented together with Det8 in section 5.11.2

5.11.2 Det8: Thermal imaging (infrared) cameras

This section presents all solutions within Action 9-A, i.e., Det1 and Det8.

Main author of the chapter: Davood Zeinali, FRN

The term “flame detectors” in this section generally refers to IR3 flame detectors and video flame detectors. The term “thermal imaging” in this section generally refers to the output of a fire detection system that uses a dedicated infrared camera as a detector for infrared heat (which is the main part of radiative heat from fires).

5.11.2.1 Problem definition and description of solution

Regulations currently do not require any fire detection systems for weather decks, but new regulatory developments and amendments are expected to soon make it mandatory to have a fire detection system in place. This is while weather decks do not have a deckhead or ‘ceiling’ structure. Therefore, fires on weather decks cannot be detected by means of conventional smoke detectors or heat sensors which are used in other ro-ro spaces. LASH FIRE Action 9-A is aimed at filling this fire detection gap by means of Det1 and Det8. The idea of Det1 and Det8 is to implement optical detectors such as flame detectors and thermal imaging cameras that can detect flames and heat from a long distance based on the emitted electromagnetic waves from the flames or hot surfaces and gases. The effective detection distance of these detectors varies depending on the size of the fire source, the sensitivity settings of the detector, and the transmissivity of the atmosphere between the fire and the detector. In addition, the detectors need to have free line of sight from the detector lens to the fire, and thus the identification of suitable mounting positions is important. The effect of extreme weather conditions on the detectors must also be considered. These are assessed as part of Action 9-A evaluations for Det1 and Det8.

5.11.2.2 Method(s) of evaluation

The evaluation of relevant detection technologies for weather decks proceeded firstly by searching for any available detection technologies and assessing each of them based on their theoretical working principle. From this long list of detection technologies, each detection method was evaluated against the constraints and conditions on weather decks and whether there were any suppliers that could provide systems for further evaluation and lab-scale testing. The outcome of this evaluation was that two different types of detectors are suitable for detection on weather decks. The two detectors are based on flame detection and thermal imaging.

Flame detection and thermal imaging solutions from different manufacturers were subsequently evaluated through laboratory fire experiments (see [13]). Both flame detection and thermal imaging showed reasonable results in the laboratory environment. However, these solutions implement an optical lens in their technology which may be covered by dirt, saltwater film, or ice on the weather deck, affecting their effectiveness for fire detection. Moreover, cargo loading and unloading

operations on board constitute possible sources of nuisance alarm based on observations from a previous study [14]. Subsequently, the promising detectors were installed on board a ship (Hollandia Seaways) to evaluate their performance under real operational and environmental conditions during different seasons in a year-long study. The systems were tested using a flare on board to confirm their fire detection capability after installation, and their subsequent performance was monitored remotely for over a year to analyse the sources of nuisance alarms and to fine-tune the detection settings accordingly. In addition, the systems were tested using a gas burner at the end of the evaluation period in March/April 2023 to assess their fire performance after having been on board for a year.

5.11.2.3 Performance assessment

The tested flame detectors performed very well in the laboratory experiments, rapidly detecting flames in their field of view. Nevertheless, the sensitivity for detection depends on the model and internal settings of the detectors. During the operational evaluations on board, flame detectors with triple-infrared (IR3) technology and one video flame detector performed well. The flare tests on board the ship confirmed that both the systems can rapidly detect flames in their field of view, while the systems did not produce a single nuisance alarm during the year-long operational study on board. After having been on board for a year, the detectors were still just as responsive when they were tested against a reference fire, i.e., a propane burner which was equivalent in size to a square-foot-sized heptane pool fire.

Two video fire detection systems (one of which was a hybrid system incorporating heat detection) were also tested on the weather deck. These produced several nuisance alarms in some months and no alarms in other months, and thus it was not possible to tune the sensitivity settings such that an acceptable monthly average of nuisance alarms could be achieved without losing adequate detection capability. Therefore, the tested video fire detection technologies cannot be considered mature enough for weather deck applications where light conditions are variable.

The thermal imaging cameras detected fires in their field of view very well in the laboratory experiments. They were also tested against the reference fire after having been on board for a year, and they were able to detect the fire as expected in general. One advantage identified for these detectors was their ability to detect hot surfaces caused by a concealed fire. Nevertheless, the detection threshold settings for the thermal imaging cameras must be adjusted according to the environment to avoid having frequent nuisance alarms. This proved to be challenging during the operational evaluations on board the ship where cargo loading and unloading produced frequent alarms by the thermal cameras. This was because the high temperature of exhaust mufflers of trucks is sometime identified as an imminent fire by the thermal cameras. The tuning of the detection settings helped reduce the frequency of alarms, but it appears that heat detection with the thermal cameras will continue to produce a minimum of 1 or 2 nuisance alarms per months, with potentially many alarms aggregated in certain months, even with the optimized settings. It is noteworthy that lowering the sensitivity of the system further is expected to render the system less useful for fire detection. Therefore, thermal imaging cameras are not recommended for weather deck applications.

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

The goal of Action 9-B is to *“Develop, demonstrate and evaluate in full-scale alternative and complementing means for quick and reliable detection on closed and open ro-ro spaces”*.

5.12.1 Det3: Video fire detection

Det3 is presented together with Det4 and Det7 in section 5.12.3.

5.12.2 Det4: Adaptive threshold settings for detection

Det4 is presented together with Det3 and Det7 in section 5.12.3.

5.12.3 Det7: Linear heat detection

This section presents all solutions within Action 9-B, i.e., Det3, Det4 and Det7.

Main author of the chapter: Davood Zeinali, FRN

The term “video fire detection” in this section generally refers to both Video Flame Detection (VFD) and Video Smoke Detection (VSD) which rely on the analysis of video footage for the recognition of flames and smoke, respectively.

The term “linear heat detection” in this section generally refers to the different types of linear heat detection systems (e.g., fibreoptic, electric, etc.).

The term “adaptive threshold settings” in this section generally refers to the use of different settings at different times, either automatically or manually, to adapt to the present operational conditions for optimal fire detection with fewer nuisance alarms.

5.12.3.1 Problem definition and description of solution

Conventional smoke detectors and heat sensors are commonly used in closed and open ro-ro spaces for fire detection. However, the response of point detectors may be significantly delayed depending on the distance of the fire to the nearest detector and the time it takes for the smoke to travel toward the detectors, which may be affected by the mechanical ventilation system on board. In open ro-ro spaces, another influential factor is wind, which may dilute or push the smoke away from the detectors such that detection becomes difficult and occasionally impossible. Furthermore, in open ro-ro spaces, exposure to harsher environmental conditions such as saline water, dirt, exhaust fumes, and frost can damage the detectors and lead to nuisance alarms. In addition, the estimated time for testing all the detectors on a large ro-ro ship is 2-4 weeks for 2 persons. Therefore, the point detectors require many hours of maintenance, testing, and device replacement work over the lifetime of the ship. LASH FIRE Action 9-B is aimed at addressing these shortcomings of the conventional point detectors by means of Det3 and Det7 which proposes to implement video analytics and linear heat detection systems. Video fire detection systems use video analytics to identify fires from a long distance, without the need for the transport of smoke or heat toward their sensor, while the linear heat detection systems can provide heat detection along the entire length of the deck using a strong sensor cable installed on the ceiling. These detection systems make it possible to improve the time required for fire detection, while they also require less maintenance work than point detectors. Accordingly, LASH FIRE Action 9-B evaluated these systems specifically for the environmental conditions on board ro-ro ships during different seasons for the development of the solutions.

In Det4, LASH FIRE Action 9-B evaluated the usefulness of adaptive threshold settings for detection. The adaptive settings essentially aim to keep the fire detection system active during operations such as cargo loading and unloading which are normally done with disabled detection systems. The adaptive detection settings are expected to lower the chances of nuisance alarms, thereby allowing the detection system to remain active during the operations mentioned earlier.

5.12.3.2 Method(s) of evaluation

A video fire detection system was firstly evaluated through laboratory experiments to see if it can recognize flames and smoke appropriately. The unit was based on a video analytics algorithm that analysed the video stream of a regular camera (no special detector unit was used). Based on this set of experiments, the video analytics algorithm was subsequently chosen for operational evaluations on

the closed deck of a ship (Hollandia Seaways). In addition, two alternative video fire detectors from other suppliers were installed on the weather deck where the variable light conditions are similar to those of open ro-ro decks.

Two different types of linear heat detection systems were also evaluated through laboratory experiments to see if they are suitable for heat detection in an environment resembling the ro-ro space. One system was based on a fibreoptic cable that allowed continuous temperature measurements along the cable, and the other one was based on an electric cable with electronic sensors embedded inside for temperature measurements at certain intervals. Followed by the experiments, one of the systems (fibreoptic) was installed on board a ship (Hollandia Seaways) to evaluate its performance under real operational conditions during a year-long study.

The threshold settings for detection were also evaluated for the systems installed on board over time to assess the possibility of using adaptive settings that could ensure an acceptable number of nuisance alarms during normal operations. In addition, the systems were tested using a reference fire at the end of the evaluation period to assess their fire performance after having been on board for a year. For the linear system tests, a propane burner was used as the reference fire source which was equivalent in size to a square-foot-sized heptane pool fire. For the video analytics system tests, a fog machine was used to produce artificial smoke which resembled real smoke very closely.

5.12.3.3 Performance assessment

The video analytics algorithm tested in the laboratory was able to recognize open flames and smoke visible to the camera. However, nuisance alarms were generated easily several times when the ambient light conditions were changed, e.g., when the gate to the test hall was opened. Accordingly, the tested algorithm was found to be only reliable for closed ro-ro spaces where the ambient lighting conditions are stable, so on board evaluations of this system were continued only on a closed deck (on Hollandia Seaways). Two alternative video fire detection systems (one of which was a hybrid system incorporating heat detection) were also tested on the weather deck where the variable light conditions are similar to those of open ro-ro decks, but it was not possible to tune their sensitivity settings such that an acceptable monthly average of nuisance alarms could be achieved without losing adequate detection capability. Therefore, the tested systems cannot be considered mature enough for such decks. On the closed deck, however, the system performed very well. The system adopted optimal flame and smoke zones in the video analytics software, avoiding vehicle lights and similar moving objects in the lower heights which would have otherwise triggered nuisance alarms. The system produced no nuisance alarms other than those produced from regular washdowns of the deck, such that water droplets landing on the lens of the camera were identified as smoke. This is expected to be acceptable as the crew can simply avoid the camera during the washdown or ignore its warnings during a washdown.

The two linear heat detection systems (electric and fibreoptic) could not be compared against each other directly because of their different default sensitivity settings which were not changed during the experiments. Nevertheless, the default settings allowed a higher number of fires to be detected by the fibreoptic system. Moreover, in cases where both the systems detected the fire, the detection time of the fibreoptic system was often shorter than that of the electric system. Based on these experiments and the limited resources available for further experiments on board a ship (Hollandia Seaways), only the fibreoptic system was prioritized for installation on board.

Implementing different (adaptive) threshold settings for detection became unnecessary for the systems installed on board the ship because of the very low rate of nuisance alarms. The video analytics algorithm in the closed deck only produced nuisance alarms when the crew did a routine washdown

of the deck. Similarly, the fibreoptic system produced nearly one alarm per month, but this is expected to be acceptable by the crew, although several detection settings were evaluated on board simultaneously, so it is still possible to use the best observed settings under different operational conditions if desired.

The final tests using a reference fire indicated that the systems which spent over a year on board were still responsive to flame and smoke as well as they were during the laboratory experiments. The linear system was able to detect the propane fire in scenarios where the point heat detectors did not activate after 15 min. Similarly, video analytics was able to detect the smoke produced by the fog machine based simply on its visual characteristics, whereas the fog machine did not trigger the point smoke detectors because the fog was just a heated mixture of water and glycol, not real smoke from a fire. All in all, linear heat detection systems are found to be very useful for fire detection in ro-ro spaces, especially for open decks where linear systems can perform better than conventional heat sensors, without triggering too many nuisance alarms. Moreover, video analytics is found to be very useful for closed ro-ro decks where light conditions are stable and just a few cameras can be used to cover a large distance for fire detection without triggering nuisance alarms.

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

The goal of Action 9-C is to *“Investigate and develop new and advancing technologies for automatic visual fire confirmation and localization”*.

5.13.1 Det5: Video fire detection

Det5 is presented together with Det6 in section 5.13.2.

5.13.2 Det6: Thermal imaging (infrared) cameras

This section presents all solutions within Action 9-C, i.e., Det5 and Det6.

Main author of the chapter: Davood Zeinali, FRN

The term “video fire detection” in this section generally refers to both Video Flame Detection (VFD) and Video Smoke Detection (VSD) which rely on the analysis of video footage for the recognition of flames and smoke, respectively.

The term “thermal imaging” in this section generally refers to the output of a fire detection system that uses a dedicated infrared camera as a detector for infrared heat (which is the main part of radiative heat from fires).

5.13.2.1 Problem definition and description of solution

Once a fire alarm is raised on board, the ship operators on the bridge must obtain a visual confirmation of the fire and its location before they can decide on the necessary actions. However, manual confirmation and localization of fires can be slow, unsafe, and sometimes impossible, as a fire can easily fill up spaces with smoke and make essential facilities unusable or inaccessible (e.g., lights, doors, etc.). LASH FIRE Action 9-C is aimed at making the confirmation and localization of fires safer and quicker by means of Det5 and Det6 which proposes to implement using visual systems such as video fire detection and thermal imaging systems.

5.13.2.2 Method(s) of evaluation

A video fire detection system was first evaluated through laboratory experiments to see if it can recognize flames and smoke appropriately. The unit was based on a video analytics algorithm that analysed the video stream of a regular camera. Based on this set of experiments, the video analytics algorithm was subsequently chosen for operational evaluations on the closed deck of a ship (Hollandia Seaways). In addition, two alternative video fire detectors from other suppliers were installed on the

weather deck where the variable light conditions are similar to those of open ro-ro decks. Furthermore, several large-scale fire extinguishment tests were performed at the lab in cooperation with WP10, which allowed investigating the usefulness of video cameras during fire suppression activities. Furthermore, several fire experiments were performed at the laboratory to evaluate the effect of wind on video cameras' perception of flames.

Thermal imaging solutions from different manufacturers were also evaluated through laboratory fire experiments. Thermal imaging showed reasonable results in the laboratory environment. However, the thermal camera lens may be covered by dirt, saltwater film, or ice, especially on the weather deck and in open ro-ro spaces, thereby affecting the system's effectiveness for fire confirmation and localization. The same issue applies to ordinary video cameras used for video analytics, but they are more likely to be used on closed decks where the environmental conditions are far better. Subsequently, the thermal imaging systems were installed on the weather deck of a ship (Hollandia Seaways) to evaluate their performance under real operational and environmental conditions during different seasons in a year-long study. In addition, the systems were tested using a gas burner at the end of the evaluation period to assess their fire performance after having been on board for a year. Moreover, several large-scale fire extinguishment tests were performed at the lab in cooperation with WP10, which allowed investigating the usefulness of thermal cameras during fire suppression activities. Furthermore, several fire experiments were performed at the laboratory to evaluate the effect of wind on thermal cameras' perception of flames.

5.13.2.3 Performance assessment

Regular cameras can provide live images that can be used to confirm and localize the fire by watching the footage. For a more systematic approach, a detection system can be used to highlight the fire area in the footage which can also be used in terms of coordinates for the autonomous fire extinguishment systems. The video analytics algorithm tested in the laboratory was able to highlight open flames and smoke visible to the camera. However, nuisance alarms were generated easily several times when the ambient light conditions were changed, e.g., when the gate to the test hall was opened. Accordingly, the tested algorithm was found to be only reliable for closed ro-ro spaces where the ambient lighting conditions are stable, so further evaluations of this system under real operational conditions were continued only on a closed deck (on Hollandia Seaways). Two alternative video fire detection systems (one of which was a hybrid system incorporating heat detection) were also tested on the weather deck where the variable light conditions are similar to those of open ro-ro decks, but it was not possible to tune their sensitivity settings such that an acceptable monthly average of nuisance alarms could be achieved without losing adequate detection capability. Therefore, the tested systems cannot be considered mature enough for such decks. On the closed deck, however, the system performed well. over a year of operational evaluations, and the final testing against a fog machine showed that the system was able to confirm and visualize the location of smoke, triggering an alarm in response, just as observed during the laboratory experiments with real fires. Two other video fire detection systems on the weather deck produced several nuisance alarms in some months and no alarms in other months, and thus it was not possible to tune the sensitivity settings such that an acceptable monthly average of nuisance alarms could be achieved without losing adequate detection capability. The large-scale fire extinguishment tests performed at the lab in cooperation with WP10 suggest that regular video cameras are most suitable for confirming and localizing the fire during the early stages of the fires (first minutes), but they become much less useful for continued monitoring of fire development later on, especially during fire suppression when a large amount of smoke is produced, effectively blinding the camera's view to the fire area. The experiments for the assessment of wind effects suggest that the flame itself occupies far fewer pixels in the footage of regular cameras compared to when there is no wind. However, reflections over other surfaces and the oversaturation of the image

sometimes makes the fire appear much bigger than it really is compared to when there is no wind. All in all, it is expected that strong wind will make it more challenging to confirm and localize fires using video analytics in a systematic way, but such video analytics is still found to be safer and more efficient than manual investigations around the fire area. Therefore, the use of regular video cameras together with video analytics is recommended as a viable solution for visual fire confirmation and localization.

The thermal imaging cameras tested in the laboratory experiments were able to detect the fires in their field of view very well. One advantage identified for these detectors was their ability to detect hot surfaces caused by a concealed fire. Nevertheless, the detection threshold settings for the thermal imaging cameras must be adjusted according to the environment to avoid having frequent nuisance alarms, although lowering the sensitivity of the system is expected to render the system less useful for fire detection. Similar to video fire detection systems, thermal imaging is able to highlight the location of the fire and can provide this in terms of coordinates to autonomous fire extinguishment systems. However, during the large-scale fire extinguishment tests performed at the lab in cooperation with WP10, it was noticed that the reflections of the fire on the wet floor or other shiny metallic surfaces were visible to the thermal camera which could be misinterpreted as secondary sources of fire, thereby distracting the resources of the autonomous fire extinguishment system and possibly the humans watching the footage. From that point of view, regular video cameras were affected less strongly, and they were easier to interpret by a human. Still, the thermal cameras were far more efficient for seeing through the smoke and for continued monitoring of fire development during fire suppression when a large amount of smoke was produced. Another advantage of the thermal cameras was that they allowed visualizing the location of persons in the fire area, whereas regular video footage did not provide the same degree and clarity of distinction. The experiments for the assessment of wind effects suggest that the flame occupies far fewer pixels in the footage of thermal cameras compared to when there is no wind. Accordingly, it is expected that strong wind will make it more challenging to confirm and localize fires using thermal imaging in a systematic way, but an analysis based on thermal imaging is still found to be safer and more efficient than manual investigations around the fire area. Therefore, the use of thermal imaging is recommended as a viable solution for visual fire confirmation and localization.



Extinguishment

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

5.14.1 Action goal

The goal of Action 10-A is to *“Develop and demonstrate feasible (cost and weight) high-efficient water-based local application fire-extinguishing system solutions for closed ro-ro spaces”*.

5.14.2 Ext1a: Dry pipe sprinkler system for ro-ro spaces on vehicle carriers

Main author of the chapter: Magnus Arvidson, RISE

5.14.2.1 Problem definition and description of solution

There is often a long delay time from the start of a fire to the discharge of the carbon dioxide system typically installed on board vehicle carriers. This is because time is needed to close the ventilation system, dampers, hatches and to confirm that no crew members are present in the protected spaces. The time delay may result in severe fire damage, as exemplified by the fires on board Courage (2015), Honor (2017), Höegh Xiamen (2020) and probably also Felicity Ace (2022). The RCM Ext1a is considered a complementary to the fixed-installed carbon dioxide system and is intended to provide rapid automatic activation and fast local fire suppression performance by the discharge of water. By suppressing or controlling a fire in its early stage, the probability for preventing the fire from escalating will improve, either by manual operations by the crew or by the discharge of Carbon Dioxide. The RCM Ext1a is based on common sprinkler components and equipment and is described in detailed design and installation guidelines.

5.14.2.2 Method(s) of evaluation

The choice and the fundamentals for the suggested design and installation guidelines of the RCM Ext1a was based on an extensive literature review and by input from WP05. The design of the system was thereafter evaluated in intermediate-scale fire suppression tests and later in large-scale performance validation tests. During the large-scale performance validation tests, some of the key installation features were evaluated, such as the installation of automatic sprinklers with respect to (obstructed) ceiling constructions.

5.14.2.3 Performance assessment

Field experience identified in the literature review indicated that fires in similar applications (such as underground parking garages) are successfully controlled by automatic sprinkler systems and that the systems are very reliable. The review did also identify a couple of fires in battery electric vehicles that was controlled by automatic sprinklers. Ro-ro vehicle spaces differs from underground parking garages in some respects; the number of vehicles per square meter is higher, larger vehicles are found and the ceiling heights are typically lower. These differences were addressed in the design and installation guidelines for the RCM Ext1a. The large-scale performance validation tests proved that the design and installation guidelines worked. The system activates at an early stage with few operating sprinklers, fire spread between vehicles are prevented or delayed and ceiling gas temperatures are reduced. The strength of the RCM Ext1a is that it relies on both long-term field experience, conventional and proven system components, and installation practices as well as the specific fire suppression validation tests.

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

The goal of Action 10-B is to “*Develop and demonstrate feasible and effective fire-extinguishment solutions for weather deck*”. There are four solutions within Action 10-B: Ext3, Ext3a, Ext4a and Ext4. The solutions have a shared problem definition, method of evaluation and performance assessment, and are therefore presented together in section 5.15.4.

5.15.1 Ext3a: Remotely-controlled fire monitor (water only) system for the protection of weather decks

Ext3a is presented together with Ext3, Ext4 and Ext4a in section 5.15.4.

5.15.2 Ext3: Autonomous fire monitor (water only) system for the protection of weather decks.

Ext3 is presented together with Ext3a, Ext4 and Ext4a in section 5.15.4.

5.15.3 Ext4: Remotely-controlled Compressed Air Foam fire monitor system for the protection of weather deck

Ext4 is presented together with Ext3, Ext3a and Ext4a in section 5.15.4.

5.15.4 Ext4a: Autonomous Compressed Air Foam fire monitor system for the protection of weather deck

This section presents all solutions within Action 10-B, i.e., Ext3a, Ext3, Ext4 and Ext4a.

Main author of the chapter: Magnus Arvidson, RISE

5.15.4.1 Problem definition and description of solution

Because fires on ro-ro weather decks grow in size and intensity extremely quickly, and ro-ro ships typically must be self-reliant on their own fire safety systems, the project aimed to seek state-of-the-art solutions that are not only fast-acting, but also effective, practicable, and cost-effective. Ro-ro weather decks present a number of challenges to both fire detection systems and fire suppression systems. Vehicles and cargo are tightly stowed which make any manual fire-fighting both difficult and hazardous. The lack of fire detection systems for weather deck could also delay the awareness of fire. All RCMs within Action 10-B represent state-of-the-art technology, and the design and installation of these system solution were expressed in design and installation guidelines developed in the project. Ext3 and Ext4a are autonomous systems, that will automatically detect and discharge the agent towards the fire. For Ext3a and Ext4 the fire monitors are remotely-controlled by an operator from a safe location. Independent of the RCM, the objective was that a fire should be safely and effectively fought.

5.15.4.2 Method(s) of evaluation

The autonomous function was evaluated in large-scale fire detection and precision tests. Fire suppression performance was evaluated in large-scale validation tests.

5.15.4.3 Performance assessment

In all fire detection and precision tests conducted, the autonomous system successfully proved the ability to rapidly detect a fire within less than 10 seconds of flame ignition, accurately determine the three-dimensional size and position, and successfully aim the water streams of the monitors to the fire location. The system also performed well in the simulated wind conditions when using a jet stream, the trajectory of which was not significantly affected. As expected, however, using a fog or cone spray pattern during the wind simulation proved ineffective due to the wind’s effect. To reduce the effect of wind conditions under actual conditions, it is suggested that any location of a ro-ro weather deck should be accessible by at least two fire monitors positioned at opposite sides of the deck.

The large-scale fire suppression tests showed that suppression of a fire in a simulated cargo trailer was possible using a single fire monitor discharging water at a late stage, simulating a fire monitor system remotely controlled by an operator. However, the use of two fire monitors improved fire suppression performance. Discharge of water at the early stage associated with an autonomous system prevented the fire from growing large, which will improve the probabilities for safe manual mop-up operations and limit fire damage. The use of Compressed Air Foam (CAF) was unsuccessful. This could be due to the foam characteristics, i.e., that the foam was too light (too 'dry') to penetrate the hot fire plume and flames or that the foam flow rate was too low.

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

The goal of Action 10-C is to *“Establish a harmonized performance level for alternative fixed water-based fire-fighting systems for ro-ro spaces and special category spaces”*.

5.16.1 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 Problem definition and description of solution

SOLAS Chapter II-2, Part G, Regulation 20, 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 complying with the provisions of the Fire Safety Systems Code (the FSS Code). The FSS Code refers to MSC.1/Circ.1430 [15], that supersedes previous requirements in IMO Resolution A.123 (V) and MSC.1/Circ. 1272 and contains design and installation requirements for prescriptive-based and performance-based (i.e., 'alternative') systems. Prescriptive-based systems should be designed per the design tables in MSC.1/Circ.1430, whilst performance-based systems should be tested to the satisfaction of the Administration in accordance with the fire test procedures in the appendix of MSC.1/Circ.1430 [15].

Concerns related to the performance of the performance-based option have been raised as the fire test procedures set a performance level that is only similar or slightly better than the performance of systems that used to be installed in accordance with Resolution A.123(V). The two primary inadequacies of the fire test procedures are that: 1) the fire test scenarios do not reflect the severity in terms of the fire load of modern vehicles and cargo and 2) the acceptance criteria in terms of the maximum allowed ceiling gas temperatures, fire damage and ignition of the targets were established with a water spray system designed per Resolution A.123(V).

5.16.1.2 Method(s) of evaluation

A review of actual fires on ro-ro ships was made. For several of the fires, the shielding effect by the body of the vehicle or trailer on water distribution by overhead sprinkler or nozzles is observed. Most of the fires documented in the fire investigation reports started inside the actual vehicle, a couple of fires in the review started on top of a lorry. Another observation is that used vehicles may be filled with combustibles (furniture, electrical appliances, clothing, etc.) that increase the fire load and the severity of a fire. It is apparent that the cause of fire due to failure in the electrical system on older vehicles is not uncommon. None of the fire investigation reports documented fuel spill fires from the vehicles. One case with a fire starting in an electric car was identified. The car was originally a conventional combustion engine car but had been rebuilt by the owner. The fire started during charging on board the ship.

New fire test scenarios representing fires in a passenger car as well as a freight truck trailer were developed. The principal design of the fire test scenarios resembled those used in the fire test procedures in the Appendix of MSC.1/Circ.1430, i.e., idle wood pallets were used as the primary fire load, but the aim was to generate more intense fires.

5.16.1.3 Performance assessment

Thereafter, benchmark tests were conducted with an automatic sprinkler system and a deluge water spray system designed per the prescriptive-based requirements in MSC.1/Circ.1430. It is concluded that the fire growth rate seems very repeatable. But for some of the tests, the fire was too severe for a meaningful fire test, which calls for a reduction of the fire load. It was also observed that the performance of the tested systems was to a large degree influenced by the position of the point of fire ignition relative to the nozzles/sprinklers at the ceiling.

The experience and outcome documented in the report D10.4 [16] will serve as the baseline for a revision of the fire test procedures in the Appendix of MSC.1/Circ.1430. This work will be documented in D10.5.



Figure 14. The ICEV1 fire size (left) at the most intense stage at about 03:30 [min:s] as compared BEV1 at the most intense stage at about 19:00 [min:s], viewed from a position in front of and behind the vehicle.

The increased use of electric vehicles has raised a concern about the performance efficiency of performance-based systems. A test series involving testing of two pairs of geometrically similar internal combustion engine vehicles (ICEV's) and battery electric vehicles (BEV's) under as equal test conditions as possible were conducted. Fire ignition was arranged to initiate fire in such a way that the liquid fuel or the battery pack was involved at the initial stage of the fire. It is concluded that a fire in the two types of vehicles is different but share similarities. However, a fire in a BEV does not seem to be more challenging than a fire in an ICEV for the drencher system performance-based design given in MSC.1/Circ.1430.



Containment

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

The goal of Action 11-A is to “*Develop and demonstrate artificial and new means for fire integrity sub-division of ro-ro spaces*”.

5.17.1 Cont1b1: A-30 fire insulation

Cont1b1 is presented together with Cont1b2 in section 5.17.2.

5.17.2 Cont1b2: Extinguishing system simultaneously activated above and below sub-dividing deck

Main author of the chapter: Anna Olofsson, RISE

This section presents both Cont1b1 and Cont1b2.

5.17.2.1 *Problem definition and description of solution*

The fire integrity of decks separating ro-ro spaces from other cargo or accommodation spaces on ro-ro passenger ships is required to be A-60 (>36 passengers) and A-30 (<36 passengers). A-30 is required for ro-ro cargo ships and vehicle carriers. Ro-ro spaces can also be designed with several internal decks, sub-dividing the spaces horizontally, for which no fire integrity requirements apply.

Without thermal fire insulation a fire can spread horizontally between internal sub-spaces within minutes. Both Cont1b1 and Cont1b2 are solutions that propose to address this by creating horizontal subdivisions containing heat and smoke in case of fire in a ro-ro space.

5.17.2.2 *Method(s) of evaluation*

For Cont1b1, computer simulation using Computational Fluid Dynamics (CFD) were conducted and results from tunnel fire tests were analysed to obtain a plausible heat exposure from a fire that can be faced in a ro-ro space. The temperatures of the analysed fire scenarios were compared with time-temperature curves used in standardized fire testing and approval of thermal insulations.

Experimental tests were conducted using type approved thermal insulation of different kinds and expose the insulation for different time-temperature curves. Different thermal insulations (stone wool and glass wool) were tested with several steel plate thicknesses (5, 6 and 12 mm), representing different uses of the ro-ro space.

Since Cont1b2 “Extinguishing system simultaneously activated above and below sub-dividing deck” is already possible to achieve with existing systems on board no further validation was performed.

5.17.2.3 *Performance assessment*

For most of the simulated scenarios the highest temperatures in the space were in better agreement with the hydrocarbon time-temperature curve than the standard (ISO 834, cellulosic) time-temperature curve.

For Cont1b1, the experimental tests showed a considerably reduced fire integrity of approved thermal insulation when exposed to the standardized hydrocarbon (HC) time-temperature curve compared to exposure to the cellulosic time-temperature curve (ISO 834). The protection time was reduced around 50% (conditional on the thickness of the steel plate) for thermal insulation based on stone wool, when exposed to a hydrocarbon heat exposure (realistic for ro-ro spaces based on the CFD simulations). Glass wool thermal insulation was impaired when exposed to the HC time-temperature curve.

Cont1b2 was not evaluated with experiments or tests. From ship integration perspective, the proposed solution was evaluated in theoretical terms. To simultaneously active extinguishing system above and below sub-diving deck will improve the safety level of the ship. The operation of the system was assumed to increase slightly in complexity.

5.17.3 Cont3b: Solid curtain, transversal mounting, fully rolled down

Cont3b is presented together with Cont3d in section 5.17.4.

5.17.4 Cont3d: Solid striped curtain, transversal mounting, fully/partly rolled down

Main author of the chapter: Anna Olofsson, RISE

This section presents both Cont3b and Cont3d.

5.17.4.1 *Problem definition and description of solution*

Cont3b and Cont3d propose to create vertical subdivisions containing heat and smoke in case of fire in a ro-ro space.

A ro-ro space is normally extending for the whole length of the ship, or at least a substantially length of the ship. From a fire spread perspective, the long ro-ro spaces are a challenge since the lack of subdivisions allow a fire to spread from cargo to cargo and in worst case along the whole vessel. Such a fire can be devastating for the crew and for the safety systems to handle. This makes the vertical subdivision containing smoke and heat extremely relevant. Therefore the solution of curtains was investigated as subdividers to prevent huge fire spread and uncontrolled fires.

5.17.4.2 *Method(s) of evaluation*

Cont3b was evaluated with a brief literature review for the theory of fabric curtains used for containment. That was followed by reduced scale fire tests to evaluate smoke shielding effectiveness of a solid curtain. Also, an onboard demonstration was conducted to assess feasibility and installation performance.

Cont3d was evaluated with a brief literature review for the theory of fabric curtains used for containment. That was followed by a large-scale setup with one curtain segments covering each lane in a ro-ro space. The test series was designed to determine effect of different loading scenarios (i.e., fully, or partly rolled down) and to evaluate the ability for persons to pass a rolled down curtain. Also, an onboard demonstration was conducted to assess feasibility and installation performance.

5.17.4.3 *Performance assessment*

The reduced scale tests suggest that a solid fabric curtain stops the smoke without disturbing smoke stratification downstream the curtain. The test also indicates that a solid curtain does not strongly affect the heat release rate (HRR). A solid fabric curtain blocks the radiation completely as the curtain is opaque. In practise, however, this total block may be hard to achieve since the fitting of a curtain inside a ro-ro space may require gaps on each side.

Both tests (reduced and large scale) show that a fabric curtain that is fully rolled down results in successful subdivision of a ro-ro space in term of shielding of hot smoke. A curtain that is partly rolled down is not as effective subdivider as a the fully rolled down.

The feasibility assessment onboard demonstrated clearly that fitting a curtain solution on existing vessels will be very challenging due to all ceiling mounted equipment and layout of girders. For newbuild ships the solution with a fabric curtain cause complexity of deck arrangement but are considered feasible.

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

The goal of Action 11-C is to *“Develop ro-ro space openings design guidelines by assessment of the risks of smoke and heat transfer from ro-ro space openings to life-saving appliances, adjacent areas and ventilation inlets”*.

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

Cont9 is presented together with Cont10 in section 5.18.2.

5.18.2 Cont10: Safety distances between side and end openings and critical areas

This section presents all solutions within Action 9-C, i.e., Con9 and Cont10.

Main author of the chapter: Tuula Hakkarainen, VTT

5.18.2.1 Problem definition and description of solution

In case of a fire in an open ro-ro space, smoke can emerge out of the side and end openings of the ro-ro space so that it transfers to critical areas such as assembly stations, LSA stowage areas and external evacuation routes. This can make these areas unusable and thus endanger safe evacuation.

Both Cont9 and Cont10 address the same problem but in different ways. Cont9 is an operational means: changing the course of the ship to a favourable direction. Cont10 is related to ship design and arrangements, i.e., positioning of ro-ro space openings and LSAs involving passengers. In both cases, the goal is to avoid the exposure of people evacuating and LSA materials to untenable conditions.

5.18.2.2 Method(s) of evaluation

Simulations of fires in ro-ro spaces of two generic ships were performed using Fire Dynamics Simulator (FDS) software to study heat transfer and smoke spread from ro-ro space side and end openings to critical areas. Several simulations with different fire locations and wind conditions were performed. Safety performance criteria for radiant heat flux, gas temperature, visibility and CO concentration were set to evaluate whether an area can be considered safe. In the simulations, the physical quantities used as performance criteria were monitored. The areas of interest such as LSAs, embarkation stations and ventilation inlets were monitored for these quantities both pointwise and in planes. In addition, the results were illustrated and evaluated using the Smokeview visualization program.

5.18.2.3 Performance assessment

Cont9 *“Ship manoeuvring/operation to limit the effect of fire at least in critical areas”*:

By analysing the results using the Smokeview visualization program, it was clearly seen that selecting a favourable course taking into account the assumed wind conditions, at least a part of the critical areas can be kept free of smoke, making them usable for safe evacuation. Thus, the analysis of the simulation results showed that manoeuvring can be used to direct smoke away from the critical areas in case of fire if navigation and weather conditions are favourable. Successful manoeuvring/operation of the ship in a beneficial direction to direct smoke away from the critical areas ensures that at least a part of the embarkation stations, LSAs and external evacuation routes can safely be used for evacuation in case of a ro-ro space fire. It should be noted, however, that manoeuvring can be impossible due to a blackout and that while side wind is favourable in terms of avoiding smoke, it might be in contradiction with safe evacuation procedures [17].

High-level general guidance for manoeuvring in case of a fire in an open ro-ro space was formulated. Recommended actions to support the selection of a beneficial course were given [4].

It is noted that since this guidance is on a general level, ship-specific instructions and procedures need to be developed on the basis of the recommendations given. More detailed guidelines should be prepared for each ship individually, to assist the ship's Master in a possible emergency.

The evaluation of manoeuvring guidelines was conducted by the crew of Stena Jutlandica. The proposed level of detail in the manoeuvring recommendations was found good. It was noted that the choice of heading is Master's decision considering fire situation, navigational and traffic conditions, evacuation/airlift activities and location of closest safe port. The crew is generally well aware of the need to select best possible heading in emergency, but it can be of good value to publish a guideline further emphasizing this and suggest strategies. Each vessel needs to interpret the generic guideline to the configuration of the ship and establish specific instructions down to an appropriate detail level [18].

Cont10 "Safety distances between side and end openings and critical areas":

By analysing the radiant heat flux, gas temperature, visibility and CO concentration values from the set of simulations and comparing them with the safety performance criteria, it was found that implementing safety distances is an effective and reliable method for controlling the risks due to heat transfer and smoke spread. Areas were identified where the defined gas temperature, radiant heat flux and CO concentration limits were not exceeded and visibility did not go below the defined limit. When the distance from openings to critical areas (such as embarkation stations and LSAs) is sufficient, the critical areas remain safe in case of a fire, and the safety of evacuation is supported [17, 4].

It is noted that the obtained simulation results, and thus the proposed safety distances, are dependent on the assumptions made about the ship's geometry, the size of the fire, environmental conditions, and operational procedures [17].

A small-scale fire test series assessing the critical heat flux for ignition for a selection of materials used in life-saving appliances (LSA) was performed. The critical heat fluxes measured were of the same order of magnitude as the critical limits assumed in simulations. Furthermore, to validate simulation results, large-scale testing was undertaken to provide comparative temperature and radiation measurements for a fire plume from an opening. Although general trends were similar, the experimental results did not provide a close correlation with the simulation results, due to smaller fire source in the tests compared to the simulated fire and differences in geometry [17].

The definition of proper safety distances between ro-ro space openings and critical areas is challenging, requiring further research and validation work. In the future, it might be possible to use either prescriptive values defined in IMO regulations or ship-specific values based on alternative, performance-based design. The alternative approaches for defining suitable safety distances could be either analytical calculation tools or advanced computational methods (such as Computational Fluid Dynamics (CFD) models). In any case, such tools need to be well validated and approved [19].

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

The goal of Action 11-D is to *"Determine the effects of natural and mechanical ventilation on fire development and evaluate current possibilities and new measures for smoke containment"*. There are three solutions within Action 11-D: Cont11, Cont13 and Cont14. Cont13 and Cont14 have a shared problem definition, method of evaluation and performance assessment, and are therefore presented together in section 5.19.3.

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

Main author of the chapter: Stina Andersson, RISE

5.19.1.1 Problem definition and description of solution

Cont11 addresses the need of a clarification of the term “permanent openings” in the SOLAS definition of different ro-ro spaces and forming a guidance of how to calculate the (area) percentage of permanent side opening 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)
- *Closed ro-ro spaces are ro-ro spaces which are neither open ro-ro spaces nor weather decks.* (SOLAS II-2/3.12)
- *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)

The part of the definition describing permanent openings and the area of these, marked with bold in the text above, is open to interpretation. “Permanent openings” could, in this context, be understood as ventilation outlets and relate to any type of ro-ro space, not only open decks. This is however in need of being defined in the rules for a common understanding of what is included in “permanent openings”.

There is currently no internationally accepted best practice for what to include in the calculation of the opening percentage. This might cause differences in how the calculations are made for ships followed by different class interpretations.

5.19.1.2 Method(s) of evaluation

As Cont11 is a suggested method of calculation and not a technical system to be implemented onboard it was decided to not evaluate the solution further.

5.19.1.3 Performance assessment

It is deemed that a unified understanding of the term “permanent opening” will facilitate the design of ro-ro ships. It will also help to avoid misunderstanding about different types of ro-ro spaces.

5.19.2 Cont13: Tactical guidelines for manual interventions

Cont13 is presented together with Cont14 in section 5.19.3.

5.19.3 Cont14: SOLAS requirement of reversible fans

Main author of the chapter: Stina Andersson, RISE

This section presents both Cont13 and Cont14.

5.19.3.1 Problem definition and description of solution

There are currently no guidelines for how to manage the mechanical ventilation in case of a fire in a ro-ro space. The current praxis is to shut off the ventilation and close fire dampers when a fire is confirmed. Crew members have expressed a desire to better understand if and how the mechanical ventilation can be used to facilitate the onboard firefighting in ro-ro spaces. The design and set up of the ventilation system varies between ro-ro spaces and ventilation is of great importance for the fire

growth rate, intensity and fire duration in ro-ro spaces. Therefore, it is important for crew to practice and understand the risks and opportunities for using mechanical ventilation during a fire.

Cont13 and Cont14 addresses this issue by providing guidance which covers risks and opportunities of using mechanical ventilation in a closed ro-ro space during a fire.

5.19.3.2 Method(s) of evaluation

The solutions have been evaluated through a study visit, interviews, computer simulations and a model scale fire test.

The study visit, and interviews were conducted for understanding the crews' view on introducing a ventilation management strategy for fire scenarios in ro-ro spaces.

Computer simulations in Fire Dynamic Simulator (FDS) were carried out to investigate how mechanical ventilation affects a fire scenario in a ro-ro space. Reversible fans were simulated as well to analyse the potential benefits of having reversible fans depending on fire location. The simulations were followed by model scale fire tests in a lab, in which the effect of mechanical ventilation was investigated further. The use of mechanical ventilation during a fire has been evaluated for fires corresponding to one car burning (5 MW).

The result from the simulations and the model scale test was used to develop a guideline for mechanical ventilation in closed ro-ro spaces in case of fire. The guideline aims at increasing the understanding for if, and how, mechanical ventilation can be used during the early phase of a fire event. The guideline was sent out to ro-pax crew during March 2023 and their feedback was incorporated into the guideline.

5.19.3.3 Performance assessment

The simulations confirm that the visibility improves when smoke from a burning car close to an exhaust fan is vented away. The model scale tests also showed that mechanical ventilation can reduce smoke density inside a closed ro-ro space, thus improving the visibility. This in turn would facilitate manual firefighting. Switching fans off is the best alternative to reduce the fire intensity but generates worse visibility conditions. If the fire grows beyond one car burning (5 MW), the current praxis of shutting down the ventilation is not challenged.

6 Selected and Defined Risk Control Options

Main author of the chapter: Stina Andersson, RISE

One of the objectives in LASH FIRE is to select and define risk control options and then perform a cost-effectiveness assessment for these. 16 RCOs were selected and defined amongst the 41 RCMs. The selection and definition process is reported in D04.6, which also presents the cost-effectiveness assessment [12]. Table 1, adapted from D04.6 [12, p. 20], summarises which RCMs were converted into RCOs. Some RCOs are a combination of several RCMs.

Table 1. List of the 16 selected Risk Control Options (RCOs). Adapted from LASH FIRE report D04.6 "Cost-effectiveness assessment report", p. 20.

WP	ID	RCM(s) of origin	Title of Risk Control Option (RCO)	TRL
06	RCO 1	Op1, Op4	Improved fire patrol. Improved fire confirmation & localization	5
	RCO 2	Op3	Improved signage and markings for effective wayfinding and localization	5
	RCO 3	Op5	Developed efficient first response	6
	RCO 4	Op7	Developed manual firefighting for Alternatively Powered Vehicles	6
07	RCO 5	Des2	Alarm system interface prototype	6
	RCO 6	Des3	Process for development of procedures and design for efficient activation of extinguishing system	6
	RCO 7	Des4	Training module for efficient activation of extinguishing system	5
08	RCO 8	Pre3	Safe electrical connection for reefers	6
	RCO 9	Pre4, Pre3	Safe electrical connection of reefers and electric vehicles (EVs)	6
09	RCO 10	Det1, Det8	Fire detection on weather decks	7
	RCO 11	Det7	Alternative fire detection in closed ro-ro spaces & open ro-ro spaces	7
	RCO 12	Det5, Det 6, Det8	Visual system for fire confirmation and localization	7
10	RCO 13	Ext1a	Dry-pipe sprinkler system for vehicle carriers	6
	RCO 14	Ext3a	Fixed remotely-controlled fire monitor system using water for weather decks	6
	RCO 15	Ext3	Fixed autonomous fire monitor system using water for weather decks	6
11	RCO 16	Cont13, Cont14	Guideline for fire ventilation in closed ro-ro space	4

6.1 Summary of Risk Control Options impact on safety

Each RCO’s impact on safety has been assessed quantitatively in D04.6 [12]. Table 2 summarizes the performance assessment made in LASH FIRE by giving an overview of the part(s) of the fire protection chain (cf. section 4) where it has been established that the specific each RCO has a positive impact on safety. For details about the quantitative assessment for each RCOs, see D04.6 [12].

Table 2. Summary of risk control options impact on safety.

Prevention	Detection	First Response	Decision	Extinguish-ment	Containment	Evacuation
RCO1: Improved fire patrol. Improved fire confirmation & localization						
X	X	X	X			
RCO2: Improved signage and markings for effective wayfinding and localization						
			X		X	
RCO3: Developed efficient first response						
	X	X	X			
RCO4: Developed manual firefighting for Alternatively Powered Vehicles						
			X	X		
RCO5: Alarm system interface prototype						
			X	X	X	
RCO6: Process for development of procedures and design for efficient activation of extinguishing system						
			X			
RCO7: Training module for efficient activation of extinguishing system						
			X			
RCO8: Safe electrical connection for reefers						
X			X	X		
RCO9: Safe electrical connection of reefers and electric vehicles (EVs)						
X			X	X		
RCO10: Fire detection on weather decks						
	X		X	X		
RCO11: Alternative fire detection in closed ro-ro spaces & open ro-ro spaces						
	X		X	X	X	
RCO12: Visual system for fire confirmation and localization						
			X	X		
RCO13: Dry-pipe sprinkler system for vehicle carriers						
			X	X		
RCO14: Fixed remotely-controlled fire monitor system using water for weather decks						
			X	X	X	
RCO15: Fixed autonomous fire monitor system using water for weather decks						
	X			X	X	
RCO16: Guideline for fire ventilation in closed ro-ro space						
				X		

7 Conclusion

Main author of the chapter: Stina Andersson, RISE

This deliverable is a summarising report of the safety impact of the solutions that have been developed and demonstrated within the LASH FIRE project. The solutions are both operational and technical in nature and cover the whole fire protection chain (ref. section 4). To assess the solutions' performance and impact on safety, the solutions have gone through different types of evaluation. This report presents an overview of all solutions, their method of evaluation and the outcome of the evaluation. A few solutions have not yet been evaluated at this stage. For these solutions, the planned evaluation has been described. It should be noted that the information in this deliverable gives a glimpse of the work conducted for each solution. For more information about each solution, please refer to WP specific deliverables.

This deliverable will provide external parties with information about the safety impact of the solutions that have been shown through the demonstration work carried out by D&D WPs in LASH FIRE. In doing so, this deliverable will contribute to the dissemination of all D&D WPs in LASH FIRE.

This deliverable contributes to 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”*.

It also contributes 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”*.

As a next step, the on-going or planned evaluation will be finalised. The outcome of the D&D work within LASH FIRE will continue to be disseminated through different channels.

8 References

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ANNEXES

ANNEX A: Summary of solutions and their method(s) of evaluation

A summary of all developed and demonstrated solutions and their method of evaluation is presented in Table 3. The listed method of evaluation is a brief summary (key words) of the text presented for each solution in the report.

Table 3. Summary of solutions and their method(s) of evaluation. For more details about the method(s) of evaluation, see report.

WP	Action	ID	Title of solution	Ship type ⁽¹⁾	Ro-ro spaces ⁽²⁾	Method(s) of evaluation	TRL
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	Demonstrated and validated on board a ro-pax ship.	5
		Op2	Manual screening of cargo at port before the loading operations	Ro-Pax, Ro-Ro	CRS, ORS, WD	Demonstrated and validated on board two ro-pax ships.	5
	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	Demonstrated and validated on board two ro-pax ships.	5
		Op4	Guidelines for the standardization and formalization of manual fire confirmation and localization	Ro-Pax, Ro-Ro, VC	CRS, ORS, WD	Demonstrated and validated on board a ro-pax ship.	5
	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	Tested through a training module, developed in Jovellanos Training Centre that belongs to SASEMAR.	6
		Op6	Technology for localization of first responders through digital information processed via network	Ro-Pax, Ro-Ro, VC	CRS, ORS, WD	Validated through a remote study on board a ro-pax ship and through extensive laboratory testing with video traces from the given ship.	6
	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	Demonstrated and validated in relevant environment (fire ground of the Jovellanos Training Centre of SASEMAR).	6

07	7-A	Des1	User friendly alarm system interface design guidelines	Ro-Pax, Ro-Ro, VC	CRS, ORS, WD	Iterative evaluation through development in collaboration with ro-pax newbuild projects. Planned workshop with shipping company representatives.	8
		Des2	Alarm system interface prototype	Ro-Pax, Ro-Ro, VC	CRS, ORS, WD	Experimental session at a shipowner's headquarters, using a simulated fire scenario.	6
	7-B	Des3	Procedures and design for efficient extinguishment system activation	Ro-Pax, Ro-Ro, VC	CRS, ORS, (WD)	Demonstrated on board a ro-ro ship.	6
		Des4	Training module for activation of extinguishment systems	Ro-Pax, Ro-Ro, VC	CRS, ORS	Demonstrated in the Jovellanos Training Centre. Participants contributed to the evaluation of the solution through a survey after the course.	5
	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	Demonstrated on board and with field evaluation. Analysed through usefulness and legal feasibility analysis. SWOT analysis based on the results from the feasibility and usefulness analyses.	6
		Des6	Guidelines for organizing the response in case of a fire emergency	Ro-Pax, Ro-Ro, VC	CRS, ORS, WD	Tested/demonstrated at Jovellanos Training Centre.	6
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	Installed at terminal to validate the system operation. Planned test with Stena Line shore and terminal crew.	7
		Pre1b	Automatic screening and management of cargo fire hazards by means of Automated Guided Vehicles	Ro-Pax, Ro-Ro, VC	CRS, ORS, WD	Planned test and demonstration ashore.	6
		Pre2	Stowage planning tool with optimization algorithm for cargo distribution	Ro-Pax, Ro-Ro, VC	CRS, ORS, WD	Laboratory tests and simulation.	4

						Planned tests with real users to validate the tool.	
	8-B	Pre3	Develop guidelines for safe electrical power connections in ro-ro spaces for reefer units	Ro-Pax, Ro-Ro	CRS, ORS, WD	Preliminary test - Shore based test campaigns to collect data in a controlled environment. On board installation of the solution.	6
		Pre4	Develop guidelines for safe electrical power connections in ro-ro spaces for charging of EVs	Ro-Pax	CRS, ORS, WD	Same as for Pre3.	6
	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)	Planned testing of selected material system according to IMO 2010 FTP Code, part 5, and IMO 2010 FTP Code, part 2.	N/A ⁽³⁾
09	9-A	Det1	Flame wavelength detectors	Ro-Pax, Ro-Ro, (VC)	WD, (CRS), (ORS)	Laboratory fire experiments. On board installation in a year-long study. On board flare test. Planned on board gas burner test.	7
		Det8	Thermal imaging (infrared) cameras	Ro-Pax, Ro-Ro	WD	Same as for Det1.	7
	9-B	Det3	Video fire detection	Ro-Pax, Ro-Ro, VC	CRS	Laboratory experiments. Operational evaluation in closed space.	7
		Det4	Adaptive threshold settings for detection	Ro-Pax, Ro-Ro, VC	CRS, ORS, WD	Evaluated through the systems (e.g., Det3, Det7) installed on board.	1
		Det7	Linear heat detection	Ro-Pax, Ro-Ro, VC	CRS, ORS	Laboratory experiments. On board installation in a year-long study.	7
	9-C	Det5	Video fire detection	Ro-Pax, Ro-Ro, VC	CRS	Laboratory experiments. On board installation in closed space.	7

						Evaluation through large-scale lab fire extinguishment tests and laboratory fire experiments.	
		Det6	Thermal imaging (infrared) cameras	Ro-Pax, Ro-Ro	WD	Laboratory fire experiments. On board installation in a year-long study. Large-scale lab fire extinguishment tests and laboratory fire experiments. On board gas burner test planned.	7
10	10-A	Ext1a	Dry pipe sprinkler system for ro-ro spaces on vehicle carriers	VC	CRS	Literature review. Intermediate-scale fire suppression tests. Large-scale fire suppression validation tests.	6
	10-B	Ext3a	Remotely-controlled fire monitor (water only) system for the protection of weather decks	Ro-Pax, Ro-Ro	WD	Large-scale fire detection and precision tests. Large-scale fire suppression validation tests.	6
		Ext3	Autonomous fire monitor (water only) system for the protection of weather decks	Ro-Pax, Ro-Ro	WD		6
		Ext4a	Autonomous Compressed Air Foam fire monitor system for the protection of weather deck	Ro-Pax, Ro-Ro	WD		6
		Ext4	Remotely-controlled Compressed Air Foam fire monitor system for the protection of weather deck	Ro-Pax, Ro-Ro	WD		6
	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	Review of actual fires on ro-ro ships. Development of revised fire test scenarios. Benchmark fire tests. Drencher system fire tests comparing the fire suppression performance for gasoline-fuelled and battery electric vehicles.	4

						Drafting of a revised fire test standard.	
11	11-A	Cont1b1	A-30 fire insulation	Ro-Pax	CRS, ORS	CFD simulations. Experimental tests.	5
		Cont1b2	Extinguishing system simultaneously activated above and below sub-dividing deck	Ro-Pax	CRS, ORS	No further validation was performed.	5
		Cont3b	Solid curtain, transversal mounting, fully rolled down	Ro-Pax, Ro-Ro	CRS, ORS	Brief literature review. Reduced scale fire tests. Demonstrated on board.	5
		Cont3d	Solid striped curtain, transversal mounting, fully/partly rolled down	Ro-Pax, Ro-Ro	CRS, ORS	Brief literature review. Large-scale fire tests. Demonstration on board.	5
	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	CFD simulations. Evaluation of manoeuvring guidelines by ro-pax crew.	6
		Cont10	Safety distances between side and end openings and critical areas	Ro-Pax, Ro-Ro	ORS	CFD simulations. Small-scale fire test.	5
	11-D	Cont11	Guidance on calculation of side openings in ro-ro spaces	Ro-Pax, Ro-Ro	CRS, ORS	No further evaluation was performed.	5
		Cont13	Tactical guidelines for manual interventions	Ro-Pax, Ro-Ro	CRS	CFD simulations. Model scale fire test in lab. Guideline tested and validated through iterative feedback from shipping company representative and ro-pax crew.	4
		Cont14	SOLAS requirement of reversible fans	Ro-Pax, Ro-Ro	CRS	CFD simulations. Model scale fire test in lab.	5
	<p>(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) TRL not applicable as no solution is being developed. However, several material systems (commercially available) were tested in lab, but just a few were applied on ro-ro ships (and cargo ships in general).</p>						