Horizon 2020

Project acronym:	**LASH FIRE**
Project full title:	**Legislative Assessment for Safety Hazard of Fire and Innovations in Ro-ro ship Environment**
Grant Agreement No:	**814975**
Coordinator:	**RISE Research Institutes of Sweden**

LASH FIRE

Deliverable D06.9

Guidelines for firefighting gear, equipment and tactics, considering APVs

June 2023

Dissemination level: **Public**

Call identifier: H2020-MG-2018-Two-Stages Starting date: 2019-09-01 Duration: 48 months
MG-2.2-2018: Marine Accident Response, Subtopic C

Abstract

Work Package 6, "Effective Manual Operations", of the LASH FIRE project, focuses on addressing the challenges associated with fighting fires involving Alternative Powered Vehicles (APVs) on board ro-ro passenger ships, ro-ro cargo ships and vehicle carriers.

This deliverable contains guidelines for firefighting gear, equipment and tactics, considering APVs aimed to enhance the effectiveness of firefighting operations. The report draws on a range of sources, including internal LASH FIRE deliverables, external research, and empirical data obtained through physical tests and trials aimed at assessing the best practices for manual firefighting of APVs.

This deliverable, together with other outputs of LASH FIRE, contribute to a suite of risk mitigation proposals and routines that have the potential to enhance fire safety on board ro-ro ships.

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

Document data

Document Title:	D06.9 – Guidelines for firefighting gear, equipment and tactics, considering APVs		
Work Package:	WP06 – Effective Manual Operations		
Related Task(s):	T06.12		
Dissemination level:	Public		
Deliverable type:	R		
Lead beneficiary:	17 – MAG		
Responsible author:	Filipe Ribeiro		
Co-authors:	Reza Karimpour		
Date of delivery:	2023-03-31		
References:	D06.7, D06.8, D11.5		
Approved by	Jaime Bleye on 2023-06-24	Martin Carlson on 2023-08-21	Maria Hjohlman on 2023-06-15

Involved partners

No.	Short name	Full name of Partner	Name and contact info of persons involved
17	MAG	Magellan-Associacao para a Representacao dos Intresses Portugueses no Exterior	Manuela Flachi, maf@magellan-association.org Filipe Ribeiro, fbr@magellan-association.org Reza Karimpour, reza.karimpour@magellancircle.eu
15	SAS	Sociedad de Salvamento y Seguridad Marítima	Jaime Bleye, jaimebv@centrojovellanos.es
1	RISE	RESEARCH INSTITUTES OF SWEDEN AB	Jonatan Gehandler, jonatan.gehandler@ri.se

Document history

Version	Date	Prepared by	Description
01	2022-06-07	Filipe Ribeiro	Structure
02	2022-12-03	Filipe Ribeiro	Work in progress
03	2023-02-12	Filipe Ribeiro	First final draft
04	2023-02-23	Filipe Ribeiro	Refined version
05	2023-02-28	Filipe Ribeiro	Version for internal revision
06	2023-03-06	Filipe Ribeiro	Updated version
07	2023-03-15	Filipe Ribeiro	New version
08	2023-03-28	Filipe Ribeiro	Version for internal review
09	2023-03-31	Filipe Ribeiro	Version for reviewers
10	2023-05-10	Filipe Ribeiro	Final version after review
11	2023-06-14	Filipe Ribeiro	Final version for final review
12	2023-06-29	Filipe Ribeiro	Final document

Content

1 Executive summary

Problem definition

This document reports the work conducted in LASH FIRE's "Effective Manual Operations" work package (WP06), action 6-D. The action addresses effective and efficient manual firefighting onboard ro-ro, ro-pax and vehicle carriers.

The project expects there can be enhancements carried out to current IMO guidelines and internal procedures for ship operators when it comes to their manual firefighting operations.

Technical approach

The development of this document builds on the approach used throughout WP06, which means that the partners used different inputs, such as investigation of current practices, literary reviews, field tests and visits, and leaning on its predecessor deliverables such as D06.7 "Evaluation and development of tactics, gear, equipment and guidelines for effective first response", and D06.8 "Development and testing of APV firefighting routines, equipment and tactics".

Results and achievements

With the work developed in the tasks that supported this deliverable, we have managed to better understand the status of this type of operation in the context of ro-ro/ro-pax ships to look for ways in which improvements can potentially be beneficial in a practical sense, and propose what these improvements could be, considering the context. The main practical results of this document are the guidelines presented in Chapter 7, which are the outcome of the work described and can be isolated as a product of this report.

The achievements of this deliverable and indeed of the different Actions of WP06 contribute partially to the bigger picture objectives of the Project (as specified below) and will serve as input to further developments and documents that will continue the work that is being done and report on the progress of the partners in this topic.

Contribution to LASH FIRE objectives

This document will contribute to the following LASH FIRE Specific Objectives:

- 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.
- Objective 4: LASH FIRE will propose new regulations and guidelines founded on common positions by drawing upon global research and experience and by facilitating international cooperation.

As well as concrete objectives of the project's work package WP06 "Effective Manual Operations":

More effective fire managing operations in all stages of a ro-ro space (in other words, a general space within these ship types that may carry APVs) fire through firefighting gear, equipment, and tactical guidelines.

Exploitation and implementation

The deliverable is intended to serve as recommendations for implementation by international ship operators, as well as regulatory and standardisation bodies. These recommendations are the product of the partners' expertise, research and work, and their dissemination aims to kickstart a process of adoption by important players in the maritime industry, specifically in the ro-ro ship sector.

2 List of symbols and abbreviations

AB	Able seaman
AFV	Alternative Fuel Vehicles
APV	Alternatively Powered Vehicles
BA	Breathing apparatus
BEV	Battery Electric Vehicle
EMSA	European Maritime Safety Agency
EV	Electric Vehicles
HF	Hydrogen Fluoride
HRR	Heat Release Rate
ICE/ICEV	Internal Combustion Engine/ Internal Combustion Engine Vehicle
IMDG	International Maritime Dangerous Goods Code
IMO	International Maritime Organization
IR	Infra-Red
Li-Ion	Lithium-ion
MSC	Maritime Safety Committee
PPE	Personal Protective Equipment
PRD	Pressure Relief Device
SCBA	Self-Contained Breathing Apparatus
SOLAS	Safety Of Life At Sea
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers
TPRD	Thermally triggered Pressure Relief Device
TR	Thermal Runaway

3 Introduction

Main author of the chapter: Filipe Ribeiro, MAG

3.1 Scope and objectives

The main objectives of the document, besides addressing the Specific Objectives mentioned in Chapter 1, are to develop an understanding of current best practices and also to propose improvements on their efficiency and effectiveness. This deliverable intends to develop guidelines for firefighting gear, equipment and tactics, in the context of ro-ro and ro-pax ships and vehicle carriers, namely considering Alternative Powered Vehicles (APVs).

3.2 Methodology and structure

The team responsible for developing the deliverable worked together to identify and analyse the current state of fire equipment and tactics and define factors that influence it, which, if improved, could make manual firefighting operations more efficient and safer.

Previous work within WP06 was analysed, specifically the activities reported in D06.7 “Evaluation and development of tactics, gear, equipment and guidelines for effective first response”, and D06.8 “Development and testing of APV firefighting routines, equipment and tactics”, and the expertise of the partners involved within WP06 and others was also studied, namely by the review of reports both internal and public of the Project. A big influence was also brought by the possibility of going on board ro-ro/pax ships and understanding state of the art and the current methods put in place.

For the formal presentation of the guidelines themselves, we have followed a structure internally developed by LASH FIRE’s partners. In terms of the structure of the document, we follow the regular structure for the Project’s deliverables, specifically for documents which propose guidelines. It is organized as follows:

- Section 1 provides an executive summary of the document, including the problem definition, technical approach, results and achievements, contribution to LASH FIRE objectives, and exploitation and implementation of the findings.
- Section 2 lists the symbols and abbreviations used throughout the document.
- Section 3 introduces the document, including its scope and objectives, methodology and structure, and its relation to other deliverables and actions of the LASH FIRE project.
- Section 4 provides a summary of the status of APV firefighting onboard, including EVs and gas-powered vehicles.
- Section 5 presents examples of firefighting gear and equipment, with a specific focus on the human element.
- Section 6 contextualizes the development of the guidelines, in terms of the work and research that served as input to the proposals formally presented in the following section.
- Section 7 offers guidelines for firefighting gear, equipment, and tactics, with a specific focus on APVs. This section includes three sub-sections: guideline for manual firefighting equipment, guideline for firefighting training, and guideline for firefighting tactics. Based on past work, these will follow a concise structure:
  - ✓ Introduction
  - ✓ Description of the guideline
  - ✓ Purpose

- ✓ Application
- ✓ Intended Recipients

- Section 8 concludes the document by outlining further work that needs to be done within the LASH FIRE project, and summarizing the key findings of the document.

3.3 Work within Effective Manual Operations Work Package

This document falls within the work done in Action 6-D “Effective and efficient manual firefighting”, thus contributing to develop guidelines and a training module for firefighting of APVs in ro-ro spaces, based on evaluation and full-scale demonstration of new equipment.

3.4 Relations to other deliverables and actions of LASH FIRE

This Deliverable comes in the follow-up of work conducted, namely in tasks T06.11 and T06.12 of LASH FIRE and received specific input from deliverables D06.7 “Evaluation and development of tactics, gear, equipment and guidelines for effective first response”, and D06.8 “Development and testing of APV firefighting routines, equipment and tactics” and of course other work done previously in the scope of WP06 and other Work Packages.

4 Summary of status of APV firefighting onboard

Main author of the chapter: Filipe Ribeiro, MAG

LASH FIRE deliverable D06.7 “Evaluation and development of tactics, gear, equipment, and guidelines for effective first response” details the importance of fast and correct action in the early stages of a fire incident. It also outlines the importance of appropriate personal protective equipment (PPE) for designated first responders and fire patrols. It goes on to emphasize the importance of training for crew members who may be appointed as designated first responders. Finally, it specifies the importance of clear communication and familiarity with UHF radio equipment, channels, and terminology, and of the availability of equipment close to the seat of the fire.

The deliverable D06.8 “Development and testing of APV firefighting routines, equipment and tactics” goes into detail regarding the work already developed, namely by RISE, in the case of firefighting of APVs, focusing on the large-scale testing done in LASH FIRE.

In this section we summarize the main points, but nevertheless it is important as a basis of understanding to have a clear comprehensive knowledge of the work there described. We also take from the document an overview of the requirements applicable in ro-ro spaces regarding effective and efficient manual firefighting based on currently applicable regulations, which includes IMO documents such as SOLAS Convention, Interim Guidelines for minimizing the incidence and consequences of fires in ro-ro spaces, and others. Through the description of the large-scale testing, it discusses the general requirements, onboard organization and crew training, and operational readiness and maintenance of firefighting equipment and systems, including fire-fighter personal protection equipment, as prescribed by SOLAS, STCW Convention, and IMO recommendations. All of this is helpful for D06.9, along with the mention of the maintenance and inspection plan recommended by IMO for manual firefighting equipment to be carried out by the crew on a regular basis, and third-party surveys conducted by Class Societies.

The number of electric cars on our roads is increasing rapidly. We already see them in large numbers on car carriers and in growing numbers on our RoPax ferries.

For the analysis conducted, they divided APVs into gas-powered vehicles and electric vehicles (EVs). Gas powered vehicles are read in terms of compressed gases, pressure-condensed gases, and cryogenic gases; whereas today’s EVs are powered by lithium-ion batteries.

In the context of ro-ro fires, the available research support that vehicle fires in APVs should be extinguished, or at least controlled in order to prevent further catastrophic damage. The energy storage should be cooled down to limit the risk of an escalating fire and possible flash fire, thermal runaway (TR), jet fires or explosions. Due to the possibility of thermal runaway in a Lithium-ion battery, electric cars pose different challenges than fossil fuel vehicles. In most cases a fire in an electric car will not affect the Lithium-ion battery, but onboard ro-ro ships, an escalating fire can have a catastrophic outcome for the ship and the persons onboard.

A thermal runaway is a chain reaction within a battery cell that can be very difficult to stop once it has started. It occurs when the temperature inside a battery reaches the point that causes a chemical reaction to occur inside the battery. This chemical reaction produces even more heat, which drives the temperature higher, causing further chemical reactions that create more heat.

The fixed systems are the most important firefighting measures. Drencher systems perform equally well regardless of fuel source in cars.

In some cases, however, it may be necessary to intervene manually near a burning car. It should be noted that in many cases methods do not differ from what would be applied in case of a fossil fueled car on fire.

Most vehicle fires do not start in the energy storage, APVs and conventional vehicles can most often be fought by the same means. Hazards related to any vehicle fire are heat, smoke, and toxic gases. Additional hazards are related projectiles as a result of small explosions from for example dampers, tyres or airbags. The main difference to internal combustion engines is that in APVs there is a risk of reignition and jet flames (which can occur without warning), and electric vehicles can also produce Hydrogen Fluoride (HF) from the battery, which is a toxic gas. HF binds easily to water, which means that drencher or any other source of water such as fire hose or boundary cooling devices washes out large part of HF gases. Water cooling devices can be used as a preventive measure in case of suspicion or signs of thermal runaway or as a post-extinguishing measure. In Annex 2, developed by Magnus Arvidson in WP10 deliverable D10.4, we can find two diagrams comparing temperature differences and heat release rates in ICE vehicles and EVs, developed in WP09 of LASH FIRE.

4.1 Types of APVs

When it comes to manual firefighting of APVs, the following is highlighted:

4.1.1 EVs

During fire: the importance of mitigating thermal runaway, as “large amounts of water would be needed to cool the energy storage”, and firefighting crew should wear PPE and breathing apparatus (BA) for fully developed vehicle fires.

Post treatment: SAE J2990[1] recommends two inspection stages (post incident vehicle inspection) after an electric vehicle have been involved in an incident. If the traction battery has been involved in the fire, there is a risk of re-ignition due to stranded energy. The vehicle should therefore be monitored (visually or with the help of an infrared/thermal camera) and later, when back to shore, taken to a quarantine area.

4.1.2 Gas-powered vehicles

During fire: it is important to watch out for jet flames from pressure relief devices (PRD) or thermally triggered pressure relief devices (TPRD). The approach towards the vehicle that is on fire, should be performed preferably at the front corners of the vehicle at an ~ 45° angle. One positive aspect with vehicle fires onboard ro-ro ships is that the vehicles are parked with the engine shut off, gear in parking mode and handbrake pulled, which means that the magnetic valve on the gas tanks is already shut limiting the gas-related hazards to the gas storage tanks. If a pressurized or liquified gas tank is located in the vehicle on fire or close to it is highly valuable to cool the tank to prevent gas release or explosion. Normally it takes many minutes of flame exposure until a gas tank becomes a risk object. This means that there is time to establish water application. This may be done manual with hoses or with passive cooling devices.

[1] Society of Automotive Engineers collection of reccomendations on Hybrid and EV First and Second Responder Recommended Practice

Post treatment: after a fire, gas containers made of composite may leak. When the fire has been extinguished the gas cylinders should be left to cool down before the vehicle is approached. As alternative a passive cooling device may be located adjacent to tank or between vehicles.

4.2 Practical Examples (LASH FIRE videos)

Within LASH FIRE's tasks, there were several trials done in manual firefighting contexts, namely with APVs, which were recorded and are available to be publicly watched[2] by interested entities. These materials have also helped us inform the proposals done within WP06, namely in this deliverable, by having the team analyse practical scenarios and develop a better understanding of the needs and constraints felt by operators in these situations.

For instance, in the case of gas-powered vehicles, there was an emphasis of the utility of water in mitigating and putting out fires in these vehicles. In the test analysed, there was also a point of not extinguishing the jet flame, as gas could accumulate and explode. It was also seen that it takes some time until the relief valve opens, which means there is time to arrange for cooling of the tank.

In the case of EVs, it was confirmed that fires in these cases can be treated in the same way as liquid-fuel cars, although in the latter if it reaches a point where battery and fuel tank respectively get involved, different fire characteristics must be considered. Further manual action might be required.

The protection of the fire response team is also a focus of one of the trials done and shown in these videos, which helped inform some parts of the guidelines suggested, as proper personal equipment is paramount to the safe and efficient manual firefighting. We recommend the watch of these videos for a better practical understanding. The "Crew Training on Effective Manual AFV Firefighting" course[3] is an excellent resource to learn more about this topic.

[2] https://lashfire.eu/videos/
[3] https://www.seably.com/courses/crew-training-on-effective-manual-afv-firefighting

5 Examples of firefighting gear and equipment

Main author of the chapter: Filipe Ribeiro, MAG

In the case of this deliverable, the focus is on manual firefighting, i.e. after first response (see D06.7), and the use of equipment, gear and tactics that can supress, extinguish or mitigate fires in APVs.

One of the main sources of input has been the development of field tests done within the project, which have evaluated several different equipment, gear and tactics for fighting fires in APVs. D06.8 has done the thorough reporting of these tests, nevertheless, the main results are listed below as background for the guidelines in Chapter 7.

From D06.7, we understand that the equipment that should be readily available for general first response activities, including extinguishers of different types, absorbents, and gear for handling leakages. The partners also describe the clothing and equipment that the designated first responder and fire patrol crew should wear, as well as technology that can be used, such as a Smart Alert System for nearby first responders.

Figure 1 - Typical SOLAS Chapter II-2 equipment

From D06.8 we know that the main equipment used were fire blankets, hand-held thermal imaging cameras, manual water hose and nozzle, water mist lance, or boundary cooling nozzle. The tests also involved the use of various firefighting tactics, such as defensive tactics like creating fire breaks, using water curtains, boundary cooling devices and employing different attack strategies. The document also discusses portable fire-fighting equipment, mentioning the requirement for portable fire extinguishers (which can be used in cases like driver cabin of a car), water-fog applicators, and portable foam applicators, which must be inspected and maintained according to the guidelines provided in Annex 2 of IMO MSC.1/Circ.1432. The FSS Code is also referenced for more details about type approval and engineering specifications of fire extinguishers and portable foam applicators.

Other known equipment are as follows:

Ventilation

- Mechanical ventilation fans be used to push smoke and heat, improving visibility for firefighters and reducing the risk of flashover.
- Ventilation openings can be used to allow smoke and heat to escape from the ro-ro space, reducing the risk of flashover.
- Tactical ventilation may be used help to improve air quality. Cargo space fans may be run in a way that evacuates toxic gases and locally creates a cleaner air for the crew to act in.
- As indicated in the report from Japan[4], "it is not a suitable strategy to stop ventilation of a ro-ro space for the purpose of preventing the growth of fire".
- LASH FIRE's own work also involved this topic, namely on Work Package 11 "Containment", which proposed usage of reversible fans for closed ro-ro spaces (to facilitate manual interventions). Thus, we suggest the reading of deliverable 11.5 "Elucidation and guidelines for ro-ro space ventilation in case of fire" for more detail on this topic.

Figure 2 - Picture from ship BAHAMA MAMA-BALEARIA of mechanical ventilators

Personal protective equipment (PPE)

From the project Safe and Suitable Firefighting[5]:

- Ensure that the fire suit is certified according to EN 469 and has the performance level 2 (X2 Y2 Z2).
- Use a 'flash hood' to ensure that neck and head is protected. This item is not included in MED, so no wheelmarked hoods are available on the market.
- Wear long sleeved clothing under the fire suit to ensure the best protection. Equip the fire station with spare undergarments for any firefighter wearing, for instance, a t-shirt.
- Wristlets with a loop around the thumb stop sleeves from going up, reducing skin exposure.
- Pre-bent knees and elbows improve the mobility.

[4] IMO, Document Submitted by Japan; *Fire safety measures for ro-ro spaces and special category spaces of new and existing ro-ro passenger ships*; 2017
[5] Burgén, Gehandler, et al; *Safe and Suitable Firefighting*; 2022

- Knee pads allow crawling on hot or hard surfaces.
- Size and fit is important for full protection and usability. Female and male body proportions are different, so men's and female's sizes should be accomplished by individual patterns.

Figure 3 - Picture from test done in Jovellanos training centre for WP06

To this end it was also advantageous to rely on the work conducted by RISE in the report "Methods and equipment for firefighting operations in ro-ro spaces"[6] which allows us to quote the following instruments tested by them in terms of firefighting equipment:

Handheld systems[2]

Land based: adjustable nozzles and adjustable water flow rate (EN15182 standard for fire service use) to create everything from a wide water mist spray to a straight narrow stream trajectory.
Marine based: operator can adjust the water stream from a wide water mist spray to a jet stream. These systems are simpler than land-based ones (complying with EN671). Corrosion is also an important fact to consider.
Water mist lance: the system creates a water cone with a diameter of approximately 1 meter, and a throw length in the range of 7-10 meter. Primarily intended to penetrate an enclosed space without allowing for oxygen ingress, then spread a water mist inside. It can be an alternative water screen for external boundary cooling. Small droplets absorb a lot of heat and the water mist lance has proven to be very effective inside the vehicle. Water mist lances are not designed for defensive approaches but can create a protective shield.

Water curtain systems[2]

Water curtain nozzles: the nozzle is attached to a water hose and is placed on the ground, therefore, no person needs to handle the equipment when in use.

[6] Vylund, Mindykowski and Palmkvist; *Methods and equipment for firefighting operations in ro-ro spaces*; 2019

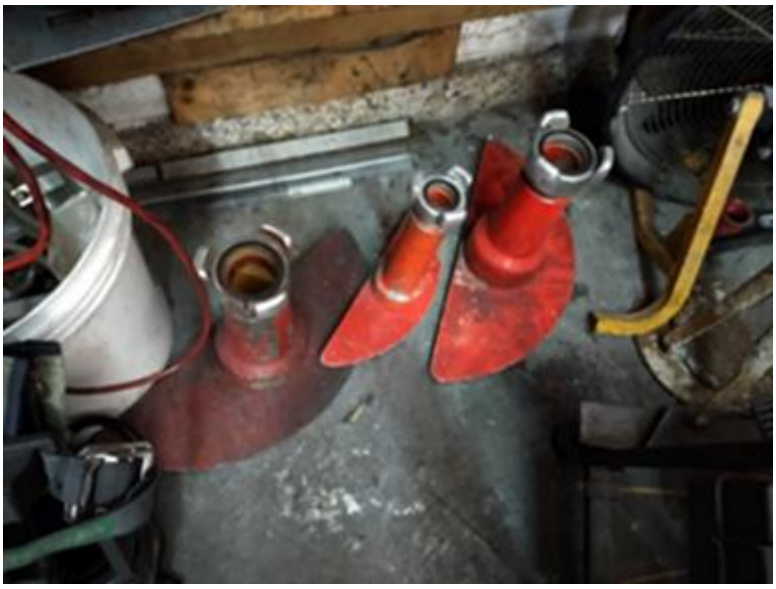

Figure 4 - Water curtain nozzles

Fire blanket

Fire blanket: the fire blanket is used to cover the vehicle on fire and thus quenching and limiting the fire. Need to be placed accurately to reach the maximum expected performance. No person needs to handle the equipment when in use. A fire blanket may be valuable for a general car fire but does NOT stop a thermal runaway with gases or jet flames. The thermal runaway will proceed regardless of oxygen, but the consequences can be suppressed with the blanket.

Figure 5 - Large fire blanket

5.1 Human Element

As WP06 concerns itself with manual operations, in this section we also discuss the human element in relation to manual operations, specifically firefighting. This topic has been given significant attention throughout the work package and is reflected in the various deliverables developed within the project. D06.7 discusses the importance of mindset, courage, and trust in the success of first response actions. It emphasizes the need for clear delegations and responsibilities and the importance of the vessel's

working culture. It is important to consider the human element in any equipment or tactics developed, as these will ultimately be used and implemented by human operators who may have varying levels of experience, undergo different training, and experience fatigue or different states of mind.

The human element is a critical factor in maritime safety and encompasses a complex set of multidimensional issues that impact maritime safety, security, and marine environmental protection. It involves various human activities performed by ship crews, shore-based management, and regulatory bodies. Unfortunately, human element failures can be attributed to 80% of maritime accidents, making it a pressing concern.

The International Maritime Organization (IMO) introduced the Standards of Training, Certification and Watchkeeping for Seafarers (STCW) Convention in 1978, which was the first internationally-agreed convention to address minimum standards of competence for seafarers. In 1995, the STCW Convention underwent a complete revision and update to clarify the required standards of competence and provide effective mechanisms for its enforcement. Since then, the IMO has adopted a significant number of amendments to enhance the standards of training for seafarers, which have been in force since 2012.

Despite these efforts, the maritime industry still experiences accidents every year. In the last two decades, a greater focus has been on reducing human errors to mitigate maritime accidents, particularly those involving Ro-Ro ships. Catastrophic accidents, such as the capsizing of the passenger/car ferry Herald of Free Enterprise in March 1987 and the tragic loss of Estonia in September 1994, were caused by human errors.

In summary, the human element is a crucial factor to consider in the development of firefighting equipment and tactics. The STCW Convention and its amendments have set the minimum standards of competence for seafarers and aim to reduce human errors in the maritime industry. However, accidents still occur, and ongoing efforts are needed to address this complex and multidimensional issue.

ELBAS has developed extensive work addressing the importance of human factors, which is extremely relevant in the context of the work developed for this deliverable. Quoting the summary of the chapter from their report, we have:

- *The challenge of fighting fires in EVs and modern vehicles is a socio-technical problem, meaning that both people-oriented and technology-oriented aspects need to be considered, and which requires broad solutions beyond what can be delivered through technical solutions alone.*
- *Detection, combined with a good CCTV system, is key to identifying and verifying a fire on a vehicle deck early.*
- *Having the ability to control all the ship's firefighting systems, including the vehicle deck drencher system directly from the bridge can make a difference when having to react fast.*
- *Uncertainty and worries concerning battery fires need to be addressed to make people at sea comfortable by knowing and understanding what they are dealing with.*
- *Additional efforts should be put towards education and training for fires at sea. This includes both a practical understanding of the fire, as well as a theoretical understanding for those not directly involved in firefighting.*
- *Knowing the number of electric vehicles and the placement of these could be an advantage to firefighting in the short run. In the long run, EV sales predictions indicate that most vehicles at sea will be electrified.*

6 Development of guidelines for firefighting gear, equipment and tactics, considering APVs

Main author of the chapter: Filipe Ribeiro, MAG

In order to develop the proposals in Chapter 7, and besides the work conducted within the project, a couple of external documents were paramount.

Naturally, D06.7 also influenced the development of this deliverable, with a couple of factors being most relevant: in its Chapter 7, it describes a two-day training session that included hands-on training on first response tactics, proposal of equipment, manual firefighting, and post-extinguishing actions. The training included drills on dry tests, pressurized jet fires, EV free burn safety awareness and firefighting procedures, first response and firefighting methods, indoor EV manual firefighting methods in combination with or without drencher system and ventilation, and post-extinguishing treatment. The drills covered the use of various firefighting equipment, including fire hoses, couplings, breathing apparatus, fire gear and PPE, water nozzles, fog nail, boundary cooling device, and fire blanket. The training was aimed at STENA LINES ro-pax crewmembers with different positions on board, including the captain, fire chief, and ECR members, who had previous firefighting experience.

In the case of D06.8, there is the presentation of the free burn test that was performed on 3 BEVs to see how the fire develops and to study thermal runaway on the EV. The aim of the test was to monitor the surface temperature of the traction battery and document the different timing of events. The critical hazards from lithium-ion batteries are identified, and the difficulty of extinguishing a battery fire is highlighted. The deliverable also provides insights from temperature data and firefighting experience during the test, describing the first response test and indoor manual firefighting, as well as the testing of a boundary cooling device.

External sources with high relevance to the work conducted in this Task were, namely, the DBI ELBAS (Electric Vehicle Fires at Sea: New Technologies and Methods for Suppression, Containment, and Extinguishing of Battery Car Fires Onboard Ships) Project report “Electric Vehicle Fires At Sea: New Technologies And Methods For Suppression, Containment, And Extinguishing Of Battery Car Fires Onboard Ships”. The report evaluated a range of equipment, gear, and tactics for responding to fires involving electric and hybrid vehicles. Some of the key findings and recommendations from the report include:

- Thermal imaging cameras are useful for identifying hotspots and assessing the effectiveness of fire suppression efforts.
- Firefighters should wear appropriate protective gear, including gloves, eye protection, and respiratory protection.
- The report recommends training for firefighters on electric and hybrid vehicle technology, battery characteristics, and the risks and challenges associated with firefighting in these situations.
- The report also recommends that fire departments and emergency services develop specific procedures and protocols for responding to electric and hybrid vehicle fires, including appropriate use of equipment and coordination with vehicle manufacturers and experts.
- ICEVs and EVs show similar total energy releases when experiencing similar fire scenarios.

- ICEVs and EVs fires vary with respect to smoke toxicity: EVs release higher concentrations of HF and some metals (i.e., Ni, Co, Li, Mn).
- ICEVs and EVs vary with respect to fire phenomenon: EVs can project jet flames and pose a significant risk of reignition, which significantly impact firefighting tactics.
- Further research and testing are needed for early detection methods of EV fires.
- Early detection and fast response by the fire crews is the key to controlling these fires safely.
- Taking advantage of existing CCTV cameras aboard combined with detection algorithms has some potential but needs to be tested onboard in a real setting.
- Advanced training of firefighter tactics for EVs is recommended to shorten the time for fire crew response and increase overall preparedness.
- Blankets and mobile sprinkler systems may be effective in preventing fire spread to neighboring vehicles when correctly and timely applied, but they should be further tested with regards to applicability in a ro-ro ship setting.
- Direct injection methods can be effective but need to be tested in a more realistic condition and if implemented requires in-depth crew training.

The “Guidance on the Carriage of AFVs in Ro-ro Spaces” report by EMSA was also analysed, and from it we can extract the following main points that are pertinent in the case of this report:

- EMSA guidance document discusses fire suppression and extinguishment in detail. The section highlights the importance of having a well-trained crew equipped with appropriate firefighting equipment to handle any potential fire incidents involving APVs. The document recommends the use of water or foam as the primary extinguishing agent for most fire scenarios, and outlines the steps involved in firefighting, such as shutting off the power supply, isolating the area, and deploying firefighting equipment.
- Additionally, that section stresses the importance of addressing the unique characteristics of APVs, such as the potential for battery reignition, in the firefighting strategy. It recommends the use of specialized firefighting agents and equipment and thermal imaging cameras, to enhance the effectiveness of the firefighting efforts. The section concludes by emphasizing the need for regular training and drills for the crew to ensure they are adequately prepared to handle any fire incidents involving APVs.
- The document also provides recommendations for training programs for personnel involved in the handling and firefighting of APVs. It highlights the importance of ensuring that all personnel involved in the handling of APVs receive adequate training, including theoretical and practical elements, and are familiar with the unique risks and hazards associated with these vehicles. The section also recommends that training programs should be regularly updated and reviewed to ensure that they remain effective and relevant. It also suggests that training programs should include regular drills and exercises to ensure that personnel are able to respond quickly and effectively to emergency situations.

Table 1 – Proposal for development of the STCW minimum standard of competence with regards APV manual firefighting (from D06.8)

Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Identify the hazards associated with carriage and charging of electric cars	Ability to identify electric battery vehicles and stablish cargo separation procedures Knowledge of possible consequences of overcharging, fast charging, charging damaged battery. Knowledge of the procedures to charge on board electric cars, risks associated and possible mitigation actions	Assessment of evidence obtained from approved training and/or instruction	Quantitative Risk assessment to estimate the likelihood of fire or thermal runaway when electric cars are loading on board.
Organize and control methods and equipment for APV firefighting operations on board ro-ro spaces	Basic knowledge on suppression systems needed in case of APV firefighting operations on board ro-ro spaces. Ability to perform firefighting technics and tactics regarding APV fires	Assessment of evidence obtained from approved training by practical demonstration, shipboard training drill or instruction	Correct installation of cooling devices for the attenuation of radiant heat with the aim of producing a blockage effect Correct selection of the right manual firefighting tactic (defensive or offensive) depending on how the fire can be reached considering fire size and potential dangers

Another important analysis was the one made to the report "Safe and Suitable Firefighting" from RISE[7], which discusses the importance of selecting the right firefighting gear, equipment, and tactics to minimize the risk of injury and death for firefighters. Some of its main results can be summarized as follows:

- Personal protective equipment (PPE) is crucial for firefighter safety, and the choice of PPE should be based on the type of firefighting operation.
- PPE and other firefighting equipment should be tested and certified to ensure they meet relevant standards.
- Training is important for firefighters to understand how to properly use PPE and equipment, as well as to develop effective firefighting tactics.

[7] Burgén, Gehandler, et al; *Safe and Suitable Firefighting*; 2022

- Risk assessments should be conducted before and during firefighting operations to identify potential hazards and adjust tactics accordingly.

Another pertinent input source was BREND 2.0[8], a project which investigated firefighting risks with alternative fuel vehicles inside ro-ro spaces, which suggests the use of manual firefighting when there is no fixed firefighting system (FFFS) or when it is not working as intended. It is the only firefighting alternative when precious attempts were not successful; as backup for spaces protected with firefighting systems (when the system has not been effective); and as stable post-firefighting like cooldown, inspection and monitoring. It elaborates by recommending an offensive approach when there is a need for lifesaving or protecting the ship. As it pertains to the intervention, the project explains that:

"With an offensive tactic, initially, the AFV fire can be extinguished as a standard vehicle fire. Traction battery will take long time to become involved and gas tanks are designed with a margin of safety in case of a fire. If possible, cool the energy storage (including traction battery and gas tanks). As soon as compressed gas tanks are being cooled or not affected by any fire, they regain a margin of safety against a pressure vessel explosion. If there are jet flames from the traction battery (below vehicle) or jet flames from gas tank´s [Temperature-activated pressure relief device] the focus should be to cool the surrounding, prevent fire spread and try to extinguish the seat of the fire. If possible and safe to do so, let the jet flame burn out."

.

[8] Gehandler, Olofsson, et al; *BREND 2.0 - Fighting fires in new energy carriers on deck 2.0*; 2022; RISE

7 Guidelines

These guidelines aim to improve current practices of firefighting gear, equipment and tactics onboard ro-ro passenger ships, ro-ro cargo ships and vehicle carriers. The guidelines are developed within Work Package 6 of the LASH FIRE project and are further described in the project deliverables D06.9 “Guidelines for firefighting gear, equipment and tactics, considering APVs” and D06.8 “Development and testing of APV firefighting routines, equipment and tactics”. The main goal is to enhance fire safety and reduce fire consequences onboard by increasing the efficiency in these operations, taking into account APVs but also within the context of conventional vehicles.

7.1 Guideline for manual firefighting equipment

Introduction

Manual firefighting equipment onboard ro-ro ships is crucial for the safety of passengers and crew. The guideline is aimed at ensuring safe and suitable manual firefighting equipment including proper maintenance and testing onboard ro-ro ships.

Purpose

The purpose of this guideline is to ensure that the firefighting equipment is suitable and always functioning correctly and efficiently. Proper maintenance and testing can help identify any issues with the equipment and ensure that it is repaired or replaced promptly, reducing the risk of equipment failure during an emergency.

Application

This guideline applies to all ro-ro spaces that have firefighting equipment onboard.

Intended Recipients

The intended recipients for this guideline includes the ship's crew responsible for maintaining and testing firefighting equipment, as well as regulatory bodies responsible for enforcing safety regulations on board ships.

Guideline

Manual firefighting equipment concern clothing and protective gear, i.e., personal protective equipment (PPE):

- Firefighting clothing and protective gear for crew members involved in firefighting operations should be readily available in fire station (or similar), preferably nearby cargo hold and engine room. This includes:
    - A ’flash hood’ to ensure that neck and head is protected.
    - Long sleeved clothing under the fire suit to ensure the best protection. Equip the fire station with spare undergarments for any firefighter wearing, for instance, a t-shirt.
    - Wristlets with a loop around the thumb stop sleeves from going up, reducing skin exposure.
    - Pre-bent knees and elbows improve the mobility.
    - Knee pads allow crawling on hot or hard surfaces.
    - Size and fit is important for full protection and usability. Sizes should accommodate all body proportions.

- All personnel involved in manual firefighting onboard ro-ro/ro-pax ships shall be equipped with the appropriate PPE to protect themselves from heat, smoke, and other hazards.
- Fire suits shall comply with EN 469 level 2 (X2 Y2 Z2), or similar, and be inspected regularly for damage or wear. Personnel should be trained in the proper use and maintenance of PPE, including donning and doffing procedures, and how to identify when it needs to be replaced.
- Each firefighter shall have their own communication device with microphone and speaker integrated in helmet or breathing mask. The device should also be IP rated.
- Use lightweight BA (breathing apparatus) cylinders over steel.
- Use flashlights that can be attached to, for instance, the helmet so that the firefighter can work with both hands. These should be EX-proof certified.
- There are many things that can be useful during a fire onboard, such as laminated GA plan, fire plans, pens, timers, wrenches, bolt cutter, crowbar, and thermal imaging camera, which could all be kept in bag(s) in the fire station.
- All this equipment (including communication devices) should be stored in the fire station.
- Firefighting tools and their locations on board:
    - Fire hoses: Ensure that the firefighting equipment includes adequate lengths of hoses to reach all areas of the ship, including below deck and in confined spaces. Hoses should be of appropriate diameter and rated for the expected water pressure. Lighter hoses are easier to operate in ro-ro space, although smaller sizes like 25mm will produce a water pressure drop in comparison to traditional 45mm.
    - Nozzles: Select nozzles that are suitable for firefighting, with adjustable spray patterns and flow rates. Nozzles should be securely attached to the hose and be easy to handle.
    - Water mist lance: Good shield/blockage effectiveness, can penetrate surfaces and be left inside enclosures for efficient extinguishing/cooling. Connect water mist lance to the fire hose.
    - Fire blanket: large size, typically 6x8 m, allows safe approach with adjacent vehicles as heat/flame barrier, as long as these are not on fire also. Reduces amount of smoke in space and no additional steam generation.
    - Boundary cooling nozzle: good shielding effect creating a vertical barrier between cars and also spray pattern pointing to the traction battery or the gas tank.

- Communication and alarm systems shall be available, including smoke detection and fire alarm systems, portable radios, and public address systems.
- Regularly inspect firefighting equipment to identify any damage, wear and tear or corrosion.
- Conduct routine testing and maintenance of equipment according to manufacturer recommendations and regulatory requirements.
- Develop and implement a maintenance and testing schedule for firefighting equipment.
- Ensure that firefighting equipment is properly stored, secured, and easily accessible in case of an emergency.
- Provide proper training to crew members on how to use firefighting equipment effectively.
- Periodic and regular fire drills can help identify malfunctions in the equipment like punctures in the hoses, empty cylinders, disconnections in the couplings.
- The table with pros and cons (Annex 1) developed in D06.8 lists firefighting equipment that may be used to tackle different APV fire situations.

7.2 Guideline for firefighting tactics

Introduction

The use of APVs is becoming increasingly popular due to their lower emissions and cost-effectiveness. However, these vehicles pose a unique challenge for firefighters in the event of a fire, especially when they are transported on ro-ro/ro-pax ships. In order to ensure the safety of passengers, crew, and cargo, it is essential to have effective and efficient firefighting tactics in place.

Purpose

The purpose of this guideline is to provide effective tactics for firefighting of APVs onboard ro-ro ships that can be used and agreed by all personnel involved in firefighting operations. By following these specific instructions, the risk of damage or injury can be minimized and the effectiveness of firefighting operations can be improved.

Application

This guideline should be applied in all firefighting operations involving APVs onboard ro-ro ships. The primary fire response in ro-ro space relies on the drencher system. Manual firefighting is the secondary option under the following conditions:

- as a proactive measure in the event of increased fire risk
- if it is a clearly safe and reasonable alternative.
- if needed as a supplement to fixed firefighting systems or if these do not work
- to save lives
- during stable conditions after the fire

Intended Recipients

This guideline is intended for all personnel involved in firefighting operations onboard ro-ro spaces, including crew members, firefighters, and other emergency responders.

Guideline

Tactic for firefighting of APVs:

- Identify the type of fuel used by the APV and the location of the fire. Before any manual firefighting can begin, it is important to identify the type of fuel used by the APV, as this will determine the best tactics for extinguishing the fire. The location of the fire will also play a crucial role in determining the appropriate firefighting equipment to be used.
- Use water to cool the fuel storage, prevent the spread of fire, and to extinguish the fire. There is virtually no risk of electrification unless there is direct contact with traction battery, which is almost impossible in real scenario.
- Hoses may be used to extinguish the fire in other parts of vehicle, cool the gas tank and or provide a water barrier to object at risk in the direction of gas release valve and potential jet flame. Note that the jet flame itself should never be extinguished because unignited gas may accumulate and explode.
- If the fire is inside the passenger compartment or cabin, use a water mist lance to penetrate the compartment and fill the compartment with water fog that will extinguish the fire efficiently. You can smash the window easily. Do not smash the window if the space is full of smoke because you can provoke a flash-over with the intake of fresh air. In any case, do not exposure directly to possible flash-over events. Do not use water mist lance in engine

compartment or directly on the battery due to the risk of contact with high voltage components

- Particular instructions for EVs:
    - Conditions for approaching the fire: If emission of gases occur that is not ignited there is a risk of surprising and/or violent ignition or even explosion, stay as far away as possible.
    - Fire in the EV not affecting the battery should be suppressed as a conventional car fire. It will probably take more than 20 minutes for the battery to ignite if the fire has not started from there.
    - If the fire is in the engine compartment or if the traction battery is involved, cool the battery and the surrounding with water to prevent fire spread or apply a fire blanket as a defensive strategy that prevents fire spread.
    - Approach to an EV with a wide cone of water alternate selected in the nozzle. The approach should be of 45º from the centre line. If possible, use at least one adjacent car as protection from possible jet flames.
    - Water from the hose should reach to the vehicle caught on fire for cooling/suppression. Try to avoid straight jet. Small water droplets have a better cooling capacity.
    - One of the special characteristics of a Lithium-Ion battery is the risk of re-ignition after the fire has apparently been extinguished. It is therefore important to monitor and cool an "extinguished" EV fire until it is safely returned to port. This should be done even if no evidence of a fire in the battery. Use fire blanket, boundary cooling nozzles or keep fire hoses ready to be used.
    - Application of fire blanket: Place the fire blanket on the deck in a safe position in front of or behind the car and unfold it. Arrange hose team for protection of blanket team and prior extinguishing of fires in adjacent cars to allow for safe approach. Two firefighters grab the blanket by the handles and pull the fire blanket over the car in a continuous movement, using adjacent cars as safety barrier. Make sure that the fire blanket is tight to the ground, by means of walking around the car as close as safely possible. The weight of such fire blanket would be 20-25 kg and requires fit, strong crew members for handling and application.
    - There is no need to remove the blanket, water mist lance or water-cooling device once they are in position. Leave in place and continue water supply until arrival in port and only discontinue on advice from shore side fire department.
- Particular instructions for gas vehicles:
    - Gas tanks may be designed according to leak-before-burst principles and are equipped with pressure relief valves that should release some or all gas in the event of fire.
    - The jet flame will be directed from the valve so knowledge of the location of the valve is valuable.
    - Mind that jet flame may be several meters long.
    - Never attempt to extinguish a burning jet flame, this may create an explosive atmosphere.
    - Depending on the fire scenario and type of gas storage, it may be possible to arrange for water-cooling of compressed or pressure-liquified gas tanks such as CNG or LPG, if other conditions allow. Never cool cryogenic tanks such as LNG since water could freeze and block the relief valve.

- Maximum total smoke diving is 40 minutes. Crew may need to be rotated with rest in between. This is also limited by air capacity in the SCBA (self-contained breathing apparatus).
- Contaminated fire suits: fire suits are almost certainly contaminated after a fire. Before SCBA is removed, it is important to take off the suits and place the contaminated PPE in airtight bags, avoiding skin or inhalation contact and performing this outside. Instructions are presented in the Skellefteå Model[9].
- Handling of all contaminated material should be carried out by crew members wearing a full fire suit or disposable one-time-use protection suits and face mask.

7.3 Guideline for firefighting training

Introduction

APVs are becoming increasingly common on ro-ro/ro-pax ships. In order to ensure the safety of passengers and crew members, it is important to develop training guidelines for firefighters to effectively respond to fires involving APVs.

Purpose

The purpose of this guideline is to enhance the safety of passengers and crew members onboard ro-ro ships by improving the knowledge, skills, and capabilities of firefighters in responding to fires involving APVs by developing simple instructions to be included in training of responsible crew members.

Application

This guideline is intended to be used as a reference and a training tool to enhance the knowledge and skills of firefighters.

Intended Recipients

The intended recipients for this guideline include all firefighters who are responsible for responding to fires involving APVs onboard ro-ro ships. This includes both new and experienced firefighters who may need additional training or refresher courses on the hazards associated with APVs and the specific firefighting techniques needed to respond to fires involving these vehicles. It should be used by training officers, firefighting instructors, and firefighters who are responsible for responding to fires involving APVs onboard ro-ro ships.

Guideline

This guideline provides a framework for training firefighters:

- Understanding of APV types: the operator should ensure that firefighting personnel understand the different types of APVs and their specific hazards. The training should cover how to identify the fuel source, the location of the fuel system, and the vehicle's potential to vent gas or reignite.
- Familiarity with Firefighting Equipment: the operator should ensure that firefighting personnel are familiar with the firefighting equipment onboard the ro-ro/ro-pax ships, including its location and operation. The training should cover the use of available firefighting equipment.

[9] Magnusson, Stefan & Hultman, Davis; *Healthy firefighters – the Skellefteå Model improves the work environment*; 2014; Swedish Civil Contingencies Agency

- Tactics and Strategies: the training should include specific tactics and strategies for fighting APV fires onboard ro-ro/ro-pax ships. This should include developing defensive and offensive strategies, implementing appropriate firefighting procedures, and using appropriate ventilation techniques.
- Emergency Procedures: training should cover emergency procedures in the event of an APV fire onboard the ro-ro/ro-pax ships. This should include communication protocols, evacuation procedures, and contingency plans.
- Safe contaminated fire suit removal practice should be trained, preferably as is presented in the Skellefteå Model.

8 Conclusion

Main author of the chapter: Reza Karimpour, MAG

In conclusion, the LASH FIRE project has provided valuable insights into the development of guidelines for firefighting gear, equipment, and tactics for ro-ro ships with a specific focus on APVs. Through the use of literature reviews, discussions with experts, and firefighting exercises, the project has developed a comprehensive set of guidelines to improve the efficiency and effectiveness of firefighting operations on board these types of ships.

Besides, The European Maritime Safety Agency (EMSA) has developed guidelines for fighting fires in electric vehicles on ro-ro ships. Ship Safety Standards - Transportation of Alternative Fuelled Vehicles (AFV) - EMSA - European Maritime Safety Agency (europa.eu)

The importance of fast and correct action, appropriate personal protective equipment, crew training, clear communication, and availability of equipment close to the seat of the fire have been highlighted in the project's deliverables. The guidelines emphasize the need to prioritize safety and innovation, and to stay up-to-date with the latest developments in the field.

The guidelines provide specific instructions for identifying the type of fuel used by the APV and the location of the fire, and outline appropriate firefighting techniques for different scenarios. The firefighting tactics guidelines makes use of traditional and new manual fire extinguishing systems. The guidelines acknowledge the human element in firefighting operations and the need for ongoing efforts to address this complex issue, including education and training for fires at sea. Guidelines are crucial for ensuring the safety of passengers, crew members, and cargo onboard ro-ro ships, especially with the increasing use of APVs

The guidelines presented in this report are pertinent for any operators and industry actors that are responsible for this type of operations. However, it is important to note that firefighting techniques and technologies studied in LASH FIRE are up-to-date as per April 2023, and there may be additional strategies and tactics that could be developed and implemented in the future. As such, ship operators are strongly encouraged to stay up-to-date with the latest developments in the field, conducting regular reviews and updates of the guidelines, and exploring new approaches to enhance the safety and efficiency of firefighting onboard ships.

9 References

Bleye, J. & Suarez, C.; *Development and testing of APV firefighting routines, equipment, and tactics (D06.8)*, LASH FIRE, 2023.

Bleye, J. & Suarez, C.; *Evaluation and development of tactics, gear, equipment, and guidelines for effective first response (D06.7)*, LASH FIRE, 2023

Burgén, J., J. Gehandler, A. Olofsson, C. Huang and A. Temple; Safe and Suitable Firefighting; 2022; RISE

European Maritime Safety Agency; *Guidance on the Carriage of AFVs in Ro-ro spaces*; 2022

Gehandler, J., A. Olofsson, J. Hynynen, A. Temple, A. Lönnermark, J. Andersson, J. Burgén and C. Huang; *BREND 2.0 - Fighting fires in new energy carriers on deck 2.0*; 2022; RISE

IMO, Document Submitted by Japan; *Fire safety measures for ro-ro spaces and special category spaces of new and existing ro-ro passenger ships*; 2017

Kleiman, A., Koch, N., Flecknoe-Brown, K., Funk, E., Wijesekere, T., Husted, B., Valiente, B., Meehan, S. and Møller, C.; *DBI ELBAS (Electric Vehicle Fires at Sea: New Technologies and Methods for Suppression, Containment, and Extinguishing of Battery Car Fires Onboard Ships) Project report "Electric Vehicle Fires At Sea: New Technologies And Methods For Suppression, Containment, And Extinguishing Of Battery Car Fires Onboard Ships"*; 2021

Magnusson, S., & Hultman, D.; *Healthy firefighters – the Skellefteå Model improves the work environment*; 2014; Swedish Civil Contingencies Agency

Olofson, A., Anderson, S., Svensson, R., Ingason, H., Temple, A.; *Elucidation and guidelines for ro-ro space ventilation in case of fire (D011.5)*, LASH FIRE, 2023

Vylund, L., Mindykowski, P., & Palmkvist, K.; *Methods and equipment for firefighting operations in ro-ro spaces*; 2019; RISE

10 Annexes

10.1 Annex 1 – Pros and cons about the pieces of equipment tested (D06.8)

Equipment	Plus	Minus
CO2 4Kg portable extinguisher	Suppression of the fire is possible in the very early stage of the fire. It is clean and does not compromise the visibility of the area	Limited cooling effect on the battery Very limited effectiveness when the fire is fully developed
Dry powder 9Kg portable extinguisher	Limits the fire growth and fire development, extinguishing at early stages of the fire. Most common fire equipment at hand	Battery pack is well hidden, so effectiveness is limited. Powder cloud may hinder firefighting operations due to poor visibility
Foam 6liters portable extinguisher	Quite effective, as the liquid state helps to reach hot hidden zones when media is applied. Good cooling effect	Not very common to find in ro-ro cargo spaces. Fluorine products will cause environmental issues.
Fire blanket 6x8m	Good efficiency for general car fire, in particular for engine/passenger/hood compartment fires. Large size, typically 6x8 m, allows safe approach with adjacent vehicles as heat/flame barrier, as long as these are not on fire also. Contains energy bursts in case of reignition. Reduces amount of smoke in space and no additional steam generation. Stabilizing psychological effect due to fire/car not visible. Short crew heat/smoke exposure time. Good option, if water system supply is not operative	A fully parked scenario with great cargo variation can jeopardize the effective blanket deployment. As firefighters need to be close to the car to apply blanket, it is not possible to do it with a fully developed fire, without previous suppression by water. Captures smoke underneath at time of application and may temporary direct it towards crew members. Require manual activities on all sides of fire scene, challenging tactical ventilation. Requires 2 crewmembers for application plus, in a developed fire state, 2 protective hose operators if water shield is needed for application and return. Limitation with roof racks and high vans to deploy the blanket smoothly
Water mist lance	Good shield/blockage effectiveness Can penetrate surfaces and be left inside enclosures for efficient extinguishing/cooling. Enables one directional approach and exit.	Unlikely but dangerous possibility of penetration of the battery pack No open/close valve on the nozzle Tight parking may hinder hose preparation.

Equipment	Plus	Minus
	Short crew heat/smoke exposure time	If water shield protection or return is needed, this must be provided by additional hose/crew.
Manual water nozzle and hose	Versatile tool for manual firefighting Can offer extinguishing from a distance. Can offer heat protection. Smaller hoses e.g. 25 mm can be easier to maneuver and pull between vehicles avoiding stuck Enables one directional approach and exit	Tight parking may hinder hose preparation. Requires continuous presence of crew At least 4 members are needed for a dynamic fire strategy. Smaller hoses are lighter but offer large pressure drop.
Boundary Cooling nozzle	Enables one directional approach/exit, and if pushed in place by a rod, avoiding close contact with car on fire. Short time crew heat/smoke exposure. Allows for engagement at developed fire stage. Enables low level approach. Protective water shield provided by device itself on the way in. Can be used to cool gas tanks with open mounting. Equally usable with varying cargo configuration. Suppresses energy bursts in case of reignition.	Two devices needed to protect from fire in one car. Will not extinguish shielded fire inside vehicle. Requires 2 crewmembers for application plus, in a developed fire state, 1 protective hose operator, if water shield on return is needed. Tight parking may hinder hose preparation. Heavier in maneuver than hose or fognail. Decrease local visibility and work environment.
IR camera	Good to confirm the presence of fire or hot spots. Necessary to monitor the evolution of the fire behavior taking periodic measures	You need one hand busy to carry the device. Adding extra equipment will reduce the comfort of the firefighter in an stressful situation

10.2 Annex 2 – Differences in Heat Release Rates in ICE vehicles and EVs (from Magnus Arvidson (RISE) WP10 D10.4)