Horizon 2020

Project acronym: **LASH FIRE**

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Performance, feasibility and integration assessment

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Abstract

The LASH FIRE project aims to develop and demonstrate operational and design solutions which strengthen the fire protection of ro-ro ships in all stages of a fire. Twenty specific challenges, also called Actions, have been identified, resulting in more than 60 developed and demonstrated solutions with regards to performance and ship integration feasibility.

Real ship application cases were in focus of the development to achieve feasible and integrable solutions. Therefore, it was crucial that ship designers and operators were involved in the development process including requirements definition, proposals for development, life cycle assessments and finally performance, feasibility and integration assessment, considering the design, production, operational and environmental aspects.

Results from the technical ship integration evaluation, life cycle cost and environmental assessment, laboratory tests, onshore and onboard demonstrators and Formal safety assessment aspects are summarized in this report. The focus is given to design, production, operational and environmental aspects.

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Content

1 Executive summary

1.1 Problem definition

The LASH FIRE project aims to develop and demonstrate operational and design solutions which strengthen the fire protection of ro-ro ships in all stages of a fire. Twenty specific challenges, also called Actions, have been identified, resulting in more than 60 developed and demonstrated solutions with regards to performance and ship integration feasibility.

Real ship application cases shall be the focus of the development to achieve feasible and integrable solutions. Therefore, it is crucial that ship designers and operators are involved in the development process including requirements definition, proposals for development, life cycle assessments and finally performance, feasibility and integration assessment, considering the design, production, operational and environmental aspects.

The main challenges were to address all the application areas, targeted by developed solutions, and providing a clear picture of the relevant maritime stakeholders' aspects.

1.2 Technical approach

To address the described problems and challenges above, a final performance, feasibility and integration assessment was performed by Work Package 5 Ship Integration (WP05) considering the full scope of the LASH FIRE. This included the integration evaluation, cost and environmental assessment results provided by WP05, final outcome of the Demonstration & Development work packages (WP06-WP11) as well as Cost effectiveness results provided by Work Package 4 Formal safety assessment (WP04) as illustrated on Figure 1. For each developed solution separately, design, production, operational and environmental aspects were provided for all types of ro-ro ships as well as new buildings and existing ships as applicable. Additionally, aspects on the cost effectiveness results were provided where appropriate.

It is worth mentioning that the established advisory groups Maritime Authority Advisory Group (MAAG) and Maritime Operators Advisory Groups (MOAG), within LASH FIRE Work package 3 Communication (WP03) supported the ship integration evaluation within the project, providing valuable feedback through dedicated workshops.

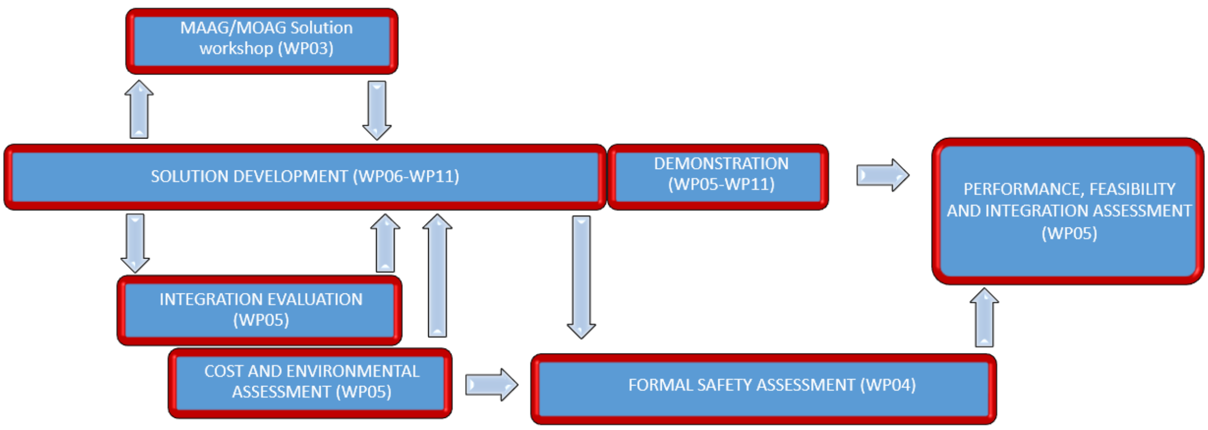

Figure 1. Ship integration assessment process

1.3 Results and achievements

This report presents an overview of the final performance, feasibility and integration assessment results addressed to all the specific developments within the LASHFIRE project, including design, production, operational and environmental aspects as well as aspects on the cost effectiveness results.

For the description of the RCM's including test and simulation results, performance assessment and impact on safety please refer to deliverables D04.10, [4]. For the description of the RCO's and cost effectiveness results please refer to deliverables D04.6 [2] and D04.7, [3]. For the ship integration evaluation, during the development process, considering design, production and operational aspects refer to deliverable D05.7, [10]. Further, cost and environmental impact was assessed and presented within D05.8, [11].

1.4 Contribution to LASH FIRE objectives

One of the main LASH FIRE objectives (Objective 2) is addressed by the ship integration work package (WP05):

> *LASH FIRE will evaluate and demonstrate ship integration feasibility and cost of developed operational and design risk control measures for all types of ro-ro ships and all types of ro-ro spaces.*

This report contributes to the objective through the final assessment for all the developed solutions within the LASH FIRE project and beyond.

1.5 Exploitation and implementation

The report can be used by LASH FIRE and external parties as it provides a description of technical and operational aspects related to innovative solutions. Further, it provides information on the expected or desired implementation, improvements and future developments.

This information can be useful for any stakeholder in the maritime industry.

2 List of symbols and abbreviations

AB	Able Seaman
ADR	Accord européen relatif au transport international des marchandises Dangereuses par Route (European Agreement Concerning the International Carriage of Dangerous Goods by Road)
AGV	Automatic Guided Vehicle
AHJ	Authority Having Jurisdiction
AI	Artificial intelligence
AIS	Automatic Identification System; Satellite transmitted positions of vessels.
APV	Alternative Powered Vehicle
BEV	Battery Electric Vehicles
CAFS	Compressed air foam system
CAF	Compressed Air Foam
CCR	Cargo control room
CCTV	Closed-Circuit Television
CFD	Computational Fluid Dynamics
CLIA	Cruise Lines International Association
CNG	Compressed natural gas
DECT	Digital Enhanced Cordless Telephone
DG	Dangerous goods
D&D WPs	Development and demonstration work packages
ECDIS	Electronic Chart Display and Information System; Electronic map and navigation tool
ECR	Engine Control Room
EEBD	Emergency Escape Breathing Device
EV	Electric vehicle
FDS	Fire Dynamics Simulator
FF	Fire fighting
FRMC	Firefighting Resource Management Centre
FSS	IMO International Code for Fire Safety Systems
FTP	International Code for the Application of Fire Test Procedures

FWBLAFFS	Fixed Water-Based Local Application Fire-Fighting Systems
GAP	General Arrangement Plan
GNSS	Global Navigation Satellite System
HCD	Human Centred Design
HD	High Definition
HGV	Heavy Goods Vehicle
HMI	Human-Machine Interface
HRR	Heat release rate
IACS	International Association of Classification Societies
IAMCS	Integrated Alarm Monitoring Control System – equipment
ICE	Internal Combustion Engine
IEC	International Electrotechnical Commission
IMDG	The International Maritime Dangerous Goods code
IMO	International Maritime Organization
IR	Infrared
ISM	International Safety Management
ISPS	International Ship and Port Facility Security Code
IR	Infrared Light
IT	Information technology
LCA	Life Cycle Assessment
LAN	Local Area Network
LLL	Low Location Lighting
LiDAR	Light Detection and Ranging
LNG	Liquefied natural gas
LPG	Liquefied Petroleum Gas
LSA	Life Saving Appliance
MAAG	Maritime Authorities Advisory Group
MOAG	Maritime Operators Advisory Group
MES	Marine Evacuation System
MFAG	Medical First Aid Guide for Use in Accidents Involving Dangerous Goods
MSC	Maritime Safety Committee

MVZ	Main Vertical Zone
NB	Nota bene, a Latin phrase meaning "note well"
NFPA	National Fire Protection Association
OOW	Officer Of the Watch
OPITO	Oil Petroleum Industry Training Organization
PC	Personal computer
PLC	Programmable Logic Controller
PTT	Press to talk
RCM	Risk control measure
RCO	Risk control option
SLAM	Simultaneous Localization and Mapping
SMAS	SMart Alert System
SCS	Safety control station, normally located on the bridge
SOLAS	International Convention for the Safety Of Life At Sea
SRtP	Safe Return to Port
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers
SW	Software
TCP/IP	Transmission Control Protocol/Internet Protocol
TR	Thermal runaway
TUGMASTER	The small vehicle that drives the trailers on/off board
UHF	Ultra Hight Frequency; Short wave radio, shorter reach than VHF
UV	Ultra Violet light
UWB	Ultra-wideband
VFD	Video Flame Detection
VGM	Verified Gross Mass
VHD	Vehicle Hotspot Detection
VHF	Very High Frequency; Short wave radio
VSD	Video Smoke Detection
WAN	Wide Area Network

3 Introduction

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One of the main LASH FIRE objectives (Objective 2) is to evaluate and demonstrate ship integration feasibility and cost of developed operational and design risk control measures for all types of ro-ro ships and all types of ro-ro spaces.

All solutions developed at LASHFIRE were considered within the performance, feasibility and integration assessment.

Six Development and Demonstration work packages (D&D WPs) addressed a total of twenty challenges, also called actions, in all stages of fire scenario originating in ro-ro spaces (Figure 2).

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

Figure 2. LASH FIRE 20 challenges (or actions).

Several solutions, also called Risk Control Measures (RCMs), were developed, validated, and demonstrated to address those challenges. Based on the preliminary list of selected solutions and from the inputs provided by the D&D WPs (Ref. deliverable D04.9, [1]), an intermediate compilation of the ship integration evaluation has been conducted by Work Package 5 Ship Integration (WP05) addressed to each specific development (Ref. D05.7, [10]).

Further, an economic feasibility study of the RCMs and Risk Control Options (RCOs) has been conducted by WP05 using LCC methodology where all related costs are included, from investment/production to operation/maintenance and until the end of the life span (Ref, D05.8, [11]). A selection of solutions provided by specific developments was assessed, with more than 40 RCMs and 16 RCOs for the selected three generic ro-ro ship types (Ref D05.1, [5]), including new buildings and existing vessels. For the assessments, a LCC tool developed within LASH FIRE was used. A comprehensive description of the LCC tool and LCC process is presented in deliverables D05.2 [6] and D05.3 [7], respectively.

Further, environmental assessment using Life Cycle Assessment (LCA) methodology was performed for manual firefighting of a vehicle fire on the car deck of a ro-pax ship (Action 6-D) and two fixed fire protection systems (autonomous and remotely operated) on the weather deck of a ro-ro cargo ship (Action 10-B), Ref D05.8.

A comprehensive description of the LCA screening tool and LCA process is presented in deliverables D05.4 [8] and D05.5 [9] respectively.

This report summarizes the results from the technical ship integration evaluation, life cycle cost and environmental assessment, laboratory tests, onshore and onboard demonstrators and Formal safety assessment aspects focusing on design, production, operational and environmental aspects.

A summary of the assessed RCM's and selected RCO's including the applicability vs ro-ro ship types and ro-ro spaces is presented within Table 1 and Table 2.

The actual Risk Control Measures (RCMs) are only specified by title in this report, where a more detailed description is found in D04.9 "Preliminary impact of solutions and related testing and demonstrations plan" [1]. Further, an overview of the testing and demonstration of the solutions is found in D04.10 "Consolidation of performance assessment and solutions' impact on safety" [4]. For the description of the RCOs and the selection process please refer to deliverable D04.6 "Cost effectiveness assessment report", [2]. Final results of the Cost-effectiveness assessment are found in D04.7 "Cost-effectiveness assessment report: Uncertainty and sensitivity analysis report" [3].

Table 1 (taken from the deliverable D04.9 [1]) summarizes the RCMs initially proposed by the D&D WPs, before the selection and definition of the RCOs.

Table 2 (taken from the deliverable D04.6 [2]) summarizes the selected RCOs.

Table 3 and Table 4 (taken from the deliverable D04.7 [3]) summarizes the final cost effectiveness results for all RCOs.

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

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

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

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

WP	Action	ID	Title of solution	Ship types[(1)]	Ro-ro spaces types[(2)]	NB, Ex[(3)]	TRL	Attribute(s) Category A[(4)]	Attribute(s) Category B[(4)]
		Cont3b	Solid curtain, vertical mounting, fully rolled down	Ro-Pax, Ro-Ro	CRS, ORS	NB	5	Mitigating	Engineering
		Cont3c	Solid curtain, vertical mounting, partly rolled down	Ro-Pax, Ro-Ro	CRS, ORS	NB	5	Mitigating	Engineering
		Cont3d	Solid stripped curtain, vertical mounting, fully/partly rolled down	Ro-Pax, Ro-Ro	CRS, ORS	NB	5	Mitigating	Engineering
	11-B	Cont5	Alternative disembarkation path through “dedicated side door”	Ro-Pax, Ro-Ro, VC?	CRS, ORS, WD	NB	5	Mitigating	Engineering
	11-C	Cont9	Ship manoeuvring/operation to limit the effect of fire at least in critical areas	Ro-Pax, Ro-Ro, VC	CRS, ORS, WD	NB + Ex	5	Mitigating	Procedural
		Cont10	Safety distances between side and end openings and critical areas	Ro-Pax, Ro-Ro	ORS	NB + Ex	5	Mitigating	Inherent
	11-D	Cont11	Guidance on calculation of side openings in ro-ro spaces	Ro-Pax, Ro-Ro	CRS, ORS	NB	5	Mitigating	Inherent
		Cont12	Configuration of side openings in ro-ro spaces	Ro-Pax, Ro-Ro	CRS, ORS	NB	5	Mitigating	Inherent
		Cont13	Tactical guidelines for manual interventions	Ro-Pax, Ro-Ro	CRS	NB + Ex	5	Mitigating	Procedural?
		Cont14	SOLAS requirement of reversible fans	Ro-Pax, Ro-Ro	CRS	NB	5	Mitigating	Engineering, Procedural
(1) Ro-Pax = Ro-ro passenger ships, Ro-Ro = Ro-ro cargo ships, VC = Vehicle carriers.									
(2) CRS = Closed ro-ro spaces, ORS = Open ro-ro spaces, WD = Weather decks.									
(3) NB = New ships, Ex = Existing ships.									
(4) Attributes as defined in MSC-MEPC.2/Circ.12/Rev.2, [65]									

Table 2. Detailed list of the 16 selected RCOs.

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

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

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

NB = new buildings, Ex = existing ships.

Table 3. Cost-effective RCOs in terms of life safety.

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

CRS = closed ro-ro space, ORS = open ro-ro space, WD = weather deck, NB = new buildings, Ex = existing ships.

Table 4. Cost-effective RCOs in saving cargo and ship.

		Cost-effective in saving cargo and ship?					
		Ro-pax		Ro-ro cargo		Vehicle carrier	
Ref	Designation	NB	Ex	NB	Ex	NB	Ex
RCO 1	Impr. fire patrol. Impr. fire confirmation & localiz.	Yes	Yes	Yes	Yes	Yes	Note 4
RCO 2	Impr. signage and markings for effective localiz.	Yes	Yes	Note 3	No	Yes	Note 4
RCO 3	Developed efficient first response	Yes	Yes	Yes	Yes	Yes	Yes
RCO 4	Developed manual firefighting for APVs	Yes	Yes	Note 3	No	Yes	Note 4
RCO 5	Alarm system interface prototype	Yes	Not assessed	Yes	Not assessed	Yes	Not assessed
RCO 6	Process [...] for efficient activation of exting.	Yes	Yes	Yes	No	Yes	Yes
RCO 7	Training module for efficient activat. of exting.	Yes	Yes	Note 3	No	Yes	Note 4
RCO 8	Safe electrical connection for reefers	Yes	Yes	No	No	Not assessed	Not assessed
RCO 9	Safe electrical connection of reefers and EVs	Yes	Yes	Not assessed	Not assessed	Not assessed	Not assessed
RCO 10	Fire detection on weather decks	Note 2	No	No	No	Not assessed	Not assessed
RCO 11	Alternative fire detection in CRS & ORS	Yes	Not assessed	No	Not assessed	No	Not assessed
RCO 12	Visual system for fire confirmation and localiz.	Yes	Yes	No	No	No	No
RCO 13	Dry-pipe sprinkler system for VC	Not assessed	Not assessed	Not assessed	Not assessed	No	Not assessed
RCO 14	Remote.-control. fire monitor using water for WD	Yes	Yes	Yes	No	Not assessed	Not assessed
RCO 15	Autonomous fire monitor using water for WD	Yes	Yes	Yes	No	Not assessed	Not assessed
RCO 16	Guideline for fire ventilation in CRS	No	No	No	No	Not assessed	Not assessed
Note 2	Found not cost-effective for the generic ship. Medium confidence in this result. Found cost-effective for some weather deck arrangements. Further evaluation needed to conclude.						
Note 3	Negative NCAF, low ΔRisk and low ΔCost-ΔBenefits for the generic ship. High confidence in these results. Found not cost-effective in some ship arrangements. Further evaluation needed to conclude.						
Note 4	Negative NCAF, low ΔRisk and low ΔCost-ΔBenefits for the generic ship. Medium confidence in these results. Further evaluation needed to conclude.						

CRS = closed ro-ro space, ORS = open ro-ro space, WD = weather deck, NB = new buildings, Ex = existing ships.

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

Main author of the chapter: Martin Carlsson, STL

This chapter gives an overview of the ship integration evaluation for Action 6-A, i.e., manual screening of cargo hazards and effective fire patrols. Two RCMs are assessed within this report:

- RCM Op1 - Improved fire patrol procedures and new assisting equipment for a more effective screening of fire hazards
- RCM Op2 - Manual screening of cargo at port before the loading operations

For the description of the RCM's including test and simulation results, performance assessment and impact on safety please refer to deliverables D04.10, [4] , D06.2, [14] and D06.5, [17]. For the description of the RCO's and FSA results please refer to deliverables D04.6 [2] and D04.7, [3]. For the ship integration evaluation, during the development process, considering design, production and operational aspects refer to deliverable D05.7, [10]. Further, cost and environmental impact was assessed and presented within D05.8, [11].

There is no standard for the equipment for fire patrol besides the use of the radio communicator and indeed, today, many ro-pax vessels are using the equipment as proposed at solution RCM Op1. Fire patrol basic set of equipment in terms of radio with monophone unit, check point reader, flashlight and pocked size IR camera is, with no disputes, highly value adding. It is also important that the fire patrol crew is dressed in fire retardant clothing, appropriate for first response in case of a fire. Further, the fire patrols should be trained in terms of safety aspects of alternatively fuelled cars and safety aspects in general. Current IMO equipment for fire patrolling is not updated and does not match new challenges with APV's or reefers in terms of fire prevention on board ro-ro vessels where LASH FIRE developments may significantly contribute. **Finally, RCM Op1 is a cost efficient measure for all types of ro-ro ships, including both new buildings and existing ships.**

Regarding the manual screening of cargo fire hazards, currently used procedure is to perform the screening during loading (only related to the most obvious issues) and periodically (1h as standard) during the fire patrol routine. Solution RCM Op2 proposes a previous screening of cargo fire hazards at the terminal before the cargo loading on board the ship. Manual cargo screening before loading is a complex activity since it is very dependent on operational conditions where the terminal is not always controlled by the operator, the turnaround time can vary from 15 minutes up to 12 hours, parking area may be fenced or open space, cargo may vary from only unaccompanied trailers to a mix with passenger vehicles. Since vehicle screening by definition must take place around potentially moving units, safest situation to perform it is when there are no movements. This is very hard to achieve since vehicles arrive continuously just prior to the departure and moves onboard as soon as loading commences. It is important to realize that the loading/unloading of the cargo is one of the most time-critical tasks within the operation of ro-ro ships, hence, new routine added to the process shall be efficient, consuming the least amount of time with the best possible results.

Finally, due to complexity of the practical screening task and challenge to actually find conditions that can be linked to a subsequent fire risk, it is advised to not perform dedicated screening activities, instead to train loading crew and fire patrols to be vigilant on high risk cargo conditions.

5 Quick manual fire confirmation, localization, and assessment – Action 6-B

Main author of the chapter: Martin Carlsson, STL

This chapter gives an overview of the ship integration evaluation for Action 6-B, i.e., quick manual fire confirmation, localization, and assessment. Two RCMs are proposed by WP06 and two RCO's selected (Ref. D04.6, [2]) and assessed within this report:

- RCM Op3 - Improvement of current signage and markings standards/conditions to support effective wayfinding and localization
- RCM Op4 - Guidelines for the standardization and formalization of manual fire confirmation and localization
- RCO1 - Fire patrol. Fire confirmation & localization
- RCO2 - Signage and markings for effective wayfinding and localization

For the description of the RCM's including test and simulation results, performance assessment and impact on safety please refer to Deliverables D04.10, [4] , D06.1, [13]and D06.3, [15]. For the description of the RCO's and FSA results please refer to Deliverables D04.6 [2] and D04.7, [3]. For the ship integration evaluation, during the development process, considering design, production and operational aspects refer to Deliverable D05.7, [10]. Further, cost and environmental impact was assessed and presented within D05.8, [11].

Consistent designations of systems and locations onboard and clear signage as proposed (RCM Op3, RCO2) is of no extra cost for new buildings and is highly supportive for fast and correct decision making and execution of actions. Even for existing ships a review and upgrade is regarded as non-disputable, even if the FSA study showed that it may not be cost effective. Improved familiarization with the ship is of great importance to introduce the concerned crew on scenarios they may encounter once they are sent for confirmation: typical signs of an incident, typical personal safety risks and default actions depending on situation. The developed guideline proposes to secure readable signage and markings and full alignment with designations in fixed safety systems such as fire plans, fire alarm systems.

Further, a guideline for practical communication is given, in order to avoid misunderstandings and delays due to technical or human related issues which implies improvements in the response times and capacity. The opinion is that it is critical to ensure that communication and location references are clear and doubtless in stressed cases of emergency. The common opinion for the integration of the RCM Op4 is that, in addition to ship familiarization, it is of great importance to introduce the crew to the possible scenarios which may be encountered during fire confirmation. It is proposed that the developed guidelines shall be aligned with EMSA Guidance on Carriage of AFVs in Ro-Ro Spaces, [63].

6 Efficient first response - Action 6-C

Main author of the chapter: Martin Carlsson, STL

This chapter gives an overview of the ship integration evaluation for Action 6-C, i.e., efficient first response. Two RCMs are proposed by WP06 and one RCO selected (Ref. D04.6, [2]) and assessed within this report:

- RCM Op5 - First response guidelines and new equipment to put out the fire in the initial stage
- RCM Op6 - Technology for localization of first responders through digital information processed via network
- RCO3 - Efficient first response

For the description of the RCM's including test and simulation results, performance assessment and impact on safety please refer to Deliverables D04.10, [4] , D06.6, [18] and D06.7,[19]. For the description of the RCO's and FSA results please refer to Deliverables D04.6 [2] and D04.7, [3]. For the ship integration evaluation, during the development process, considering design, production and operational aspects refer to Deliverable D05.7, [10]. Further, cost and environmental impact was assessed and presented within D05.8, [11].

First response guidelines and new equipment to put out the fire in the initial stage (RCM Op5, RCO3) includes a definition of first response concept, the role of designated first responder and a standard communication terminology protocol to secure prompt understanding. Understanding is very important since the terminology may differ between different operators and other stakeholders. Another important aspect is the expected action of a first responder, which is currently based on the traditional use of a fire extinguisher or any useful equipment. On the other hand, the establishment of a designated first responder should not prevent the urgent engagement of any other member of the crew in the early phase of a fire. The operational implications of this solution are changed procedures, enhanced training and, in some cases, investment in fire safe work clothes for crew members. It is suggested to establish a guidance considering vehicle fuel type such as petrol, diesel, battery, CNG or LNG, aiming to a uniform guideline regardless of the fuel type. This is to avoid complexity and additional requirements to the responder in an early stage, with regard the fuel type. It is of critical importance to make a good use of the first minutes after the fire is detected.

The proposed technology for localization of first responders through digital information processed via network (RCM Op6) is very interesting for implementation on board ro-ro ships. However, after the onboard trials, it was clear that the system is currently far from being mature enough for implementation, in terms of basic functions, hardware, and adaptions to specific marine and ro-ro requirements and conditions.

7 Effective and efficient manual firefighting- Action 6-D

Main author of the chapter: Martin Carlsson, STL

This chapter gives an overview of the ship integration evaluation for Action 6-D, i.e., effective and efficient manual firefighting. One RCMs proposed by WP06 and one RCO selected (Ref. D04.6, [2]) and assessed within this report:

- RCM Op7 -Training, new equipment and procedures to suppress APV fires with special focus on Li-Ion batteries fires
- RCO4 - Manual firefighting for Alternatively Powered Vehicles

For the description of the RCM's including test and simulation results, performance assessment and impact on safety please refer to deliverables D04.10, [4] , D06.8, [20] and D06.9, [21]. For the description of the RCO's and FSA results please refer to Deliverables D04.6 [2] and D04.7, [3]. For the ship integration evaluation, during the development process, considering design, production and operational aspects refer to deliverable D05.7, [10]. Further, cost and environmental impact was assessed and presented within D05.8, [11].

Fixed extinguishment systems are always the first choice in a developed fire situation, meaning that manual firefighting will be normally used after or during drencher operation. However, there may be cases where manual activity in vicinity of a vehicle at risk or under fire is needed or preferred, therefore, relevant knowledge and skills must be secured on a crew level. Using 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.

The probability of a thermal runaway in an electric car is generally low and the normal fire in an electric car not affecting battery should be suppressed similar as a conventional car fire. Due to that fact, consequences are comparable with fossil fuel cars, which leads to FSA result being less cost effective. However, the topic of fire risks of electric cars have lately been very much in discussion, triggering a need to establish facts and efficient methods, as to establish crew confidence. Therefore, actions in this direction are, in ship operators opinion, undoubtedly positive, increasing knowledge and competence to handle these situations.

As operational costs are very low, limited to extra cost for added content in external training, 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.

8 Improved bridge alarm panel design - Action 7-A

Main author of the chapter: Michael Stig, DFDS

This chapter gives an overview of the ship integration evaluation for the Action 7--A i.e. Improved bridge alarm panel design. Two RCMs are proposed by WP07 and one RCO selected (Ref. D04.6, [2]) and assessed within this report:

- RCM Des1: User friendly alarm system interface design guidelines
- RCM Des2: Alarm system interface prototype
- RCO5: Alarm system interface prototype

For the description of the RCM's including demonstrator, test and simulation results, performance assessment and impact on safety please refer to deliverables D04.10, [4] , D07.3, [24], D07.5, [26] and D07.6, [27]. For the description of the RCO's and FSA results please refer to deliverables D04.6 [2] and D04.7, [3]. For the ship integration evaluation, during the development process, considering design, production and operational aspects refer to deliverable D05.7, [10]. Further, cost and environmental impact was assessed and presented within D05.8, [11].

A design guideline for the industry, as proposed within RCM Des1, is highly welcomed and needed for a harmonisation of the alarm designs, as the current various system designs that may be found on board ships, are ranging from quite user-friendly and intuitive systems to systems that provide very little guidance or perhaps even provide misguidance to the crew/operator.

The demonstration of the prototype of the Digital Fire Central (DFC) was performed (RCM Des2, RCO5), developed based on the novel design guidelines. The demonstration performed at DFDS's facilities included experts/seafarers who are active on ro-ro & ro-ro/pax vessels. The feedback from the stakeholders who tested the DFC is very positive. The results showed a high level of effectiveness, efficiency, satisfaction, and intuitiveness that surpass current installations seen on board.
Specifically, a full understanding of the location, spread, and intensity of the fire as well as cargo information, tracking of the development of the fire, and effectiveness of used countermeasures which is highly valued and can guide the Fire leader in his decision-making process on how to approach the fire. Further, all devices related to a fire incident and firefighting such as the sprinkler system, the fire doors, ventilation, fire dampers can be activated on the DFC.
The DFC may provide shorter response time, minimize misunderstandings between the operator and crewmembers and reduction of errors in decision making.
On the other side, the proposed solution is focusing on organizational solutions where the integration of the solution into ship systems was not in focus and found not to be mature for a full integration evaluation especially for existing ships. For the new buildings, the solution may be easily integrable, considering that a complete solution according to the proposed system requirements is available on the market, i.e., from the ship system providers.

Finally, the opinion is that such installation should improve the fire safety on board ro-ro ships and shall be seriously considered for all type of ro-ro ships new buildings. On top of that, the implementation of solution is shown to be cost-effective for all types of ro-ro ships.

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

Main author of the chapter: Michael Stig, DFDS

This chapter gives an overview of the ship integration evaluation for the Action 7-B, i.e., firefighting resource management centre. Two RCMs are proposed by WP07 and two RCO's selected and assessed within this report:

- RCM Des3: Procedures and design for efficient extinguishment system activation
- RCM Des4: Training module for activation of extinguishing systems
- RCO6: Process for development of procedures and design for efficient activation of extinguishing system
- RCO7: Training module for efficient activation of extinguishing system

For the description of the RCM's including test and simulation results, performance assessment and impact on safety please refer to deliverables D04.10, [4] and D07.9, [30]. For the description of the RCO's and FSA results please refer to deliverables D04.6 [2] and D04.7, [3]. For the ship integration evaluation, during the development process, considering design, production and operational aspects refer to deliverable D05.7, [10]. Further, cost and environmental impact was assessed and presented within D05.8, [11].

The implementation of the reflection, evaluation and change (REC) process for efficient extinguishment system activation (RCM Des3, RCO6) is found to be feasible for new buildings with no significant impact on the cost whereas for existing ships it may significantly vary depending on the ship, crew, etc. as may affect the ship systems. Hence, the procedures and design are adapted to actual working context, experiences and practices of the actual crew in the actual vessels and final implementation of recommendations, as resulted from the output from the REC process, depends on the ship operator strategic decision and may not affect ship systems but operational procedures only. Generally, in a fleet with many vessels, types of vessels and different crews for each vessel, it is most likely valuable to have harmonized company standards and avoid deviations in the process. Finally, it is crucial that all steps in the process are considered and well described. **However, the final implementation of recommendations implies improvements in the activation processes, with the crew in as a target group and highly recommended for implementation.**

Training for the activation of extinguishing systems (RCM Des4, RCO7) is deemed to significantly improve the release procedures of the fixed firefighting systems, thereby enabling a faster response, especially in the case of drencher systems. Generally, the training will improve the participants' competences, especially for CO2 systems as there are various manufacturers and system activation arrangements, that differ in significant ways in their way of deployment and operation. However, this variety may be an issue for a single training provider. Furthermore, for CO2 systems, it is recommended to take into account the mandatory 100 % accurate headcount of the crew before activating the system. It is suggested that this process should be carried out on board through enhanced and frequent drills, rather than being conducted ashore at a training facility.

Regarding drencher system activation, the opinion is that onboard training may add more value compared to onshore training and agree with recommended incorporation of drencher activation to the on-board training routines.

In terms of the onboard trials, the feedback from the crew confirms the need for an additional training in order to improve the flexibility and reaction time of the fire team. Further, the formal safety assessment results showed that for a ro-ro cargo the implementation is not cost effective considering onshore training. However, for the ro-pax and vehicle carriers the implementation is cost effective according to the formal safety assessment.

Finally, the implementation of the proposed training course is found positive, considering the above recommendations.

10 Firefighting resource management centre - Action 7-C

Main author of the chapter: Michael Stig, DFDS

This chapter gives an overview of the ship integration evaluation for the Action 7-C i.e. firefighting resource management centre. The RCMs proposed by WP07 and assessed within this report are:

- RCM Des5: Integrated solutions for fire resource management, combining relevant sources of information, including drone and camera monitoring system.
- RCM Des6: Guidelines for organizing the response in case of a fire emergency.

For the description of the RCM's including demonstrator, test and simulation results, performance assessment and impact on safety please refer to deliverables D04.10, [4] , D07.4, [25], D07.7, [28], D07.8, [29], and D07.11, [32]. For the ship integration evaluation, during the development process, considering design, production and operational aspects refer to deliverable D05.7, [10]. Further, cost and environmental impact was assessed and presented within D05.8, [11].

The proposed integrated solutions for fire resource management (RCM Des5) are found to be very valuable to the ship operator as they include integrated sources of information and additional equipment that may lead to improvements towards early detection, easier and faster decision making and hence increased fire safety on board. This new stream of data by using the suggested drone system provides intelligence that most likely would not be available through stationary sensor equipment or by human intelligence due to potential unacceptable risks to human life in a fire scenario. However, such system should be seen complementary to existing fire safety systems. There are still some challenges identified for a straightforward implementation related to cost and legal feasibility addressing relevant maritime and airspace regulations.

A set of tools and guidance on how to manage the available resources in the best way, as suggested within RCM Des6, could be highly valuable, as it would ensure a stable learning process for individual and organizational learning. Simulation of these tools with crew members showed an increased awareness of others' perspectives, a more detailed understanding of the functions required in fire-emergency management, increased creativity in order to anticipate and train for unexpected events and an enhanced exchange of experience.

Specifically, the concept where a firefighting school combined with a bridge simulator, gave the opportunity for a full-scale exercise in a very realistic environment. The training instructors could in every phase of the exercise apply extra stress towards participants such as navigational hazards, ship-shore communication jamming or multiple fire alarms for the bridge team. The Fire commander and the firefighting teams tested additional equipment as fire blanket, CO2 and compress foam. As an extra feature poor communication was added. During the debriefing of the navigational team and firefighting team they used FRMC-cards ¨conditions cards¨ to systematically adding words to their actions. Card by card they put words on their decisions and the cards were used to spot arising hazards and an inspiration for planning of future fire drills. In general, positive feedback was received from the participants. And it was concluded that such exercises most likely have the ability to add value to the on-board drills and exercises.

The proposed solution is found highly valuable at a low cost and recommended for implementation.

11 Automatic screening and management of cargo hazards-Action 8-A

Main author of the chapter: Martin Carlsson, STL

This chapter gives an overview of the ship integration evaluation for the Action 8-A i.e. automatic screening and management of cargo hazards. The RCMs proposed by WP08 and assessed within this report are :

- RCM Pre1a: Cargo scanning and identification and tracking system
- RCM Pre1b: Automatic screening with rolling drone
- RCM Pre2: Stowage planning tool with optimization algorithm for cargo distribution

For the description of the RCM's including demonstrator, test and simulation results, performance assessment and impact on safety please refer to deliverables D04.10, [4] , D08.1-D08.4, [33]-[36] and D08.7-D08.13, [39]-[45]. For the description of the RCO's and FSA results please refer to deliverables D04.6 [2] and D04.7, [3]. For the ship integration evaluation, during the development process, considering design, production and operational aspects refer to deliverable D05.7, [10]. Further, cost and environmental impact was assessed and presented within D05.8, [11].

The solution of cargo scanning and identification and tracking system (RCM Pre1a) will contribute to identify and avoid fire risks onboard and/or highlight units with increased risk for extra attention during voyage. If a link between screened parameters and onboard fire risk can be established, it will enable fact-based decision making and resource prioritization which implies an increased fire safety on board. Related equipment may be located at terminal gate, at ramp of the ship or somewhere else inside the terminal area, depending on what is most practical where the opinion is that is most suitable for terminals with large cargo flows.

The solution is demonstrated at Stena Majnabbe – terminal in Gothenburg. Vehicle and temperature measurements and staff alerts are proven to work well. The process to inspect the reefer unit after the selection by the screening system and the decision process and interaction between terminal staff and ship crew was ongoing at the time of writing this report.

The Automatic screening with rolling drone (RCM Pre1b) is interesting since large number of cargo units/vehicles can be covered with less equipment. However, the solution needs to be further developed to be brought forward as a proposal.

The Stowage planning tool with optimization algorithm for cargo distribution (RCM Pre2) will provide more transparent overview to the fire safety situation onboard as well as to provide decision support for fire safety increase on each voyage. It may also lead to continuous crew learning to improve localization of fire dangerous units in relation to vessel conditions and other units. One theoretical possibility is to use the algorithm result to optimize stowage of vehicles. This may be done to an acceptable cost for individually handled units such as unaccompanied trailers, but is not realistically applied to self-driving units due to their mode of handling in port. On a statistical level, operator may gain knowledge on concentration of fire risks in operations. Additionally, the algorithm result in way of the risk contribution matrix of location against cargo type could be used to evaluate different ship designs in terms of fire safety. To support late stage changes, and information transfer interface such as tablets or similar equipment, may be used by loading officers, tug master drivers and other terminal coordinating staff. Other crew members on board need "hands free" equipment for manoeuvre and lashing instructions.

12 Guidelines and solutions for safe electrical connections - Action 8-B

Main author of the chapter: Martin Carlsson, STL

This chapter gives an overview of the ship integration evaluation for the Action 8-B i.e. guidelines and solutions for safe electrical connections. Two RCMs are proposed by WP08 and two RCO's were selected (Ref. D04.6, [2]) and assessed within this report:

- RCM Pre3 - Develop guidelines for safe electrical power connections in ro-ro spaces for reefer units
- RCM Pre4 - Develop guidelines for safe electrical power connections in ro-ro spaces for charging of EVs
- RCO8 - Safe electrical connection for reefers
- RCO9 - Safe electrical connection of reefers and electric vehicles (EVs)

For the description of the RCM's including demonstrator, test and simulation results, performance assessment and impact on safety please refer to deliverables D04.10, [4] , D05.10, [33], D08.5, [37] and D08.6, [38]. For the description of the RCO's and FSA results please refer to deliverables D04.6 [2] and D04.7, [3]. For the ship integration evaluation, during the development process, considering design, production and operational aspects refer to deliverable D05.7, [10]. Further, cost and environmental impact was assessed and presented within D05.8, [11].

The main aim for fire safety for reefer units, and other cargo, is to prevent loading of any substandard units. This is very challenging in practice but may be attempted by prompting transport companies to secure and show proof of good service and condition of units. Units should be also checked either by manual or automated screening on arrival to terminal as considered in Chapters 4 and 11.   As suggested in guidelines for safe electrical power connections in ro-ro spaces for reefer units (RCM Pre3, RCO8), if each reefer connection is individually monitored and an alarm from the monitoring system is treated with more sense of urgency compared to present earth faults, the time from first trigger to confirmed fire situation will be shortened.

The proposed solution has been demonstrated on Stena Scandinavica and shown to be reliable and usable. Finally, manageable for both new buildings and existing ships.

Certain EV charging systems have monitoring of charging session and vehicle included. Others will be less advanced or less open to communication with external systems and therefore require external monitoring such as proposed in RCM Pre4. It is a great advantage to have access to a "black box" monitoring system, this gives flexibility for different charging solutions. False alarms must be eliminated to avoid poorly based interruption in charging service to the client. The proposed solution to monitor EV charging is considered manageable for both new buildings and existing ships.

The proposed solutions address the riskiest cargo related to fire challenge. With these solutions in place, there would be a clear added value providing more precise analysis of reefers and EV's in terms of status and location of a problematic units. The crew gets a better insight into fire risk assessment and will have the possibility to act with higher attention. Therefore, response times and investigation effort will be shorter. Value and effectiveness is confirmed by the FSA for ro-pax ships, but shown not cost-effective for ro-ro cargo vessels. However, it is recommended also for ro-ro cargo vessels due to the large ro-ro deck area and a smaller crew compared to ro-pax, leads to smaller ability for strong manual interventions and lack of frequent fire patrols in cargo spaces.

13 Fire requirements for new deck materials - Action 8-C

Main author of the chapter: Vito Radolovic, FLOW

This chapter gives an overview of the ship integration evaluation for the Action 8-C i.e. fire requirements for new deck materials. The RCM proposed by WP08 and assessed within this report is:

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

For the description of the solutions and an overview of the testing and demonstration please refer to deliverables D04.9, [1] and D04.10, [4], respectively. For the ship integration evaluation, during the development process, considering design, production and operational aspects refer to deliverable D05.7, [10].

The knowledge of the material properties and requirements, specifically for reaction to fire properties, may lead to a reduced lead time and cost of the design and approval process by reducing uncertainties and may generally increase the application of such materials on ro-ro ship. Further, it may have positive impact during the fire management operations.

Considered composite materials and intumescent coating systems were found most relevant from WP05 perspective, and so the impact of the results may be significant.

14 Means for detection on weather deck - Action 9-A

Main author of the chapter: Lena Brandt, DFDS

This chapter gives an overview of the ship integration evaluation for the Action 9-A, i.e., means for detection on weather deck. Two RCMs are proposed by WP09 and one RCO selected (Ref. D04.6, [2]) and assessed within this report:

- RCM Det1 – Flame wavelength detectors
- RCM Det8 – Thermal imaging (infrared) cameras
- RCO10 – Fire detection on weather deck

For the description of the RCM's including demonstrator, test and simulation results, performance assessment and impact on safety, please refer to deliverables D04.10, [4] and D09.1, [47]. For the description of the RCO's and FSA results please refer to deliverables D04.6 [2] and D04.7, [3]. For the ship integration evaluation, during the development process, considering design, production and operational aspects refer to deliverable D05.7, [10]. Further, cost and environmental impact was assessed and presented within D05.8, [11].

The proposed solutions have potential to significantly increase the possibility of an early detection of fires on weather decks. Further, the integration is found feasible for both new buildings and existing ships at a reasonable cost.

The conducted onboard tests showed that the alarm threshold setting of the detector is a key factor defining the performance of the detector. Correspondingly, there is a trade-off between early detection and frequency of nuisance alarms that could be expected. The cameras installed onboard and being exposed to the weather elements have shown to be reliable and usable. Specifically, the final testing of detection solutions on board the HOLLANDIA SEAWAYS was a success, although the weather conditions was unfavourable. Weather conditions during the test was rain and a strong wind from the forward part of the vessel going through deck 7 and the weather deck. All detectors were activated by the flame. However, going through the history of alarms, it was found that one of the video flame detectors has not sent any signals to the alarm panel due to improper installation. Flame detectors with triple IR technology and heated lens window, that can reduce condensation and icing on the camera lens, could be a good solution as the vessel sail in these unfavourable weather conditions. During the onboard trials, all the detectors identified the flame, including the video flame detector, which was installed improperly, as it had its alarm LED turned on upon seeing the flame. However, the video flame detector did not send any signals to the control panel, so its history of alarms during the fire experiments and during the operational trial is unknown. Accordingly, only multiband infrared flame detectors are recommended as a viable solution for weather decks. Infrared cameras produce nuisance alarms even with adjusted settings, and so not recommended.

During the tests, the crew on board HOLLANDIA SEAWAYS expressed their concern regarding the lack of fire detection systems normally installed on the weather deck, although the area is covered with CCTV cameras. An upgraded version or additional detection would be preferred.

However, the implementation of weather deck detection is found to be cost wise ineffective in terms of life and cargo safety, where the main reason of such result is a low fire ignition frequency (statistical data) on weather decks.

Nevertheless, the installation of a weather deck detection system is recommended for both ro-pax and ro-ro cargo weather decks.

15 New means for fire detection in closed and open ro-ro spaces - Action 9-B

Main author of the chapter: Michael Stig, DFDS

This chapter gives an overview of the ship integration evaluation for the Action 9-B i.e. new means for fire detection in closed and open ro-ro spaces. Three RCMs are proposed by WP09 and one RCO selected (Ref. D04.6, [2]) and assessed within this report:

- RCM Det3 - Video detection
- RCM Det4 - Adaptive detection threshold settings
- RCM Det7 - Linear heat detection
- RCO11 - Fire detection in closed ro-ro spaces & open ro-ro spaces

For the description of the RCM's including demonstrator, test and simulation results, performance assessment and impact on safety please refer to deliverables D04.10, [4] and D09.2, [48]. For the description of the RCO's and FSA results please refer to deliverables D04.6 [2] and D04.7, [3]. For the ship integration evaluation, during the development process, considering design, production and operational aspects refer to deliverable D05.7, [10]. Further, cost and environmental impact was assessed and presented within D05.8, [11].

From the ship integration point of view, simplicity, reliability and costs are important factors for the selection and implementation of a new detection system. Further, the fire detection systems should be able to detect fires on cargo with novel materials and technologies.

In general, traditional smoke detectors were found to detect fires more rapidly in almost all scenarios, as demonstrated during simulations. However, there are certain advantages of the proposed detection technologies over the traditional systems as found at RCM Det7, such as minimal maintenance requirements and improved coverage.

The onboard test trials, specifically the final testing in March 2023 on board the HOLLANDIA SEAWAYS were a success. The video detection system was tested onboard only in the closed ro-ro space using artificial smoke (generated by a fog machine), which was detected successfully. Depending on the distance of the smoke source from the camera, the detection time varies from 10s of seconds to several minutes after smoke generation. The linear heat detection (LHD) system was tested in the open ro-ro space along with conventional heat sensors using a propane burner with a peak heat release rate of 140 kW. The fire was detected by the LHD system in two scenarios: once along the sides of the deck, and once along the centre of the deck with an obstruction against wind at lower heights which simulated the presence of passenger cars in the deck. The conventional heat sensors did not detect any of the fires, especially because there was unfavourable wind with a high velocity along the length of the deck, in the order of 5 m/s. The strong winds from the forward part of the vessel going through the empty open deck made it difficult for the propane flame to be detected. This was why additional gypsum boards were used to give shelter, simulating the presence of cargo at lower heights in the deck. During the test it was found that the flame detector for the open ro-ro space was activated immediately, even though it did not see the flames directly.

The lack of activation of vessels own detectors was a great concern for the crew. Given the various side openings at deck 7 and at deck 5, the vessel struggles with faulty detectors due to the harsh weather conditions, and the cost of the replacement of detectors is high. The crew see a great advantage to use the LHD cable as maintenance and checks are not very time consuming. In case of damage to the LHD cable, the relevant crew members such as the Electrician or Engineer can be trained to do a replacement of the damaged part with the proper tool in a short amount of time. Furthermore, in the case of a fibreoptic LHD system, heat monitoring is done along the entire length of the cable compared to the regular fire detectors which only detect near the area where they are fitted.

The VFD & VSD systems (RCM Det3) do seem to have a good potential as CCTV systems are already being used on ro-ro cargo decks for existing tonnage, even though the coverage, picture quality and maintenance may pose a challenge.

The solution of adaptive threshold settings for detection (RCM Det4) is expected to be only integrable for new buildings due to potential difficulties with system software adjustments and approval issues.

The proposed solutions have a potential for increasing the possibility of detecting fires in closed and open ro-ro spaces, however, at a relatively high life cycle cost. High cost finally resulted that the installation of such system is found not to be cost effective with exception of saving cargo on ro-pax ships. It needs to be emphasized that the cost significantly depends on the ro-ro space arrangement and shall be considered for the specific application.

Finally, video fire detection can be recommended for closed ro-ro spaces as an effective and economical solution. For open ro-ro spaces, LHD systems are strongly recommended.

16 Means for automatic fire confirmation, localization and assessment - Action 9-C

Main author of the chapter: Michael Stig, DFDS

This chapter gives an overview of the ship integration evaluation for the Action 9-C i.e. means for automatic fire confirmation, localization and assessment. Two RCMs are proposed by WP09 and one RCO selected (Ref. D04.6, [2]) and assessed within this report:

- RCM Det5 - Video fire detection
- RCM Det6 - Thermal imaging (infrared) cameras
- RCO12 - Visual system for fire confirmation and localization

For the description of the RCM's including demonstrator, test and simulation results, performance assessment and impact on safety please refer to deliverables D04.10, [4] and D09.3, [49]. For the description of the RCO's and FSA results please refer to deliverables D04.6 [2] and D04.7, [3]. For the ship integration evaluation, during the development process, considering design, production and operational aspects refer to deliverable D05.7, [10]. Further, cost and environmental impact was assessed and presented within D05.8, [11].

The proposed solutions have a potential for increasing awareness on a fire situation within ro-ro spaces, providing a prompt and detailed information to the crew, and enabling a prompt fire confirmation and localization as well as a quick first firefighting response.

The VFD & VSD systems (RCM Det5) do seem to have potential as CCTV systems are already being used on ro-ro cargo decks. However, the coverage, picture quality/resolution and maintenance of the CCTV may cause challenges.

Thermal infrared imaging cameras (RCM Det6) have advantages over other systems (VSD & VFD) due to the ability to detect heat sources without direct line of sight to flames and/or smoke. Moreover, these type of systems may need fewer cameras to still give full coverage of a ro-ro deck. Such cameras will work independently of ambient light conditions. Finally, thermal infrared imaging cameras may be a contributor to early detection of (concealed) fires.

According to the onboard trials, the feedback from the crew shows that the video fire detection is an effective and economical solution as it can, in principle, use existing CCTV, albeit a local server must be installed to allow analyzing the footage in situ. Thermal imaging systems can provide more information but they are more costly and prone to nuisance alarms.

The life cycle cost of these visual system for fire confirmation and localization is relatively high, especially for vehicle carriers. High cost finally resulted that the installation of such system is likely not cost-effective for ro-ro cargo and vehicle carriers while for ro-pax ships, it may be cost effective.

For additional aspects, see also Chapter 14 and Chapter 15.

17 Local application fire-extinguishing systems - Action 10-A

Main author of the chapter: Urban Lishajko, WAL

This chapter gives an overview of the ship integration evaluation for the Action 10-A i.e. local application fire-extinguishing systems, which has been added the description "Automatic first response fire protection systems" since it is better describing the intention of the action.

Three RCMs are proposed by WP10 and one RCO selected (Ref. D04.6, [2]) and assessed within this report:

- RCM Ext1a - A dry pipe sprinkler system. Note: This is per definition an automatic system
- RCM Ext1b - An automatic deluge water spray system utilizing open nozzles
- RCM Ext2 - A deluge system using rotating CAFS nozzles
- RCO13 - Local application fire-extinguishing systems

For the description of the RCM's including demonstrator, test and simulation results, performance assessment and impact on safety please refer to deliverables D04.10, [4] and D10.1, [50].For the description of the RCO's and FSA results please refer to deliverables D04.6 [2] and D04.7, [3]. For the ship integration evaluation, during the development process, considering design, production and operational aspects refer to deliverable D05.7, [10]. Further, cost and environmental impact was assessed and presented within D05.8, [11].

There are several operational advantages in a dry pipe sprinkler system (RCM Ext1a) compared to open nozzle systems. Since the sprinklers are activated by the heat close to the fire, the number of nozzles and thereby the amount of water is limited, consequently the system could be made more optimized in terms of size, capacity and costs. The vessel stability issue connected to water on deck would be less pronounced compared to open nozzle deluge systems. The dry pipe system with bulb nozzle-design is closed and clean with less risk for contamination of cargo during normal service.

Contrary, an open nozzle deluge systems (RCM Ext1b) has an advantage from an extinguishing point of view compared to dry pipe systems, as water can be applied over large deck sections instantly, comparable to drencher systems on Ro-Pax vessels. However, as a complement to CO2, this type of system can be unnecessarily large and complicated and thereby costly.

Deluge systems should be designed for the simultaneous activation of the two (or four) adjacent deluge sections with the greatest hydraulic demand at a minimum water discharge density. This results in a total water demand that is higher than that of a dry pipe system (Ref RCM Ext1a). Another drawback compared to a dry pipe system is that a large number of deluge valves are required and that drainage will be even more demanding.

A deluge system using rotating CAFS nozzles (RCM Ext2) was disregarded for further evaluation as it was proven to be more expensive to install and maintain serviceable than the two solutions discussed above. Furthermore, it was not proven that CAFS offered any improved fire protection performance in the fire intermediate-scale tests conducted in the LASH FIRE project.

RCO 13 relates to the RCM Ext1a (A dry pipe sprinkler system) which was found to be the only realistic alternative RCM from cost and technical point of view among the other proposed RCMs for a local fixed firefighting system, intended to complement a CO2 fixed firefighting system.

An open nozzle deluge system has its advantages but was deemed to be too large and costly to be feasible as a complement to a CO2 system. Introducing such a system could be more relevant if it is done to replace the CO2 system, but that is outside the scope of Action 10-A.

Fire tests in LASH FIRE showed that a water-based system can control a vehicle fire and prevent it from spreading from vehicle to vehicle for 30 minutes which means that the initial assumptions for Action 10-A were relevant.

A quick first action is in general always crucial for the outcome of a fire incident onboard. On ocean going vehicle carriers manual firefighting attempts should not be counted out but in general the possibility to access a vehicle in the cargo space is low considering the way vehicles are stowed and lashed. Attempts for manual firefighting could hamper the release of CO_2 where valuable time margins could be lost because of the strict safety requirements for the crew before the release can be done. Therefore, firefighting tactics should focus on situation awareness and the aim for quick release of the fixed firefighting system. The proposed local application firefighting system could bridge this gap and effectively and quickly isolate a fire and give the crew valuable time for assessment of the situation and the possible release of the CO_2 system. Related to the carriage of APVs, a local application firefighting system could enhance safety in that a quick action to isolate a fire in any type of vehicle would lower the risk of involving APVs such as BEV or CGV. It would also offer a way to apply water into the space in order to faster cool down the fire scene after CO_2 has been released, and thereby to lower the risk for secondary damage to batteries or the heating of compressed gas tanks in the space.

Compared to a CO_2 system, any type of water sprinkler system will be more complicated inside the cargo space due to piping installations for coverage on each deck and due to the fact that sprinkler nozzles must be carefully located in the deck head structure. Vehicle carriers often have several movable deck panels which adds to the complexity. The scupper and drain systems must be re-designed. These facts mean that a retrofit on existing vessel would be very complicated and not a realistic option. For a new building, the system could be integrated into the design from the start which could be done with lesser costs than for a retrofit. However, the cost effectiveness assessments performed for a new building show that this RCO still has a negative result due to high installation costs and due to the fact that fires statistically occur only sporadically, especially during the transport of new vehicles on a vehicle carrier.

Even though cost effectiveness calculations show that the overall saving for the shipping industry is negative in the bigger picture, the RCO13 should be interesting from a principal point of view in that it offers a reasonable way to enhance the safety on vehicle carriers.

18 Weather deck fixed fire-extinguishing systems - Action 10-B

Main author of the chapter: Vito Radolovic, FLOW

This chapter gives an overview of the final performance, feasibility and integration assessment for the Action 10-B i.e. weather deck fixed fire-extinguishing systems. Four RCMs were proposed by WP10 and two RCOs selected (Ref. D04.6, [2]) for the Formal Safety Assessment (FSA):

- RCM Ext3 - Autonomous fire monitor (water only) system for the protection of weather decks
- RCM Ext4 - Remotely-controlled Compressed Air Foam fire monitor system for the protection of weather decks
- RCM Ext3a - Remotely-controlled fire monitor (water only) system for the protection of weather decks
- RCM Ext4a - Autonomous Compressed Air Foam fire monitor system for the protection of weather decks
- RCO14 - Fixed remotely-controlled fire monitor system using water for weather decks
- RCO15 - Fixed autonomous fire monitor system using water for weather decks

For the description of the RCM's including large scale on shore and onboard test results, performance assessment and impact on safety please refer to deliverables D04.10, [4], D10.2, [51] and D10.3, [52]. For the description of the RCO's and FSA results please refer to deliverables D04.6 [2], D04.7. For the ship integration evaluation, during the development process, considering design, production and operational aspects refer to deliverable D05.7, [10]. Further, cost and environmental assessment was assessed and presented within D05.8, [11].

The final result of the Action 10-B is the design guideline for the Weather deck fixed fire-extinguishing systems. According to the guidelines, the system is supposed to be designed in terms of flow rates, discharge duration and positions of fire monitors in order to suppress and thereafter control a fire to facilitate (if needed) manual firefighting operations to completely extinguish a fire.

The ship integration, life cycle cost (LCC) and environmental assessment was performed for the proposed solutions, developed according to the guidelines, where integration was considered on the reference generic ships, Magnolia Seaways, the generic ro-ro cargo ship and Stena Flavia, the generic ro-pax ship. Further, life cycle cost assessment results were used for the Formal Safety assessment (FSA) within WP04. A view on the FSA results as well as on shore and on board test results is presented within this report.

From the ship integration and operation point of view, the proposed solutions are considered to be manageable for both new buildings and existing ships with minor impact on the ship arrangement and increasing the level of fire safety.

Currently, there are no rules or requirements for weather deck fixed fire-extinguishment systems and automatic detection system. However, it is being considered by IMO and it seems it is likely to come into force in the near future. The implementation of such systems is therefore currently a decision left to the ship operators.

The use of an autonomous or remote-controlled fire monitors for firefighting purposes is found to be both more effective and considerably safer than manual firefighting involving crew members, especially as any manual operation of fire monitors shall be remote-controlled from a safe position. A fully autonomous system minimizes the crew involvement and will offer advantages in terms of faster awareness of a fire and almost immediate activation.

The on shore large scale test results proved that the performance objectives of the system solutions were met when using water, while the tests with CAF were not as successful, as a proper quality of foam and flow rate was not reached. The use of foam, is, however, expected to improve the performance of water only for fire scenarios involving flammable liquids.

The test results showed that heavy weather condition may influence the possibilities to reach a fire from two application angles, however, it was demonstrated that even a single fire monitor can provide fire suppression given that the water reaches the fire. Considering this result, it is reasonable that smaller parts of the deck area “shielded” by deckhouses or superstructures may not to be protected with a minimum of two fire monitors, as prescribed by the design guideline, but only with one fire monitor.

Finally, the two RCO’s considering the use of water were selected for the FSA.

The life cycle cost assessment of the proposed weather deck fire monitor system solutions was performed and results provided for the FSA. It needs to be emphasized that the installation cost is considerably dependent on the weather deck arrangement. Specifically, obstructions arrangements such as engine casing and deckhouses as well as deck area size and shape, have a significant impact on the number of fire monitors and fire detectors to be installed, which represent the majority of the installation and maintenance cost. Finally, it is difficult to scale the cost per ship type, lane meters, or deck area, where the cost shall be calculated on a case-by-case basis. This issue was further assessed within the FSA where a sensitivity and uncertainty assessment were performed for the proposed RCO’s, Ref. D04.7 [3]. The results showed that, indeed, the cost-effectiveness is dependent on the weather deck arrangement, specifically in term of ro-pax life safety of existing ships where case by case assessment is suggested. For ro-pax new buildings, in term of ro-pax life safety, both RCOs are confirmed to be cost effective. In terms of saving cargo and ship, again both RCOs are found to be cost effective for ro-pax and ro-ro cargo new buildings and for ro-pax existing ships. Further, the implementation of both RCOs is not cost-effective for ro-ro cargo existing ships.

The Life Cycle Assessment (LCA) indicates that the predicted number of serious fires likely to occur on the weather deck of a ship, configured like the considered generic ship Magnolia Seaways, is so low that the environmental impacts of producing, using, and disposing of a fixed water-based fire protection system outweigh the benefits. However, a low probability of serious fire does not mean that new fire safety measures should not be implemented.

Finally, the opinion is that the installation of a weather deck fixed fire-extinguishing systems shall be mandatory for ro-pax new buildings and existing ships and ro-ro cargo new buildings.

19 Updated performance of alternative fixed fire-fighting systems - Action10-C

Main author of the chapter: Obrad Kuzmanovic, FLOW

This chapter gives an overview of the final performance, feasibility and integration assessment for the Action 10-C i.e. updated performance of alternative fixed fire-fighting systems. The RCM proposed by WP10 and assessed within this report is:

- RCM Ext5 - Development of a relevant fire test standard for alternative fixed water-based fire-fighting systems intended for ro-ro spaces and special category spaces.

For the description of the RCM including test results, performance assessment and impact on safety please refer to deliverables D04.10, [4] D10.4, [53] and D10.5, [54]. For the ship integration evaluation, during the development process, considering design, production and operational aspects refer to deliverable D05.7, [10]. Cost assessment is presented within D05.8, [11].

The objective of Action 10-C is not to literally develop any performance-based systems, instead it is to establish a harmonized performance level for performance-based systems that is similar to that of prescriptive-based systems.

The concern is that the performance-based systems that have passed the tests do not provide a fire suppression performance that is comparable to that of the prescriptive-based system design in MSC.1/Circ.1430, [62]. New fire test scenarios representing fires in a passenger car as well as a freight truck trailer were developed, benchmark fire suppression tests were conducted with systems designed per the prescriptive-based requirements in MSC.1/Circ.1430. Thereby, new acceptance criteria was established and revised fire test procedures developed.

The developed fire test procedures for performance-based systems in more realistic and relevant manner equalize the safety levels for prescriptive- and performance-based systems where ultimately, performance-based systems can achieve similar or better performance properties as prescriptive-based system.

Cost assessment was not performed, however, proposed new standards may have impact on the system design requirements and thus impact on the life cycle cost, specifically, system integration cost. Further, it is assumed that the routines for inspections, testing, and maintenance are similar for performance-based and prescriptive-based systems and that the use of performance-based system is not resulting in additional operational costs.

Moreover, the development results provide an insightful view related to fires in electric vehicles. It is found extremely important to reduce uncertainties and suspicions which are currently associated with this topic. Fires in electric vehicles have gained a lot of space in the media and an indication of the severity of such fires on ro-ro spaces on board ships are desired.

The fire tests involving ICEV's and BEV's indicate that a fire in a BEV does not seem to be more challenging than a fire in an ICEV for a system design in accordance with the prescriptive-based requirements in MSC.1/Circ.1430. The overall conclusion is that a fire in a battery electric vehicle does not seem to be more challenging than a fire in a gasoline-fueled vehicle for a drencher system designed in accordance with current recommendations in MSC.1/Circ.1430.

20 Division of ro-ro spaces - Action 11-A

Main author of the chapter: Vito Radolovic, FLOW

This chapter gives an overview of the final performance, feasibility and integration assessment for the Action 11-A i.e., division of ro-ro spaces. The RCMs proposed by WP11 and assessed within this report are:

Horizontal subdivision of ro-ro spaces:

- RCM Cont1b1 - A-30 fire insulation at decks separating ro-ro spaces
- RCM Cont1b2 - Extinguishing system simultaneously activated above and below sub-dividing deck

Vertical subdivision of ro-ro spaces:

- RCM Cont3b - Solid curtain, transversal mounting, fully rolled down
- RCM Cont3d - Solid striped curtain, transversal mounting, fully/partly rolled down

For the description of the RCM's including test results, performance assessment and impact on safety please refer to deliverables D04.10, [4], D11.1, [55] and D11.2, [56]. For the ship integration evaluation, during the development process, considering design, production and operational aspects refer to deliverable D05.7, [10]. Further, cost assessment is presented within D05.8, [11].

The proposed horizontal subdivision RCMs Cont1b1 and Cont1b2 will improve the safety level of the ship for a relatively low impact on the ship and ship systems arrangement and integration cost. However, at solution Cont1b1, requirements with respect to fire integrity, and gas tightness of decks shall be further clarified. Further, the simulation results (obtained by using the specific time-temperature curve) and conclusions on fire safety significantly affect current rules and regulations requirements and should be carefully presented to the stakeholders as it questions current standards, Ref D05.7, [10].

Hence, the RCM Cont1b1 may be considered as "low hanging fruit" for implementation into regulatory requirements for ro-pax new buildings, where the opinion is that the requirements at RCM Cont1b2 shall be further developed before implemented into regulatory requirements.

The proposed vertical subdivision RCMs Cont3b and Cont3d are found to be manageable for both ro-pax and ro-ro cargo new buildings, but hardly manageable for ro-ro spaces with movable decks. Tests results show that a curtain that is fully rolled down results in effective subdivision of a ro-ro space in term of shielding of hot smoke where a partly rolled down curtain is not as effective subdivider as a fully rolled down curtain. Further, several design aspects, such as arrangement at movable decks, interference with surrounding structure, equipment, cargo and crew passageways, etc. are not fully developed, hence not mature for implementation. For further developments, it is proposed that a functional requirement is set for the definition of vertical subdivision.

Furthermore, discontinuation in cargo stowage on deck significantly influence the cargo handling operations and cargo loading flexibility leading to significant increase of operational cost for both Cont3b and Cont3d (arranged at movable decks).

It needs to be emphasized that the impact on the integration into the ship as well as life cycle cost are dependent on the ro-ro space arrangement, specifically, cargo space size (area) and deck structural arrangement. Hence, it is difficult to scale the impact per ship type, lane meters, or deck area, and shall be assessed on a case-by-case basis.

The opinion is that both Cont3b and Cont3d are not mature for implementation into regulatory requirements. Further, the acceptance by maritime stake holders is questionable due to significant operational cost.

21 Ensuring safe evacuation – Action 11-B

Main author of the chapter: Vito Radolovic, FLOW

This chapter gives an overview of the final performance, feasibility and integration assessment for the Action 11-B i.e., ensuring safe evacuation. The RCM proposed by WP11 and assessed within this report is:

- RCM Cont5 -Alternative disembarkation path based on slides

For the description of the RCM including numerical simulation and test results, performance assessment and impact on safety please refer to deliverables D04.10, [4] and D11.3, [57]. For the ship integration evaluation, during the development process, considering design, production and operational aspects refer to deliverable D05.7, [10]. Further, cost assessment was not assessed as the development was found to be not mature for ship integration and further assessments.

Action 11-B solutions suggest recommendations for the design of Ro-Ro ships to ensure safe evacuation during safe return to port and when arriving at foreign port. Different alternative means of ship abandonment (pilot door, bunker door, use of slides) were considered, in case all ordinary shore connections are unavailable, provided a safe path toward these means is designed and a safe solution is implemented to reach the quay. Alternative paths were evaluated and found to give a reasonable evacuation time.

Generally, the solutions are integrable into ship systems and operations, but a more detailed technical specification are required to fully assess the integration on board and its costs. Proposals for further developments are given within D05.7, [10].

The arrival at foreign port after safe return to port and safe evacuation is a topic not very well covered by present regulations, especially for ro-pax vessels (the scenario when the fire blocks ro-ro and passenger loading ramps and gangways also cannot be used due to foreign port). Therefore, the recommendation is to further develop the alternative disembarkation for ro-pax new buildings, considering shell doors. Design guidelines may be developed, so the shell door and evacuation routes from assembly stations can be designed for alternative evacuation, including fire integrity, stairways, corridors, dedicated embarkation ramp, etc.

Alternative disembarkation solution considering the use of slides from the assembly station level, was found to be a non-safe solution and consequently disregarded.

Further, evacuation model result, which is worth mentioning, showed that the time required for the assembly phase is by far shorter than the fire development. This step does not require any new specific risk control measure.

22 Safe design with ro-ro space openings - Action 11-C

Main author of the chapter: Martin Carlsson, STL

This chapter gives an overview of the ship integration evaluation for the Action 11-C i.e., safe design with ro-ro space openings. Two RCMs finally proposed by WP11 and assessed within this report are:

- RCM Cont9 - Ship maneuvering to limit the effects of fire in critical areas
- RCM Cont10 - Safety distances between side and end openings and critical areas

The following solutions were discarded during the development process and not considered for further assessments within WP05, Ref. D05.7 [10]:

- RCM Cont7 - Closure of side openings
- RCM Cont8 - Shutters for side openings

For the description of the RCM's including, test and simulation results, performance assessment and impact on safety please refer to deliverables D04.10, [4] D11.4, [58] and IR11.15, [59]. For the ship integration evaluation, during the development process, considering design, production and operational aspects refer to deliverable D05.7, [10]. Further, cost and environmental impact was assessed and presented within D05.8, [11].

The choice of ship heading is Master's decision considering fire situation, navigational and traffic conditions, evacuation/airlift activities and location of closest safe port. Optimal heading may change during evolvement of a situation. The ship maneuvering guideline (RCM Cont9) intends to give decision support to Master when selecting ships course in a fire situation. The crew is generally aware of the need to select the best possible heading in an emergency, but it can surely be of good value to publish a guideline further emphasizing this and suggest strategies. However, each vessel needs to interpret the generic guideline to the configuration of the ship and establish specific instructions down to an appropriate detail level. The proposed guidelines for ship maneuvering is found manageable within ship operation, especially since it is highly efficient due to the fact that implementation cost of such guidelines is very low.

The result of the analysis of safety distances between side and end openings and critical areas (RCM Cont10) show that significantly larger distances are needed in comparison with the one previously suggested (FireSafe and IMO Circular 1615, [64]). However, it is decided not to propose prescriptive numbers, instead continue developing an evaluation method suitable for application by ship designers. Such alternative design method, enabling a case-by-case assessment, must be suitable from a design point of view and as a proposal for IMO. The proposed solution may potentially imply significant redesign of new ro-pax vessels with same deck arrangement. Implementation of safety distances for side openings may lead to complete banning of the open ro-ro space due to the reason that the minimum required area of openings, according to the Authorities' requirements, might not be fulfilled. During and since SSE7, the IMO process has expressed non-approval of a direct ban of open ro-ro decks. If the intention or a practical consequence of any proposal restricting positions or number of side openings is actually a ban of open ro-ro deck, it must be taken into consideration. Further, the ambition to limit open roro-spaces is in contradiction to promoting well-ventilated spaces for alternatively fuelled vehicles. Restrictions on side openings would also reduce the ability to carry certain categories of dangerous goods (DG), as approved by the Administration.

Finally, along with muster stations and Life Saving Appliance (LSA), it is proposed to identify other objects and areas, which are worthy to protect. Further, fire safety distance criteria should then be established as function of type of area.

23 Ro-ro space ventilation and smoke extraction – Action 11-D

Main author of the chapter: Obrad Kuzmanovic, FLOW

This chapter gives an overview of the final performance, feasibility and integration assessment for the Action 11-D i.e., ro-ro space ventilation and smoke extraction. Four RCMs are proposed by WP11 and one RCO was selected (Ref. D04.6, [2]) and assessed within this report:

- RCM Cont11 – Guidance on calculation of side openings in ro-ro spaces
- RCM Cont12 – Configuration of side openings in ro-ro spaces
- RCM Cont13 – Tactical guidelines for manual intervention
- RCM Cont14 – SOLAS requirement of reversible fans
- RCO16 - Guideline for fire ventilation in closed ro-ro space

For the description of the RCM's including test and simulation results, performance assessment and impact on safety please refer to deliverables D04.10, [4] and D11.5, [60]. For the description of the RCO's and FSA results please refer to deliverables D04.6 [2] and D04.7, [3]. For the ship integration evaluation, during the development process, considering design, production and operational aspects refer to deliverable D05.7, [10]. Further, cost and environmental impact was assessed and presented within D05.8, [11].

The openings and ventilation configuration play an important role on fire and smoke spreading. However, there are lack of procedures and requirements related to ventilation management in case of a fire. Therefore, proposed solutions tend to solve that known issues.

A guideline on calculation of side openings in ro-ro spaces that clearly define the requirement is well accepted as an ambiguous procedure how to calculate side openings was often a problem in design practice. However, such consideration may lead to a reduced design flexibility and further some arrangements on existing ships will not fall into any ro-ro space definition.

Developments within the RCM Cont12 are well received, as the result provided optimal size and configuration of openings in an open ro-ro space maintaining the required ventilation. Suggested configurations are found manageable for new buildings, however, considering closures in way of LSA, engine casings, communication and ventilation ducts, the implementation is manageable at a certain level.

As the ventilation system is, in most cases, specially customized for each ship, it is very difficult to issue general guidelines on how to operate it during fire incidents. The proposed guidelines, with instructions on how to operate with the ventilation system, during a small fire, are found very useful from operational and design point of view. Even the FSA results showed that the solution is not cost effective, it is found as a "low hanging fruit" for implementation as the related costs is relatively low.

24 Conclusion

Main author of the chapter: Vito Radolovic, FLOW

This report summarize the Work Package 5(Ship integration) final assessment results addressed to all the developments within the LASHFIRE project.

Design, production, operational and environmental aspects were considered for all 20 Actions, including several solutions, applicable ro-ro spaces and ro-ro ship types. The assessment process involved continuous exchange with the development teams to further improve the developed solution and to ensure a feasible solution further assessed through the life cycle cost, formal safety assessment and demonstration of the most promising solutions. Finally, performance, feasibility and integration assessment were performed considering all the LASH FIRE assessments result.

This report contributes to the LASH FIRE specific Objective 2:

> *LASH FIRE will evaluate and demonstrate ship integration feasibility and cost of developed operational and design risk control measures for all types of ro-ro ships and all types of ro-ro spaces.*

25 References

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[11] LASH FIRE, Ship integration cost and environmental assessment (D05.8), 2023.

[12] LASH FIRE, Safe electrical systems and equipment demonstrator (D05.10), 2023.

[13] LASH FIRE, Development of and guidelines for quick manual fire confirmation and localization (D06.1), 2021.

[14] LASH FIRE, Guidelines for manual screening of cargo fire hazards and effective fire patrols (D06.2), 2022.

[15] LASH FIRE, Development of and guidelines for communication of fire confirmation (D06.3), 2022.

[16] LASH FIRE, Background and testing of smart alert system of nearby first responders (D06.4), 2021.

[17] LASH FIRE, Development of new standard for effective fire patrols and recommendations for manual screening of cargo fire hazards (D06.5), 2022.

[18] LASH FIRE, Development of smart alert of nearby first responders (D06.6), 2022.

[19] LASH FIRE, Evaluation and development of tactics, gear, equipment and guidelines for effective first response (D06.7), 2023.

[20] LASH FIRE, Development and testing of APV firefighting routines, equipment and tactics (D06.8), 2023.

[21] LASH FIRE, Guidelines for firefighting gear, equipment and tactics, considering APVs (D06.9), 2023.

[22] LASH FIRE, Study and analysis of regulations, accident investigations and stakeholders for bridge alarm panel design (D07.1), 2020.

[23] LASH FIRE, Field study report of alarm panel insufficiencies and improvement identification (D07.2), 2022.

[24] LASH FIRE, Design guidelines for bridge alarm panels (D07.3), 2023.

[25] LASH FIRE, Development of firefighting resource management centre design (D07.4), 2022.

[26] LASH FIRE, Alarm system interface prototype (D07.5), 2022.

[27] LASH FIRE, Alarm system interface prototype development and testing (D07.6), 2022.

[28] LASH FIRE, Development and onboard assessment of drone for assistance in firefighting resource management and rescue operations (D07.7), 2023.

[29] LASH FIRE, Design definition and development of firefighting resource management simulator prototype (D07.8), 2022.

[30] LASH FIRE, Development and implementation of design guidelines and procedures for extinguishing system activation (D07.9), 2023.

[31] LASH FIRE, Deployment and validation of firefighting resource management simulator prototype (D07.10), 2023.

[32] LASH FIRE, Firefighting resource management simulator prototype (D07.11), 2023.

[33] LASH FIRE, Definition and parametrization of critical fire hazards, classification of cargoes, transport units, engines, fuels and vessels and identification methodologies (D08.1), 2021.

[34] LASH FIRE, Fire hazard mapping visualization tool with fire hazard matching integrated (D08.2), 2022.

[35] LASH FIRE, Development of fire hazard mapping visualization tool with fire hazard matching integrated (D08.3), 2022.

[36] LASH FIRE, Stowage planning optimization and visualization aid (D08.4), 2023.

[37] LASH FIRE, Development and validation of safe electrical systems, equipment and routines (D08.5), 2023.

[38] LASH FIRE, Guidelines for electrical systems, equipment and routines, providing safe electrical connection of reefers and electrical vehicles in ro-ro spaces (D08.6), 2023.

[39] LASH FIRE, Description of stowage plan visualization aid demonstration (D08.7), 2023.

[40] LASH FIRE, Stowage plan visualization aid (D08.8), 2023.

[41] LASH FIRE, Prototyping and demonstration of vehicle identification tool (D08.9), 2023.

[42] LASH FIRE, Demonstration of prototype for detection of potential ignition sources (D08.10), 2023.

[43] LASH FIRE, Description of prototypes and demonstration for identification of vehicles and ignition sources (D08.11), 2023.

[44] LASH FIRE, Consolidated guidelines on screening systems [including ignition prevention sensors], appropriateness and placement indications (D08.12), 2023.

[45] LASH FIRE, Overall integration with firefighting control centre (D08.13), 2023.

[46] LASH FIRE, Fire risk assessment and establishment of requirements [material property performance and test method for evaluation] for combustible surfaces in ro-ro spaces (D08.14), 2023.

[47] LASH FIRE, Developed weather deck fire detection solutions and recommendations (D09.1), 2023.

[48] LASH FIRE, Developed ro-ro spaces fire detection solutions and recommendations (D09.2), 2023.

[49] LASH FIRE, Evaluations and recommendations for fire confirmation and localization (D09.3), 2023.

[50] LASH FIRE, *Description of the development of local application fire-extinguishing systems and selected solutions (D10.1), 2022.*

[51] LASH FIRE, *Onboard demonstration of weather deck fire-extinguishment solutions (D10.2), 2023.*

[52] LASH FIRE, *Description of the development of weather deck fire-extinguishing systems and selected solutions (D10.3), 2023.*

[53] LASH FIRE, *Large-scale validation of the new fire test standard for alternative fixed fire-fighting systems (D10.4), 2023.*

[54] LASH FIRE, *Updated test standard for alternative fixed fire-fighting systems (D10.5), 2023.*

[55] LASH FIRE, *Development, theoretical evaluation and preliminary assessment of requirements for horizontal division of ro-ro spaces (D11.1), 2022.*

[56] LASH FIRE, *Development of means for sub-division of ro-ro spaces (D11.2), 2022.*

[57] LASH FIRE, *Development of means for ro-ro ship safe evacuation conditions in relation to fire integrity and walk-off abandonment (D11.3), 2022.*

[58] LASH FIRE, *Description of development and assessment of safe ro-ro space openings (D11.4), 2022.*

[59] LASH FIRE, *Calculation methods for safety distances of ro-ro space openings (IR11.15), 2022.*

[60] LASH FIRE, *Elucidation and guidelines for ro-ro space ventilation in case of fire (D11.5), 2023.*

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26 Indexes

26.1 Index of tables

26.2 Index of figures