FIRESAFE II

Detection systems in open ro-ro and weather decks

Final Report

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Project Partners:	Bureau Veritas Marine & Offshore RISE Research Institutes of Sweden, Fire Research Stena Rederi
WP Leader:	RISE Research Institutes of Sweden
Authors:	Pierrick Mindykowski, RISE Research Institutes of Sweden Jérome Leroux, Bureau Veritas Marine & Offshore Ola Willstrand, RISE Research Institutes of Sweden Blandine Vicard, Bureau Veritas Marine & Offshore Franz Evegren, RISE Research Institutes of Sweden Mattias Frösing, Stena Rederi Lisa Gustin, Stena Rederi

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1 ABSTRACT

One of the main issues with regard to fire safety of open ro-ro spaces and weather decks is that detection systems may not be as efficient as in closed ro-ro spaces. Several recent total losses of ro-ro ships have stressed the need for investigating more efficient fire detection solutions.

This study evaluated available and emerging fire detection technologies for use in open ro-ro spaces and on weather decks. A review of relevant regulations was performed as well as an evaluation of the expected efficiency of the identified alternative detection technologies, considering detection time and sensitivity to weather conditions, loading conditions and deck configuration, as well as cost.

Fibre optic linear heat detection and thermal imaging camera detection were selected for fire tests in open ro-ro space and on weather deck, respectively, onboard a commercial RoPax vessel. Both systems were found functional and suitable for the relevant ro-ro space environments. The risk reduction potentials of the systems were quantified and a cost-effectiveness assessment was performed. Thermal imaging camera detection was found cost-effective for all types of RoPax (Existing ships and Newbuildings), and fibre optic linear heat detection system was found cost-effective for *Standard* and *Ferry RoPax* (Existing ships and Newbuildings).

2 EXECUTIVE SUMMARY

The main objective of Part 4 of the FIRESAFE II study was to investigate the possibilities and effectiveness of installation of new fixed fire detection systems for open ro-ro spaces and weather decks of ro-ro passenger ships (existing or newbuildings), with an aim to discuss specific proposals for rule-making.

In order to perform this investigation, a review of regulations concerning fire detection systems was conducted. This review gave an overview of fire detection requirements applicable for ro-ro spaces of ro-ro passenger ships, with a specific focus on weather decks and open ro-ro spaces, to provide a base for the discussion.

Through consultation with detection specialists, both within and outside the maritime industry, available and emerging fire detection technologies relevant for open ro-ro spaces and weather decks were identified. The basic principles of each of the technologies are described in the report.

The relevance, benefits and limitations of the identified systems were evaluated during a workshop with all project partners. A conclusion from the identification and first evaluation of the new fire detection systems was that none of the identified systems seemed optimal for both types of ro-ro spaces.

For open ro-ro spaces, the following systems were judged to have the highest potential and were short-listed for further evaluation:

- Fibre optic linear heat detection;
- Aspirating smoke detection (ASD); and
- Gas detection, only in combination with ASD.

For weather decks, the systems judged to have the highest potential were:

- Video detection: Smoke [or combined smoke] and flame] video detection
- Video detection: Thermal imaging camera
- Video detection: Flame video detection
- Flame detection

With a view to assess the performance and adequacy of the short-listed systems for the different types of ro-ro spaces, a further specific evaluation was carried out. Based on the results of a workshop and an extensive literature review of fire detection tests, it considered two main aspects:

- Relevance and applicability for open ro-ro spaces and weather decks;
- Qualitative evaluation of the activation time and its sensitivity to cargo configuration depending of the deck configuration.

In order to have a first assessment of the cost-effectiveness of the systems, costs of each of the systems (for components and installation for a given ship) were also estimated through quotations from relevant detection system manufacturers. While the cost of a conventional point smoke and heat detection system for open ro-ro spaces was estimated to € 55 000, the estimated total costs for the short-listed new systems with judged high potential varied from € 50 000 to € 105 000. For the systems considered for weather decks, the costs varied from € 65 000 to € 150 000.

Based on the evaluation of the short-listed systems, a selection process was carried out based on a decision-support matrix, to select the two alternative detection systems to be tested. The results of this selection were unanimous among the different partners of the project, with the Fibre Optic Linear Heat system selected for the open ro-ro space and the thermal imaging camera system selected for the weather deck.

Both selected systems were evaluated in fire tests onboard a commercial RoPax vessel with a weather deck and an open ro-ro space (the latter with a conventional heat and smoke detection system). A Liquefied Petroleum Gas burner was used to reproduce a cargo fire and several fire scenarios were evaluated to challenge both detection systems.

Both systems were found functional and suitable for the relevant ro-ro space environments. On the weather deck, the thermal imaging camera detected a relatively small fire (80 kW) at a distance of around 50 meters. It was also capable of detecting a fire when the gas burner was fully obstructed (after around 3 minutes for a fire of 300 kW) or half obstructed (after half a minute for a fire of 80 kW). Even when heavy rain was simulated between the fire source and the thermal imaging camera, fire was detected (after 4 minutes for a fire of 400 kW). For the open ro-ro space, the fibre optic linear heat detection system showed capacities to detect a fire faster than a conventional point heat detection system. The improved performance was judged to be mainly attributed to the used detection criterion, based on a rate of temperature rise instead of a given critical temperature. Furthermore, the new system also provided improved coverage and thus a shorter required traveling distance of the hot gases, contributing to further shortened detection times.

The second part of the onboard tests was to test the false alarm rate of each alternative systems. The systems were therefore left onboard the test vessel for one month. The vessel did not record any fire or give any alarm from the conventional heat and smoke system nor from the fibre optic linear heat detection system. The thermal imaging camera system recorded many alarms during period, but only during cargo loading and unloading.

Based on the onboard fire detection tests as well as simulation studies performed in the FIRESAFE II study, the risk reduction potential was assessed for each selected detection system. For the fibre optic linear heat detection system, the detection fault tree developed within FIRESAFE II for open ro-ro spaces was used to quantify the effects on each failure node probability. As no fixed fire detection system is required for weather deck, a new fault tree was developed to assess the risk reduction from the thermal imaging camera fire detection system.

The costs for the implementation of the selected fire detection systems were estimated in further detail. Technical items available on the market were as far as possible quantified by offers from system manufacturers. In addition, the cost estimations were contributed by previous cost assessments from internal projects, specifications, reconstructions, etc. A cost-effectiveness assessment was performed, and both of the selected systems were found cost-effective assuming a Gross Cost of Averting a Fatality (GCAF) of €7 M.

The findings of the cost-effectiveness assessment are summarised in the below table.

	Newbuildings			Existing Ships		
Detection system	*Cargo RoPax*	*Standard RoPax*	*Ferry RoPax*	*Cargo RoPax*	*Standard RoPax*	*Ferry RoPax*
Fibre optic linear heat detection	Not cost-effective	Cost-effective	Cost-effective	Not cost-effective	Cost-effective	Cost-effective
Thermal Imaging Camera	Cost-effective	Cost-effective	Cost-effective	Cost-effective	Cost-effective	Cost-effective

3 CONTENTS

4 TABLE OF FIGURES

5 TABLE OF TABLES

6 INTRODUCTION

6.1 Scope and Objectives

The main objective of FIRESAFE II was to improve the fire safety of ro-ro passenger ships by cost-efficient safety measures reducing the risk of ro-ro space fires, with an aim to discuss specific proposals for rule-making. In part 4 of the study, reported here, the objective is to investigate the possibilities and effectiveness of alternative fixed fire detection systems in open ro-ro decks and on weather decks of passenger ships (newbuildings and existing).

6.2 Background

In 2016, EMSA initiated the FIRESAFE study in order to investigate cost-efficient measures for reducing the risk from fires on ro-ro passenger ships with a focus on Electrical Fire as ignition source as well as Fire Extinguishing Failure. These areas were considered the greatest risk contributors by the EMSA Group of Experts on fires on ro-ro decks.

The study also produced a coarse risk model covering the various stages of a fire incident on a ro-ro passenger ship, namely: ignition, detection/decision, extinguishment, containment and evacuation.

In 2017, EMSA initiated the FIRESAFE II study to investigate risk control options for mitigating the risk from fires on ro-ro decks in relation to Detection and Decision (Part 1) as well as Containment and Evacuation (Part 2), which were not specifically addressed in FIRESAFE.

Early detection is often cited as key to preventing loss of life, ship and extensive cargo damage. However, one of the main issues with open ro-ro spaces and weather decks is that detection systems may not be as efficient as in enclosed ro-ro spaces. To address this hazard, EMSA launched a specific part focusing specifically on detection systems in open ro-ro and weather decks, running in parallel with the two aforementioned parts.

Except the lack of a required detection system on weather deck, the main challenge for open ro-ro spaces and weather decks concerns the potentially significant ventilation, which can delay and delocalize detection. There are also challenges with regard to the potential fire scenario. The fire will be well-ventilated and for open ro-ro spaces the steel deck directly above the cargo reflects heat and accumulates smoke, which promotes fire spread. There are also notable challenges with regard to escape ways, location of live-saving appliances and air intakes to the engine room and emergency generator space, which can be contaminated and damaged by smoke.

These challenges have materialized in recent years through several total losses of ro-ro ships with open ro-ro spaces (e.g. Norman Atlantic, Sorrento, Lisco Gloria, Und Adriyatik).

6.3 Methodology

In order to achieve the objective described in section 6, a five step methodology was followed. Details of the steps are provided below:

- 1st step: Desk study to evaluate the efficiency of available and emerging fire detection technologies for use in open ro-ro and on weather decks;
- 2nd step: Selection of the system expected to have the best performance in combination with a feasible cost;
- 3rd step: Testing of the selected system in order to measure the expected risk reduction in relation to a conventionally expected detection times;
- 4th step: Cost-effectiveness assessment for the selected systems; and
- 5th step: If relevant, development of specific proposals for rule-making.

In this report, alternative systems refer to available and emerging fire detection systems for use in open ro-ro and on weather decks, which are different from the systems commonly used[1].

Regarding open ro-ro spaces, it should be noted that the alternative systems may also be studied as an add-on to the current systems.

[1] In practice, in open ro-ro spaces, the most common type of detection system relies on smoke detectors and there is no requirement for detection system on weather decks

7 REVIEW OF REGULATIONS

The present review aims to give an overview of fire detection requirements applicable for ro-ro spaces of ro-ro passenger ships, with a specific focus on weather decks and open ro-ro spaces.

7.1 Reference documents

Requirements related to fire detection are mainly covered by IMO regulations and in a few IACS texts. As a general remark, there are few specific requirements related to fire detection in rules from Classification Societies and in national regulations and interpretations. Therefore, this review is mainly based on the IMO and IACS documents presented in the Table 1.

Table 1. List of documents used for the review of regulations of fire detection requirements applicable in ro-ro spaces of ro-ro passenger ships

IMO Documents	Safety of Life at Sea (SOLAS) Convention, as amended in 2017
	Fire Safety Systems (FSS) Code, as amended in 2017
	MSC/Circ.1035 – Guidelines for the use and installation of detectors equivalent to smoke detectors
	MSC.1/Circ.1242 – Guidelines for approval of fixed fire detection and fire alarm systems for cabin balconies
	MSC.1/Circ.1369 – Interim explanatory notes for the assessment of passenger ship systems' capabilities after a fire or flooding casualty
	MSC.1/Circ.1430 – Revised guidelines for the design and approval of fixed water-based fire-fighting systems for ro-ro spaces and special category spaces, May 31, 2012
	MSC.1/Circ.1437 – Unified interpretation of SOLAS II-2/21.4
IACS Documents	UI SC35 rev.3 – July 2013 "Fixed Fire Detection and Fire Alarm System"
	UI SC73 rev.2 – Nov. 2005 "Fire protection of weather decks"
	UI SC117 rev.2 – Nov. 2005 "Fire detection system with remotely and individually identifiable detectors"
	UR E22 rev.2 – June 2016 "On Board Use and Application of Computer based systems"
Classification Rules	BV Rules for Steel Ship (NR467), as amended in January 2018
	BV NR598 "Implementation of Safe Return to Port and Orderly Evacuation" dd. January 2016
	DNVGL Rules for the Classification of Ships, January 2017
	LR Rules and Regulations for the Classification of Ships, July 2016
	NKK Rules for the Survey and construction of Steel Ships, June 2016
	MMF (French Flag Administration) Division 221 "Passenger ships engaged in international voyages and cargo ships of more than 500 gross tonnage", 04/08/17 edition

Flag Administration Regulations	US Coast Guard Code of Federal Regulations (CFR) 46, 2017 online edition
	Swedish Transport Agency (Swedish Flag Administration) “Comments and interpretations by the Swedish Transport Agency regarding IMO Conventions”, version 03 dd.15/05/2017
	MCA (UK Flag Administration) Guidance on SOLAS Ch.II-2
Other documents	Cruise Lines International Association (CLIA) industry policy on fire detection on covered mooring decks as exposed on https://www.cruising.org/about-the-industry/regulatory/industry-policies/fire-protection/fire-protection-measures-for-covered-mooring-decks
	MSC 96/6/1 submitted by CLIA at IMO MSC 96 (2016) “Fire protection in category "A" machinery spaces and on covered mooring decks”

It should be noted that the present review is based on the currently applicable regulations. Therefore, some of the requirements detailed below may not be applicable on old ships. As an indication, FSS Code Chapter 9, dedicated to fixed fire detection systems has been fully reviewed through MSC.311(88) and applies to ships of which the keel was laid after 01/07/2012.

7.2 Definitions

7.2.1 *Ro-ro space, vehicle space and special category space*

Cargo spaces are spaces used for cargo, cargo oil tanks, tanks for other liquid cargo and trunks to such spaces. (SOLAS II-2/3.8)

Ro-ro spaces are a type of cargo spaces, defined accordingly (SOLAS II-2/3.41):

Ro-ro spaces are spaces not normally subdivided in any way and normally extending to either a substantial length or the entire length of the ship in which motor vehicles with fuel in their tanks for their own propulsion and/or goods (packaged or in bulk, in or on rail or road cars, vehicles (including road or rail tankers), trailers, containers, pallets, demountable tanks or in or on similar stowage units or other receptacles) can be loaded and unloaded normally in a horizontal direction[2].

Vehicle spaces are cargo spaces intended for carriage of motor vehicles with fuel in their tanks for their own propulsion. (SOLAS II-2/3.49)

Special category spaces are those enclosed vehicle spaces above and below the bulkhead deck, into and from which vehicles can be driven and to which passengers have access. Special category spaces may be accommodated on more than one deck provided that the total overall clear height for vehicles does not exceed 10 m. (SOLAS II-2/3.46)

Special category spaces are the most frequent type of closed ro-ro spaces on ro-ro passenger ships.

7.2.2 *Closed, open and weather deck*

One of the most important definitions for the current study is the definition of closed and open ro-ro space and weather deck. Ro-ro spaces can be divided in these three categories depending on how they are enclosed:

- Weather deck is a deck which is completely exposed to the weather from above and from at least two sides. (SOLAS II-2/3.50)

[2] In other words, ro-ro spaces are vehicle spaces into which vehicles can be driven. It is to be noted however that, for the purpose of the application of SOLAS II-2/19, the following interpretation can be found in MSC.1/Circ.1120 and IACS UI SC 85: “Ro-ro spaces include special category spaces and vehicle spaces”

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

SOLAS states that a weather deck is a deck which is completely exposed to weather from above and from at least two sides. IACS UI SC 86 additionally details that: “For the purposes of Reg. II-2/19 a ro-ro space fully open above and with full openings in both ends may be treated as a weather deck.” For practical purposes, fixed fire-extinguishing systems cannot be fitted on weather decks due to the absence of deckhead. Therefore, this criterion is often used for a practical definition of weather decks.

It can be noted that ro-ro spaces with less than 10% openings are considered closed, even though such a deck can have significant openings. Furthermore, one deck can include several categories of ro-ro spaces and the borders between for example weather deck and closed deck can be vague.

As a reference criterion, it can be considered that a vehicle space that needs mechanical ventilation is a closed vehicle space.

7.3 Requirements

Below are presented different requirements for systems, their performance, the system arrangement, including required fire detectors and electrical arrangements.

7.3.1 *Type of systems, spaces to be covered*

7.3.1.1 General requirement

SOLAS II-2/20.4.1 requires a fixed fire detection and fire alarm system to be fitted in all ro-ro spaces.

It is widely accepted however that no fixed fire detection and fire alarm system is required on weather decks used for the carriage of vehicles with fuel in their tanks, as per IACS interpretation UI SC73.

It is to be noted that fire detection is required in open ro-ro spaces (although some discussion on this point regularly arises at the shipbuilding phase).

7.3.1.2 Special category spaces

In special category spaces, SOLAS II-2/20.4.3.1 allows that a fixed fire detection and fire alarm system is replaced by an efficient fire patrol system, maintained by a continuous fire watch at all times during the voyage.

It is to be noted that some Flag States require a fixed fire detection system, independently of the existence of continuous fire watch (e.g. French Flag).

7.3.1.3 Type of fixed fire detection system

SOLAS II-2/20.4.1 requires a standard fixed fire detection and alarm system in line with the FSS Code requirements. For practical purposes, it can be noted that sample extraction smoke detection systems are not allowed on ro-ro passenger ships since SOLAS II-2/20.4.2 prohibits such systems[3] in “*open ro-ro spaces, open vehicle spaces and special category spaces*”. Therefore, this regulation overview will focus on fixed fire detection and fire alarm systems as described in Chapter 9 of the FSS Code.

In addition, on passenger ships constructed on or after 1 July 2010, the system is to be addressable *i.e.* capable of identifying remotely and individually each detector and manually operated call point (FSS Code

[3] Sample extraction smoke systems have been prohibited in SOLAS 1989 amendments (MSC.13(57)), applicable to ships constructed on or after 1 February 1992. As far as BV knows, this was a consequence of the bad service conditions observed on ro-ro ships for such systems (pipe ageing and corrosion) which usually had a common steel piping with the gas fire-extinguishing system.

Ch 9 §2.1.7). Before 2010, the fixed fire detection system was required to be divided in sections, and to be able to indicate in which section a detector has been activated.

7.3.1.4 Fire patrol

Efficient fire patrols are required as per SOLAS II-2/7.8 and SOLAS II-2/20.4.3.1. On passenger ships carrying more than 36 passengers, it is made clear that each member of the fire patrol is to be provided with a two-way portable radiotelephone apparatus, properly trained and familiar with the ship.

7.3.2 *Performance*

7.3.2.1 General

SOLAS II-2/20.4.1 sets the following general performance requirements:

- "The fixed fire detection system shall be capable of rapidly detecting the onset of fire"
- "After being installed, the system shall be tested under normal ventilation conditions and shall give an overall response time to the satisfaction of the Administration"

Common practice as per Bureau Veritas field experience is to test the system using a smoke generator. A usual criterion is that the fire detection system is to be activated within 3 minutes.

A similar criterion can be found in French Flag Regulations (div 221-II-2/7.4) and Bureau Veritas Rules (NR467 Pt F, Ch 3, Sec 1 [3.2.15]) for fire detection in unattended machinery spaces.

FSS Code Ch.9 §2.1.2 lists the following main functionalities for the fire detection system:

- "control and monitor input signals from all connected fire and smoke detectors and manual call points;
- provide output signals to the navigation bridge, continuously manned central control station or on-board safety centre to notify the crew of fire and fault conditions;
- monitor power supplies and circuits necessary for the operation of the system for loss of power and fault conditions; and
- *the system may be arranged with output signals to other fire safety systems*" (communication, alarm and public address systems, ventilation, fire doors and fire dampers, fire extinguishing and systems supporting evacuation such as Low Location Lighting (LLL))

7.3.2.2 Maintenance

In-service testing and proper maintenance are required in FSS Ch 9 §2.5.2, SOLAS II-2/7.3 & SOLAS II-2/14.2.2.

7.3.3 *Prescriptive detection system arrangement*

7.3.3.1 Location of detectors

SOLAS II-2/20.4.1 clarifies that the "*spacing and location* [of the detectors] *shall* [… take] *into account the effects of ventilation and other relevant factors*". Further detail is provided in FSS Ch 9 §2.4.2, together with a table summarizing the maximum spacing between detectors:

"*Detectors shall be located for optimum performance. Positions near beams and ventilation ducts, or other positions where patterns of air flow could adversely affect performance, and positions where impact or physical damage is likely, shall be avoided. Detectors shall be located on the overhead at a minimum distance of 0.5 m away from bulkheads, except in corridors, lockers and stairways.*"

Table 2. Spacing of detectors (FSS Ch. 9 Table 9.1)

Type of detector	Maximum floor area per detector (m^2)	Maximum distance apart between centres (m)	Maximum distance away from bulkheads (m)
Heat	37	9	4.5
Smoke	74	11	5.5

It can be noted that FSS Code requirements for detector location are applicable for all kinds of spaces; they are not specific for ro-ro spaces. Furthermore, in case the fixed fire extinguishing system is a manual deluge system, automatic deluge system or pre-action system, MSC.1/Circ.1430 makes it clear that:

- only smoke or heat detectors are allowed below hoistable ramps; and
- reduced spacing is to be considered for spot-type heat detectors where beams project more than 100 mm below the deck.

7.3.3.2 Section arrangement

Fire detection sections are not allowed to cover more than one MVZ (FSS Ch 9 §2.4.1.4). In addition, a fire detection section covering a ro-ro space is to be separated from (FSS Ch 9 §2.4.1.2):

- Control station
- Service spaces
- Accommodation spaces

For practical purposes, this means that ro-ro spaces are to be provided with dedicated fire detection sections, since ro-ro spaces generally are located in a dedicated Main Horizontal Zone. Only machinery spaces other than category A located in the same horizontal zone can be covered by the same detection section.

In addition, in case the fixed fire extinguishing system is a manual deluge system, automatic deluge system or pre-action system, MSC.1/Circ.1430 requires that fire detection sections be the same as the zones of the fixed fire-extinguishing system: "The area of coverage of the detection system sections should correspond to the area of coverage of the extinguishing system sections."

For practical purposes, on addressable fire detection and fire alarm systems, several sections may be arranged in series on the same electrical cable and separated by suitably located isolators.

7.3.4 Fire detectors

7.3.4.1 General

The fire detection system is to include fire detectors and manually operated call points.

FSS Code Ch 9 §2.1.5: All components to be qualified for operation in marine environment (standard requirements for electrical equipment onboard ships). In addition fire detectors located in hazardous areas[4] are to be adequate for such use (FSS Ch 9 §2.3.1.8).

7.3.4.2 Type of detectors

The FSS Code allows "*Detectors […] operated by heat, smoke or other products of combustion, flame, or any combination of these factors.*" (FSS Ch 9 §2.3.1.1)

As a complement, in case the fixed fire extinguishing system is a manual deluge system, automatic deluge system or pre-action system, MSC.1/Circ.1430 requires that two types of fire detectors are combined.

In addition, it may be noted that several Flag States and classification societies require smoke detectors exclusively or in combination with other detectors in ro-ro spaces. BV Rules require that smoke detectors

[4] For practical purposes, fire detectors installed in ro-ro spaces below the bulkhead deck are in Zone 1, others are in Zone 2, since fire detectors are fitted on the deckhead.

are installed in ro-ro spaces (NR467 Pt C, Ch 4, Sec 12 [3.1.1]). Similar requirements are given by the US Coast Guard and the Swedish Flag. The MCA (UK Flag Administration) requires smoke detectors exclusively or a combination of smoke and flame detectors.

The requirement to have at least smoke detection in ro-ro spaces is based on the fact that smoke detection is considered as more reliable than standard flame or heat detectors. Standard heat or flame detectors are also considered less efficient in ro-ro spaces since:

- Heat sensors located on garage space deckhead were expected to result into quite long activation times due to deck height
- Flame detectors were expected to lead to a number of false alarms due to reflections etc.

7.3.4.3 Qualification and performance standards

In general, fire detectors are to be qualified according to EN 54:2001 and IEC 60092:504 (FSS Ch 9 §2.3.1 and MSC/Circ.1035). Usual performance requirements are:

- For smoke detectors: Activation for 2% obscuration/m ≤ smoke density ≤ 12.5% obscuration/m

  "Smoke detectors […] shall be certified to operate before the smoke density exceeds 12.5% obscuration per metre, but not until the smoke density exceeds 2% obscuration per metre"

- Heat detectors: Activation when 54°C ≤ temperature ≤ 78°C

  "Heat detectors shall be certified to operate before the temperature exceeds 78ºC but not until the temperature exceeds 54ºC, when the temperature is raised to those limits at a rate less than 1ºC per minute."

- Carbon monoxide detectors: Alarm threshold set at 40ppm, sensitivity settings to be adjusted considering the fire hazard, likely source and risk of false alarm.

In addition, provisions are given for in-service function testing (FSS Ch 9 §2.3.1.6).

7.3.5 *Electrical arrangement*

7.3.5.1 System architecture

The system is to be organized into sections as per FSS Code Ch 9 §2.1.4 and 2.4.1.1.

The first initiated fire alarm is not to prevent any other detector from initiating further fire alarms as per FSS Code Ch 9 §2.1.6.3, applicable to addressable systems.

7.3.5.2 Components

- The control panel is to be tested according to standards EN 54-2:1997, EN 54-4:1997 and IEC 60092-504:2001 (FSS Ch 9 §2.3.2)
- Cables are to be flame retardant as per IEC 60332-1 (FSS Ch 9 §2.3.3)
- Cables routed through MVZ that they do not serve and cables to control panels in an unattended fire control station are to be fire resisting as per IEC 60331 (FSS Ch 9 §2.3.3)

7.3.5.3 Sources of power

7.3.5.3.1 Continuous fire detection capability

The fixed fire detection and fire alarm system is to be fed from two sources of power with separate feeders, including an emergency source of power (FSS Code Ch 9 §2.2.1). An emergency source of power has to comply with the requirements of SOLAS II-1/42 and 42-1 regarding location and autonomy. Especially, it has to be able to supply the fire detection system for 36 hours, after which it has to be capable of operating the fire alarm for 30min (FSS Ch 9 §2.2.4). It is either the ship emergency generator (+ transitional source of emergency power) or dedicated accumulator batteries (FSS Ch 9 §2.2.4 & 2.2.5).

An automatic change-over switch is to be provided to manage the transition between the main and emergency source of power, and a fault should not lead to the loss of both power supplies.

No temporary loss of the fire detection capability due to this change-over switch is accepted. In addition, a transitional battery may be required if the temporary loss of power can damage the fire detection system as per FSS Ch 9 §2.2.2.Although the alarm sounder is not formally required to be part of the fire detection system, IACS UI SC35 makes it clear that it is to be powered from a main and emergency source of power and from the transitional source of emergency power where required.

7.3.5.3.2 Sizing of the source of power

The power supply is to be sufficient for operation with 100 detectors activated, or all detectors provided onboard if this number is lower than 100 (FSS Ch 9 §2.2.3).

7.3.5.4 Consequences of a fault

After an electrical fault or electrical failure:

- Identification capability is to be kept in the whole section, except for the faulty detector (FSS Code Ch 9 §2.1.6.1, applicable to addressable systems)
- The initial configuration is to be restored (FSS Code Ch 9 §2.1.6.2, applicable to addressable systems)

7.3.5.5 Temporary disconnection

FSS Code Ch 9 §2.1.1 allows temporary disconnection of the fire detectors in ro-ro spaces during loading and off-loading, provided:

- Detectors in other spaces remain operational
- Fire patrol is maintained in the ro-ro space while the detectors are disconnected
- The detectors are automatically re-connected after a pre-set duration

MCA (UK Flag Administration) clarify in their guidance that:

- Manual call points and manual release mechanisms may not be disconnected
- The duration of the timer is to be adapted to the time of loading/unloading
- The central unit is to indicate whether the detector sections are disconnected or not

7.4 Fixed fire detection systems for outside areas

As detailed in 7.3 above, fixed fire detection systems shall be provided in enclosed and open ro-ro spaces of ro-ro passenger ships, but not on weather decks.

This section lists existing regulations or documentation that could be used in order to propose solutions that might be relevant for open ro-ro decks and weather decks.

7.4.1 *Fire detection for cabin balconies*

Fire detection is required on passenger ship cabin balconies unless the furniture and furnishings are of restricted fire risk as a result of SOLAS[5] 2006 amendments (See SOLAS II-2/7.10). Since they are installed in non-enclosed spaces, these systems can be a useful reference with respect to fire detection in open ro-ro space and on weather decks.

Fire detection systems on cabin balconies are to be in line with MSC.1/Circ.1242. Basically, these guidelines are very close to chapter 9 of the FSS Code, as detailed in paragraph 7.3. The following requirements can be stressed, since they are related to adaptation to an outdoor location:

[5] See Res. MSC.216(82).

2.3 The system should be capable of fire detection on cabin balconies with expected wind conditions while the vessel is underway

2.4 […] External components should additionally be designed to withstand sun irradiation, ultraviolet exposure, water ingress and corrosion normally encountered on open deck areas.

2.6 The location and spacing of the detectors should be within the limits tested.

For practical purposes, fire detection systems installed on cabin balconies rely on flame detection technology, since it is not affected by wind as heat or smoke detectors would.

7.4.2 *Fire detection on covered mooring decks*

Following a fire on the aft mooring deck of the Grandeur of Seas, CLIA recommends to its members to implement a fixed fire detection system and a fixed fire extinguishing system on covered mooring decks. Flame and smoke sensor technology integrated into CCTV systems are deemed effective as fire detection systems for covered mooring decks, and more adequate than conventional fire/smoke detection systems.

8 IDENTIFICATION OF RELEVANT ALTERNATIVE DETECTION SYSTEMS

In order to identify relevant alternative fire detection systems, a workshop was conducted. The participants represented a wide field of expertise, a list of which is provided in annex A1.1.

The workshop was organized in three steps. The first step consisted in establishing the current means for detection (by a regulatory review) as well as the challenges for detection in open ro-ro spaces and weather decks. Thereafter, a list of possible alternative fire detection systems was created, along with their advantages and disadvantages. The third step entailed discussions on the applicability of each system for the different types of ro-ro decks. Based on the previous steps, a list of relevant alternative fire detection system was determined.

The preliminary list of possible relevant alternative fire detection systems included the following technologies:

- Fibre optic linear heat detection
- Aspirating smoke detection (Sample extraction smoke detection)
- Gas detection
- Flame detection
- Video detection
- Light beam linear smoke detection
- Acoustic detection

8.1 Presentation of possible relevant fire detection systems

8.1.1 *Fibre optic linear heat detection*

Fibre optic linear heat detection is an optomechanical type of linear heat detection. The cable, which basically is the same as used in telecommunication, is routed back and forth for example in the ceiling of the protected area. For a single detection system, consisting of an optical fibre and a detector unit, the cable may be several kilometres in length. The detector unit emits a light pulse into the optical fibre and detects reflected light returning through the fibre optic cable. The intensity or wavelength of the reflected light together with the time between emitting the light pulse and detecting the reflected signal provides information about the temperature along the fibre optic cable. It is possible to monitor continuously temperature distribution along the entire cable and to follow temperature variations during fire.

There are some different technologies within fibre optic heat detection. The most common techniques for distributed temperature sensing are Raman scattering, Brillouin scattering and fibre Bragg gratings (FBG), of which Raman scattering is the most common [1]. Both Raman and Brillouin scattering use the temperature dependence of light scattering due to molecular vibrations within the glass core of the optical fibre. Fibre Bragg gratings are modifications of the fibre which enable reflection of a temperature depending specific wavelength from the grating (the modification of the fibre core). The gratings (temperature sensing points) can for example be spaced every meter along the cable.

Fibre optic heat detection is used in a wide range of applications, including tunnels, conveyer belts, pipelines, wildlands, aircrafts and hazardous or EMI (electromagnetic interference) intense environments.

Some pros and cons identified and discussed during the workshop are presented in Table 3.

Table 3. Pros and cons for fibre optic linear heat detection

Pros	Cons
• One detector can cover a large area (several km of fibre optic cable per detector) • Fast activation time compared to other heat detection technologies • Robustness against EMI, humidity, dirt and dust • Continuous monitoring of temperature even during fire • Low false alarm rate (depending on setting, but generally lower for heat detection) • Easy service (one detector unit) • Sustain high temperatures (exact temperature depends on coatings and type of fibre) • Redundancy is easy to implement (loop of the fibre cable or adding of a second detector unit)	• Heat detection is considered slow compared to other technologies • Convective heat transport from fire to detector is needed. Area height and airflow can be crucial • Hard to detect smouldering fires (low heat) • Sampling system (time delay between light pulses). However, not an issue since order of seconds • More expensive than other linear heat detection systems

8.1.2 *Aspirating smoke detection*

Aspirating smoke detection (ASD), or sample extraction smoke detection as it is named at IMO, consists of a pipe network with small holes (sampling points) where smoke and air is sucked into the pipe network and transported to a detector unit. The detector unit consist of a smoke chamber usually much more advanced and more sensitive than conventional point smoke detectors.

Several sampling points will dilute the smoke if the smoke is only present at one sampling point. ASD systems are therefore classified based on the sensitivity at one sampling point when clean air is sampled from the other holes. Class C means that the sensitivity is comparable to conventional point smoke detectors, while Class A and B means a more sensitive detector. ASD systems are often used where it is important to have a very early warning, especially in combination with high airflow. That is the reason why these systems are common in e.g. data centres and air ducts. An experimental study on fire detection in buses showed that among several tested systems, ASD systems are the least affected by high airflow at the position of the detector/sampling hole [2]. ASD systems are used in many other applications as well, e.g. in applications where one aspirating system can replace many point smoke detectors.

Some pros and cons identified and discussed during the workshop are presented in Table 4.

Table 4. Pros and cons for aspirating smoke detection

Pros	Cons
• One detector can replace many conventional point smoke detectors • Less sensitive to airflows at the sampling point compared to conventional point smoke detectors • ASD is considered as very early warning for smouldering fires • Detector unit can be protected, hidden and located in a clean environment (easy service access) • Sampling pipe network can be used also for gas detection if needed (interesting for Alternatively Fuelled Vehicles)	• Space needed for sampling pipe network • Smoke transport from fire to sampling points needed. Affected by area height and airflow. • Transport delay time for long pipes and dilution of smoke if many sampling points are used (often compensated by a more sensitive detector) • Sometimes sampling between different pipes (sampling delay time) • Ageing problem reported for metal pipes • Addressability

8.1.3 *Gas detection*

Gas detection includes many types of technologies and is used to detect flammable or toxic gases as well as fire products, such as CO and CO_2. CO point detectors are common fire detectors in buildings and are often used as a complement to smoke detectors, for example to avoid false alarms. Detection of flammable gases is most often associated with detection of different hydrocarbons. In general, flammable gas detection needs less sensitive detectors compared to toxic gas detection since the levels of toxic gases that may be harmful for humans are often much lower than the LEL (lower explosive limit) of flammable gases. Different principles and technologies available for gas detection include for example catalytic sensors, infrared (IR) technology, semiconductors, electrochemical sensors and thermal conductivity sensors. Some technologies are more suitable for toxic gases and other for flammable gases.

Some pros and cons identified and discussed during the workshop are presented in Table 5.

Table 5. Pros and cons for gas detection (flammable gases and fire products)

Pros	Cons
• Early warning (fire or explosion risk) • Possible to detect gas leakages from alternatively fuelled vehicles • Can be combined with an aspirating smoke detection system	• Sensitive to airflow (however, with high airflow there is also less risk of accumulation of flammable gases) • Easily contaminated and consumed by time (catalytic and electrochemical sensors). IR gas detectors are more robust to a higher initial cost. • May require frequent calibrations

8.1.4 *Flame detection*

Flame detectors detect electromagnetic radiation emitted by flames, which radiate in the visible, the ultraviolet (UV) and the infrared (IR) spectrum. Soot particles radiate almost as black bodies, which means that there will be a wide radiation spectrum, similar as for the sun, mainly in the infrared spectrum (heat radiation). Hot soot particles also cover the visible spectrum (the characteristic yellow light from a flame), but particles with lower temperature radiate only in the infrared spectrum (smoke). Different molecules in the flames radiate at specific narrow bands either in the UV or in the IR spectrum, e.g. CO_2 is typically detected at 4.3 µm. Radiation in the ultraviolet spectrum is due to electron transitions and radiation in the infrared spectrum is due to molecular vibrations. Flame detectors are usually constructed to detect radiation at one or several of these narrow bands to be able to distinguish a flame from other sources of black body radiation, e.g. hot metal surfaces or sunlight. Most common today are multi-spectrum IR detectors using several wavelength bands or combined IR/UV detectors using both spectrums.

Some pros and cons identified and discussed during the workshop are presented in Table 6.

Table 6. Pros and cons for flame detection

Pros	Cons
• One detector can cover a large area (field of view) • Volume detection (no need for heat and smoke transport to the detector) • Very fast detection in case of flaming fire • Not much affected by airflow and weather • Some new flame detectors have possibility to mask certain area of their field of view (hot spots with high risk of false alarms)	• Cannot detect smouldering fires • Historically there have been a high risk of false alarms (especially UV detectors and single wavelength detectors) • Field of view affected by obstructions • Sensitive for contamination of detector lens/window • Some flame detectors cannot detect slow growing fires

8.1.5 *Video detection*

Video detection uses a camera and software for image analysis. The camera provides either a visual or a thermal image and detection of flames or smoke is achieved by image analysis. The analysis can consider colours, motion, shape, transparency, flicker, energy, or boundary disorder information in the video or a combination thereof combined by different algorithms [3].

Video detection is a fairly new technology which mainly is used in special applications. Flame video detection is an easier and more mature technology than smoke video detection. However, smoke video detection has great advantage in early detection of slow growing fires and smouldering fires. For already existing surveillance camera systems (CCTV), fire detection algorithms may be added to the software.

Some pros and cons identified and discussed during the workshop are presented in Table 7.

Table 7. Pros and cons for video detection

Pros	Cons
• Both smoke and flame detection are possible (some systems use only smoke OR flame detection) • Can be combined with surveillance • One detector can cover a large area (field of view) • Volume detection (no need for heat and smoke transport to the detector) • Fast detection • Alarm events are easy to locate and monitor • Possible hydrocarbons and H_2 detection (thermal imaging camera)	• Apprehension to use it due to the relative immaturity of the technology • False alarm rate (e.g. due to reflections, but depending on technology and settings) • Slower than flame detection because of image processing (can be faster if smoke detection is used) • Field of view affected by obstructions • Hard to detect smoke in poor light conditions • Probably more affected by weather conditions compared to flame detectors (visual cameras) • Sensitive for contamination of detector lens/window

8.1.6 *Light beam linear smoke detection*

Light beam linear smoke detection consists of a light source and a photocell separated in space. The light source emits a light beam which is detected by the photocell and any smoke interfering with the light beam will be detected. There is usually tens and sometimes hundreds of meters between the light emitter and the detector. These systems are often used in for example high ceiling buildings (atriums, warehouses etc.), where the smoke does not reach the ceiling due to smoke stratification. They are also used in outdoor applications, such as power plants or oil rigs.

Some systems use a reflector, such that the beam travels back and forth, and has the photocell located together with the light emitter. There could also be two light beams at different wavelengths, which are not attenuated equally by smoke. By comparing the signals from the two beams one can distinguish smoke from other beam interfering false alarm sources.

Some pros and cons identified and discussed during the workshop are presented in Table 8.

Table 8. Pros and cons for light beam linear smoke detection

Pros	Cons
• Possible to cover long distances with a single detector • Linear detectors provide better coverage than point detectors • Can be positioned lower than ceiling height or outdoors (no ceiling) • Smoke detection means early warning for most fires (especially smouldering and slow growing fires)	• Beam alignment important. Ship deflection can be a problem • Smoke concentration and transport is affected by airflow • Can be sensitive to other light sources, e.g. sunlight reflections • May give false alarms to anything blocking the beam (dust, fumes, objects, etc.) • Lack of attachment points for the system along the sides of weather decks

8.1.7 *Acoustic detection*

Ultrasonic detection is available for high pressure (typical over 10 bars) flammable gas leakages. Acoustic detection of gases compared to conventional gas detection has advantages in coverage (volume detection) and is not affected by airflow and transportation of gases to the detector. However, the pressure must be high such that detection of ultrasonic tones is possible which may be only applicable to AFV, e.g. using compressed gas (CNG) or compressed hydrogen for fuel cells. In conclusion, for fire detection this solution does not seem to fit for the current study.

8.2 Selection of alternative fire detection system

The selection of alternative fire detection systems was based on the pros and cons of each system, presented above, as well as the challenges for detection in open ro-ro spaces and on weather decks. The main points made in the discussion during the workshop are summarized below.

8.2.1 *Fibre optic linear heat detection*

Fibre optic linear heat detection was the only heat detection technology discussed. Heat detection is generally considered as slow compared to smoke detection but has other benefits such as low false alarm rate and better monitoring of fire development and fire spread. However, since response time is very important fibre optic linear heat detection was considered as the best choice. Linear detection provides better coverage than point detection with shorter response time in case of non-optimal fire locations. Furthermore, heat detectors responding on temperature rate-of-rise in addition to a fixed alarm temperature have generally better response times. Fibre optic heat detection combine linear detection, temperature rate-of-rise detection and good addressability of temperature location along the sensor and seems to have the ability of continuous monitoring of temperatures also during fire.

The question of the effect of the ship deflection and vibrations on the capacity of the detector has been raised. This question has been tackled with an explanation of the technology used by the system; it relies on molecular vibrations which cannot be affected by ship deflection and vibrations.

One of the main issues with fibre optic linear heat detection is the difficulty to use it on a weather deck. Indeed, the detector (fibre cable) needs to be positioned relatively close to a possible fire (source of heat i.e. radiation or convection). Therefore, this solution is envisaged to be positioned in open ro-ro space only[6].

8.2.2 *Aspirating smoke detection*

It should be noted that even if SOLAS II-2/20.4.2 had forbidden its use in open ro-ro spaces, open vehicles spaces and special category spaces, this system is considered here as a possible alternative fire detection system.

This system is reputed to have an earlier alarm than smoke detection. However, one important issue is the addressability of the system. To address the fire location, one would need to have separate sampling pipes that cover specific areas. There are systems that allow complex pipe networks to be connected to one detection unit, giving multiple addressable zones for one detection system. It is also possible to address the fire location by changing the pipe flow direction at an alarm. After purging the pipes, the flow direction is again changed and by measuring the time until smoke is again detected the system can identify where the smoke enters the pipes.

As well as the previous alternative system, the ASD system cannot be installed on weather deck.

8.2.3 *Gas detection*

Only detection of flammable gases was considered during the workshop. Detection of flammable gases at an early stage may prevent a fire or explosion scenario and is interesting for ro-ro spaces with increasing number of alternative fuel vehicles. Gases that are relevant to be able to detect are e.g. methane (CNG and LNG vehicles), propane/butane (LPG vehicles), hydrogen (fuel cell vehicles) and combustible gases from battery ventilation (electric and hybrid vehicles).

As this type of detector can be combined with an aspirating smoke detection system, this alternative system is considered primarily in that combination, then envisaged to be positioned in open ro-ro space only. Note that LPG is heavier than air and would be difficult to detect with such a system.

8.2.4 *Flame detection*

Flame detection has been used for long time in different industry applications (Oil and Gas industry), especially where liquid or gas fires are expected to occur (high risk areas). As long as the flames are within the detector’s field of view most flame detectors activate an alarm within seconds or sometimes within milliseconds. In addition, flame detection is also often used for outdoor applications due to difficulty of smoke and heat detection. Flame detectors may face difficulties with sun and light reflections causing false alarms. However, considering visibility (field of view when installed between cargo and deckhead) this system is not suitable to be installed in open ro-ro space but nevertheless considered for weather deck.

8.2.5 *Video detection*

In the case of video detection, as this system is a fairly new technology, the discussion has been based on own experiences. Three system technologies can be distinguished:

- Smoke or combined smoke and flame video detection: this system is based on video analysis of CCTV camera feed installed on board. Cameras must have a quite good resolution. The system is only applicable in illuminated areas and the system seems to be really sensitive to exterior lights (reflections and moving shadows) causing false alarms. Therefore, this system could possibly be considered for weather deck.
- Video detection using thermal imaging camera: these cameras are generally more expensive compared to conventional CCTV cameras but have the ability to detect thermal events that might result in a fire. False alarms can be an issue, but this type of video detection is reputed less sensitive to exterior lights as targeting infrared light spectrum. It is considered for weather deck.

[6] This detection system was also considered for use in closed ro-ro spaces in an extended cost effectiveness assessment later in the study.

- Flame video detection (visual or near infrared): this system can be integrated with existing CCTV cameras or use special designed cameras. Video detection of flames is generally less sensitive to false alarms compared to smoke video detection. Some systems have been extensively used in oil and gas industry. Experiences from this industry show a robust system against dusts, salt, moisture, etc., and having a low ratio of false alarms. From those experiences, this system is primarily considered for weather deck.

8.2.6 *Light beam linear smoke detection*

Due to ship deflections this system can be questioned if positioned in longitudinal direction and if positioned transversely the lack of appropriate attachment points along the sides of most weather decks, it was decided to not consider light beam linear smoke detection for further evaluations. However, a supplier of this type of system claims that tolerances of the system are enough to handle ship deflection. Light beam linear smoke detection is together with smoke video detection the only realistic approaches for smoke detection on weather deck. Though not considered further in this report, the system might be relevant if side structures are available for system attachment.

8.2.7 *Acoustic detection*

This system does not fit for the current study and the project group did not know of any commercial acoustic detection systems for fire detection. In conclusion, this technology was not selected for further evaluation.

8.3 Conclusion of the selection of relevant alternative fire detection systems

The main conclusion is that no system is optimal for both types of ro-ro spaces. The alternative systems discussed in the previous subchapter were therefore divided for further evaluation with regard to the specific type of ro-ro spaces where they are most relevant, as presented below:

- Fibre optic linear heat detection – **Open ro-ro space**
- Aspirating smoke detection – **Open ro-ro space**
- Gas detection, only in combination with ASD – **Open ro-ro space**
- Video detection: Smoke or combined smoke and flame detection – **Weather deck**
- Video detection: Thermal imaging camera – **Weather deck**
- Video detection: Flame video detection – **Weather deck**
- Flame detection – **Weather deck**
- Light beam linear smoke detection – **Not further analysed**, however, could be relevant for weather decks if solid side structures above cargo height are available
- Acoustic detection – **Not selected**

9 EVALUATION OF RELEVANCE/APPLICABILITY OF SYSTEMS IN OPEN RO-RO SPACE AND WEATHER DECK

A conclusion of the above review of relevant alternative fire detection systems was that no system seems to be optimal for both open ro-ro space and weather decks. Indeed, according to the definitions in paragraph 7.2.2, a weather deck is completely exposed to weather from above and from at least two sides, which implies that installation of a detection system requiring detectors above to the fire is impossible.

In this context, the evaluation of the applicability of alternative fire detection systems for open ro-ro spaces and weather decks will be split between those two types of decks.

9.1 Open ro-ro space

Fibre optic linear heat detection requires a ceiling structure for attachment of the optical fibre cable and it is hence not relevant for weather decks. Heat transport is affected a lot by high airflows and the system is probably most suitable for closed or open ro-ro spaces with the forward end closed. However, comparing different heat detection systems, the fibre optic system has the lowest response time. In addition, a fibre optic cable can easily be routed with smaller spacing without significantly increasing costs, which is good for improved activation time. Furthermore, the fibre optic linear heat detection is reputed insensitive to harsh environment with moisture, dirt, salt, etc. and does not need to be covered during drencher testing.

A fibre optic heat detection system can be installed together with a smoke detection system, if combined smoke and heat detection is preferred. Heat detection complements smoke detection with better monitoring of fire development and fire spread and it can also stay activated during loading and discharging of the deck. The fibre optic cable can easily be routed together with, for example, the pipe network of an ASD system.

Concerning open ro-ro spaces and smoke being ventilated away through side openings, it was discussed within the project group whether heat detection systems might have a better possibility to detect fire than smoke detection systems. Heat detection systems are generally not affected by heat radiation but only by heat convection, which means that earlier detection than with smoke is unlikely. Another safety measure may be to have video detection based on smoke or combined smoke and flame detection, covering the side openings (and fore and aft), which means that video detection could be suitable for open ro-ro spaces for complementary detection.

Aspirating smoke detection systems require, as for the optical fibre system, a ceiling structure for attachment of pipes and they are not relevant for weather decks. However, although it is forbidden on ro-ro passenger ships (see 7.3.1.3), ASD systems may be considered relevant for open ro-ro spaces. The smoke "accumulators" (mentioned in the FSS Code) are assumed to be the same as sampling holes. Referring to Figure 1 it can be seen that the coverage area of an accumulator can be 288 m^2, which is substantially more than what is allowed for point smoke detectors (74 m^2). Ageing and corrosion problems have been reported for these systems when metal pipes common with extinguishing systems have been used. It is preferable to use pipes dedicated only for detection of smoke and gases.

As mentioned in the previous chapter, ASD systems are often used where it is important to have a very early warning, especially in combination with high airflow, since the ASD systems are little affected by airflow at the position of the sampling points. Conventional point smoke detectors rely on diffusion of the smoke from outside the detector to inside of the detector. With high airflow this process is slow and smoke will be difficult to detect. Because of this, ASD systems seem to be more suitable for open ro-ro spaces compared to conventional point smoke detectors. In addition, ASD systems are generally much more sensitive than conventional point smoke detectors, which is beneficial in high airflow areas since the airflow will spread and dilute the smoke produced. Furthermore, if the smoke is present at several sampling points, the total amount of smoke will be easier to detect. However, current regulations are somewhat restrictive and allow no more than four accumulators connected to the same detection unit.

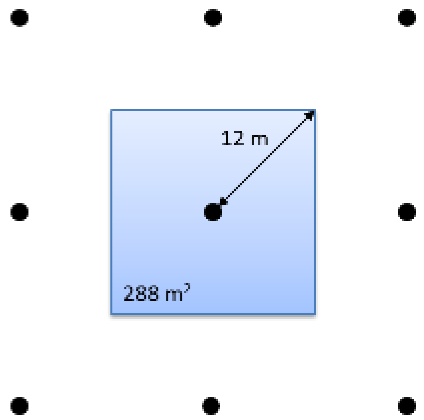

Figure 1. Possible spacing of accumulators (sampling points) fulfilling the regulations.

9.2 Weather deck

Flame and video detectors are suitable for weather decks since they can overlook large areas from a distance. A deckhead is not required for these types of detectors but it is rather a reason to why they are generally not applicable for open ro-ro spaces. Indeed, in open ro-ro spaces, the field of view can be very limited due to a small space between the cargo and the ceiling. However, these types of detectors may be relevant for open ro-ro spaces if the ceiling height is well over the cargo height or if they are used as complementary detectors to fixed smoke/heat detection systems.

Regarding robustness to weather conditions, many flame and video detection systems are used for outdoor applications, on oil rigs for example, and should be sufficiently robust. The most sensitive part of the detector is the detector lens/window, which can be affected by dirt or ice. To protect against ice formation, internal heating of the window can be provided for the detector and it is common that these systems have internal lens supervision, which means that a fault signal is provided if the lens/window is contaminated. In addition, weather conditions such as rainfall, snowfall, fog and sun reflections may either cause false alarms or blinding/shielding such that a fire might remain undetected.

Advanced flame detectors today are fairly robust. Using multi spectrum detection in combination with advanced algorithms, for instance analysing the flickering of the radiation, should prevent a lot of potential false alarms. However, sun blinding can be a problem, which means that combined radiation from a fire and the sun might be interpreted as no fire. Other weather conditions should not affect detection by flame so much. Furthermore, detection by flame radiation means rather slow detection in case of smouldering fires or slow growing fires. Another challenge is that the field of view of the detector can be significantly affected by high cargo, such as trucks.

For a discussion on video detection, reference is made to the categorization introduced in the paragraph 8.1.5, i.e. smoke or combined smoke/flame video detection (visual), video detection using thermal imaging camera and flame video detection (visual or near infrared).

Smoke video detection has great potential for early detection of a fire. However, there is sometimes still a trust issue with regard to false alarms for these systems. On weather decks specifically, there are a range of potential issues that might cause problems, e.g. sun reflections, shadows, exhaust, fog, rain, water splashes from sea, etc. For these systems to be effective, they probably need some training (software learning from background effects) for the specific application.

Video detection using thermal imaging camera is similar to flame video detection, but the image analysis has some different conditions. For example, in the visual spectrum one can use colour analysis that is not possible for thermal images. However, a thermal imaging camera will be less affected by weather conditions and light conditions. Poor light is especially a problem for smoke video detection.

Flame video detection is the most mature video detection technology. Flames are easier than smoke to detect and there is less risk of false alarms. Flame video detection is very similar to conventional flame detection in many aspects but could be more affected by weather conditions. For example, rainfall will affect a camera image more than it affects flame radiation intensity reaching the detector. However, video detection also adds value by monitoring and visualization of the alarm event.

10 EVALUATION OF ACTIVATION TIME

10.1 Literature on activation time of different fire detection systems

The activation time of a detector depends on many factors, for example the detector location relative to the fire, the fire scenario, the detector technology, the airflow, and thermal inertia or delay times within the system. Figure 2 presents a typical fire scenario with respect to detection technologies. Most fires have an incipient stage and release smoke before any flames are visible, which could last for minutes up to several hours. When flames are present the fire will normally develop fast with increased heat release. Electrical fires, which have been identified as one of the main risk contributors on ro-ro decks in the previous FIRESAFE study, typically start as smouldering fires. As seen in the figure, gas and smoke detection has potentially faster activation times than flame and heat detection for these types of fires. However, gas and smoke have to be transported to the location of the sensor (except for smoke video detection) with enough concentration for activation of an alarm and this might only be possible for a larger fire. It should be noted that gases could even be detected before fire occurs (e.g. in case of a leakage) but also that detectable gases are not always produced before smoke. For a liquid or gas fire, which starts as a flaming fire, detection response time will primarily depend on the transportation time of gas, smoke, heat and radiation from the fire to the detector.

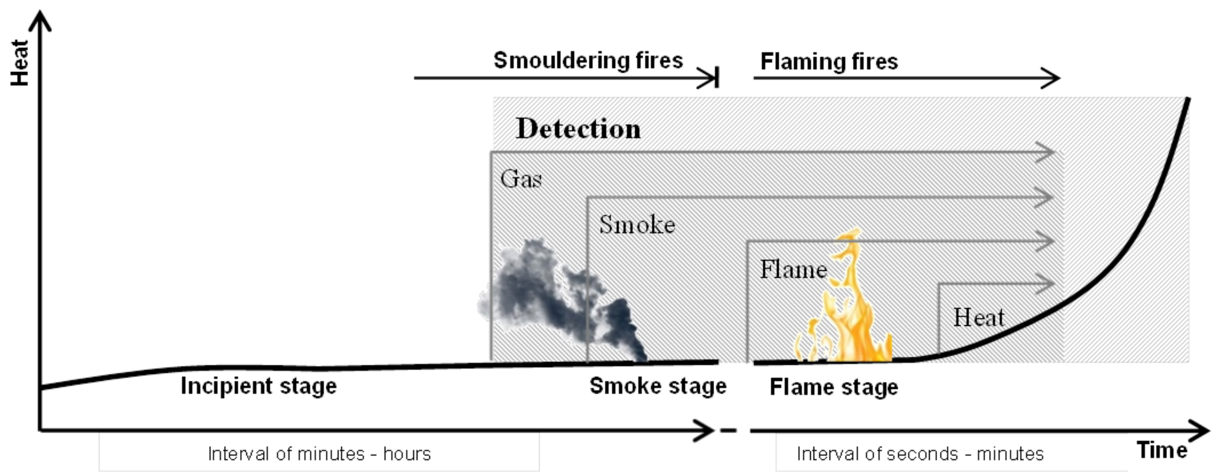

Figure 2. Typical fire scenario with respect to fire detection (or prevention with respect to gas).

To compare different fire detection systems with respect to activation time, all factors discussed above must be taken into account. The fire scenario will affect the possibility of rapid response for different technologies, but this could also to some degree be compensated by smaller detector spacing. Comparison within the same type of technology is easier to achieve by focusing on for example sensitivity settings, internal delay times, thermal inertia or airflow sensitivity.

For further evaluation of activation times, some different fire detection tests presented in literature are summarized below.

Törnskogstunneln, Stockholm [4]

Nine different fire tests were conducted; seven with about 0.5 MW gasoline or heptane fire and two fires with plastic components (test 8-9). Wind velocity was 3-6 m/s, with most tests carried out at 6 m/s. Smoke detectors were placed 100 m and 200 m downstream the fire location. Flame detectors were placed 25 m and 60 m upstream the fire location (FlameA and FlameB being different types). A summary of activation times is presented in Table 9. Temperature measurements showed just a few degrees difference in the tunnel ceiling for these fire tests, at most an increase of 2-3°C in about 5 min.

Table 9. Detector performance in Törnskogstunneln, Stockholm.

Test	Smoke 100 m (min)	Smoke 200 m (min)	FlameA 25 m (min)	FlameA 60 m (min)	FlameB 25 m (min)	FlameB 60 m (min)
1	2.2	2.6	0.1	0.1	-	0.2
2	3.0	3.8	0.1	0.1	3.6	0.2
3	1.3	1.7	0.1	0.1	1.7	0.2
4	3.0	3.7	0.2	0.1	-	0.4
5	2.2	3.0	0.6	0.2	-	0.4
6	1.4	2.9	0.1	0.1	-	0.2
7	2.9	3.3	0.1	0.0	1.6	0.1
8	-	-	-	-	-	3.9
9	-	-	-	1.0	-	2.3

Northern Link tunnel, Stockholm [4]

The 16 different tests are summarized in Table 10. The ceiling height of the tunnel is 6.6 m, and gasoline was used as fuel. The “camera” was an incident detection camera system, which could also detect a fire event, positioned 10 m upstream the fire location. The LHD system was a fibre optic linear heat detection system and the smoke detectors were positioned 100 m (S1) and 190 m (S2) downstream the fire location.

Table 10. Detector performance in Northern Link tunnel, Stockholm.

Test	Wind [m/s]	HRR [MW]			Time to detection (after ignition) [m:ss]				
		0.5-1.5 min	1.5-3.5 min	3.5-5 min	Camera	Pre-alarm (LHD)	Alarm (LHD)	Smoke S1	Smoke S2
1	3	0.54	0.79	0.75	00:50	-	-	1:41 (0:55)	3:34 (1:33)
2	3	0.75	1.21	1.47	00:55	05:36	-	1:40 (1:08)	2:47 (1:50
3	3	1.57	2.18	1.54	00:33	00:58	01:06	1:04 (0:55)	2:20 (1:54)
4	3	2.65	3.60	1.69	00:29	00:50	00:50	1:00 (0:56	2:01 (1:37)
5	3	1.35	2.01	1.55	00:34	01:05	01:21	1:07 (0:54)	2:17 (1:38)
6	3	0.69	1.17	1.48	00:59	05:00	-	1:43 (1:06)	3:10 (1:50)
7	3	0.31	0.52	0.60	01:09	-	-	2:38 (1:16)	4:05 (2:00)
8	6	0.36	0.48	0.62	02:44	-	-	4:02 (1:06)	5:08 (2:33)
9	6	0.88	1.37	1.31	01:13	04:38	-	2:49 (0:49)	3:16 (1:20)
10	6	1.45	2.26	1.89	01:03	01:50	01:54	1:58 (1:01)	2:27 (1:28)
11	7.7	1.68	2.68	1.03	00:55	00:56	01:20	1:30 (0:39)	2:09 (0:57)
12	7.7	0.88	1.53	1.14	02:06	-	-	2:47 (1:10)	3:20 (1:56)
13	7.7	0.58	0.95	0.19	02:35	-	-	2:16 (0:40)	2:46 (1:29)
14	1.5	0.40	0.54	0.61	01:11	02:00	-	2:21 (1:40)	4:22 (3:47)
15	1.5	0.88	1.24	1.31	00:42	00:55	01:03	1:41 (1:28)	3:46 (3:25)
16	1.5	0.87	1.21	1.45	00:36	01:07	01:15	1:31 (1:22)	3:13 (2:24)

Fire experiment in a cable tunnel [5]

Fire experiments were conducted in a small cable tunnel with ceiling height 2.2 m and with cable racks on each side of the tunnel. Four systems were tested: two electrical heat sensing cables (one with fixed temperature response and one with temperature rate-of-rise response), a Raman scattering fibre optic sensing cable and a FBG fibre optic sensing cable. The detectors were routed together with the cables in the racks. A small-scale test was conducted with a heated cable (no flames) where the detectors had to be in contact with the heated cable to give a response. In this test the electrical heat sensing cables were faster than the optical fibre sensors, basically due to different spatial resolutions for the different sensors.

In the large-scale fire test where an alcohol fire was located on the tunnel floor both the fibre optic systems activated an alarm in about 30 seconds. The response time of the rate-of-rise electrical heat sensing cable was about 50 seconds and 150 seconds (2 repetitions) and the fixed temperature sensing cable activated after about 300 seconds.

Fire experiment in a real metro station [6]

Aspirating smoke detection systems were tested, and it may be interesting to compare activation times versus smoke temperatures in the ceiling at that time. Three different fuels were used for the test fires; smouldering paper, smouldering cotton wick and flaming plastics. For the smouldering fires the first warning from the detection system was achieved after about 13 min (paper) and 3 min (cotton wick). At these times the temperature difference between smoke and ambient was less than 0.5 °C. For the flaming fire the warning was achieved in about 1 min and the temperature difference was then about 5 °C, which means that a rate-of-rise heat detector could have worked as well in that scenario.

Response time comparison of spot smoke detection and ASD [7]

This is a comprehensive study of full-scale comparison tests of spot smoke detectors and aspirated smoke detection systems in a telephone switch centre. The report is from 1999 and the detectors tested could have been improved since then. The coverage of each spot detector was 19 m^2 and 37 m^2 (two separate systems) and the aspirating detectors were installed according to manufacturer recommendations. Sampling points were spaced similar to the 19 m^2 spot detectors. The facility was 1670 m^2. In total, 56 tests were conducted.

The 19 m^2 spaced spot detector system and the aspirating system performed comparably, while the 37 m^2 spaced spot detector system provided a decreased level of performance. The aspirating system responded sooner in a majority of tests, however, the spot detector system detected a greater number of smoke sources. It should be noted that the spot detector system used is designed for this application and has a lower sensitivity compared to conventional point smoke detectors.

Fire detection tests in toilet compartment and driver sleeping compartment of buses [2]

Fire detection tests were conducted in mockups of a bus toilet compartment and a driver sleeping compartment. Most tests were performed in the toilet compartment mockup and the response times are presented in Table 11. The most interesting conclusion from the tests is that the aspirating systems were less sensitive to high airflows compared to point detectors (mainly ref. to pos. 2 in the table where the highest airflow was present).

Table 11. Detector performance in bus toilet compartment. The response times are given in seconds after ignition.

"ND" = No detection "s" = smoke sensor "h" = heat sensor		Toilet compartment						
		Cig.	Trash can		Heptane pool		Plastics & rubber	
		Low fan	Low fan	High fan	Low fan	High fan	Low fan	High fan
Detectors	Pos.	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
Point smoke det.	1	ND	ND	ND	27	43	57	ND
	2	ND	ND	ND	32	61	69	ND
	4	ND	42	45	46	47	39	37
Point smoke/ heat det.	1 s	ND	ND	ND	41	30	32	ND
	1 h	ND	ND	ND	82	56	ND	ND
	2 s	ND	ND	ND	25	56	39	ND
	2 h	ND	ND	ND	32	ND	ND	ND
Asp. smoke/ heat det.	2 s	ND	ND	ND	25	38	33	ND
	2 h	ND	ND	ND	ND	ND	ND	ND
	4 s	ND	21	21	40	36	12	21
	4 h	ND	ND	ND	ND	ND	ND	ND
Asp. smoke det.	1+4	51	52	54	43	46	46	50

Flame detection tests [8], [9]

These two reports include flame detector tests with several different flame detectors. 36 different detectors were tested in indoor bench tests, including false alarm tests. False alarm sources included arc welding, different light sources and spark sources. Most detectors were immune to most false alarm sources, but arc welding is a source of systematic false alarm when it is present at the close proximity of detectors. The most sensitive detectors to false alarm sources were those with the shortest response times in fire tests.

12 different flame detectors were included in outdoor fire tests where the distance to different fire sources was altered. The measured maximum detection distances for different fires (heptane, ethanol, cardboard, methane and hydrogen) generally deviated a lot, at both longer and shorter distances, from the values specified by the manufacturers. Some interesting conclusions are that an earlier detection occurs in windy conditions and that detectors are not hindered by the presence of snow or frost.

Another test, focused on methanol fires, evaluated 10 different flame detectors. Both methanol and heptane fires were used in combination with different obstructions and interfering sources. All detectors had a response time of less than 10 seconds for most of the fire scenarios. An interesting aspect is that completely obstructed fires can be detected due to reflections from the fire on metal surfaces, at least at short distances (about 10 m).

Video detection tests [10], [11], [12]

First two reports present some tests in road tunnels. For the first report, the response times for different distances and fire sizes are presented in Table 12. The article estimates that a conventional heat sensor cable would need a fire size of 3-4 MW for activation in tunnels.

Table 12. Video detector performance in a road tunnel [10].

Video-based detector				
Fire Size	HRR	25m	70m	95m
0.1 m2	0.25MW	40s	93s	N/D
0.2 m2	0.5 MW	37s	82s	N/D
0.5 m2	1 MW	32s	64s	121s

For the second report, the response times are presented in Table 13. Detection is based on both flame and smoke analysing and the detector activates an alarm for open fires as well as obstructed fires.

Table 13. Video detector performance in a road tunnel [11].

Fire scenario	Test number	Fire source (m)	Fuel type	HRR (kW)	Air velocity (m/s)	Test distance (m)	Response time (s)
Open fire	T-1	0.3 x 0.3	Gasoline	100 - 125	0	110	8
	T-2	0.3 x 0.3	Gasoline	100 - 125	5.0	110	26
	T-3	0.3 x 0.3	Gasoline	100 - 125	0	90	14
	T-4	0.3 x 0.3	Gasoline	100 - 125	5.0	90	8
	T-5	0.6 x 0.6	Gasoline	550 - 650	5.0	90	8
	T-6	0.3 x 0.3	Gasoline	100 - 125	1.5	60	7
	T-7	0.3 x 0.3	Gasoline	100 - 125	5.0	60	8
	T-8	0.6 x 0.6	Gasoline	550 - 650	5.0	60	8
Fire in the vehicle	T-9	0.6 x 0.6	Gasoline	550 - 650	0	50	25
	T-10	0.6 x 0.6	Gasoline	550 - 650	0	50	6
Fire under the vehicle	T-11	0.6 x 0.6	Gasoline	550 - 650	1.5	60	70
	T-12	0.6 x 0.6	Gasoline	550 - 650	3.0	60	95
	T-13	1.0 x 1.0	Gasoline	1500 - 1700	5.0	90	18
Fire behind the vehicle	T-14	0.6 x 0.6	Gasoline	550 - 650	5.0	50	100
	T-15	1.0 x 1.0	Gasoline	1500 - 1700	5.0	50	17
	T-16	1.0 x 1.0	Gasoline	1500 - 1700	3.0	50	13
Stationary vehicle fire	T-17	Passenger compartment	Wood and Foam	~ 1700	0	50	110
	T-18	Passenger compartment	Wood and Foam	~ 1700	3.0	50	80
Moving vehicle fire	T-19	0.3 x 0.3	Gasoline	~ 125	0	5	27
	T-20	0.3 x 0.3	Gasoline	~ 125	0	50	No Alarm

The third report presents some different fire tests with a smoke video detector and also some tests with detector disturbances, such as illumination changes and moving people in front of the camera. The system seems to be robust with respect to these tests and for the different fire scenarios the response time is typically 30-60 seconds from the time when smoke is visible.

Infrared Video Systems [13]

This report highlights the possibility of thermal imaging cameras to detect a hot spot or heating event, which could result in a fire. To detect a possible fire event before happening can be considered as very early warning.

Real fire incidents [14]

DNV-GL has studied 35 fires within ro-ro spaces between 2005 and 2016. Reliable data for detection was available for 10 cases. The time to detect the fire is short for at least eight of these, and there are no indications that there were significant delays for the two remaining cases. The fire was detected by the fire detection system in seven cases, by fire patrol/crew in two cases, and essentially simultaneously by the fire detection system and fire patrol in one case. In eight cases there was a fixed fire detection system (assumed to be smoke detection), in one case a sample extraction smoke detection system and in one case no fixed fire detection system (weather deck). Two cases provide some more details regarding activation time, one stating that detection[7] was achieved after 4-5 minutes and one where the fire detection system activated an alarm 2 minutes after the fire event was detected by crew passing by.

10.2 Deck loading configuration and its influence on activation time

According to the bibliography presented previously, the time detection has a strong dependency to the fire scenario and situation context. In the case of the present study, a possible fire is also dependant on the cargo and its loading configuration, as further discussed below.

10.2.1 *Definition of deck loading configuration*

The present study focuses on fire detection on weather deck and open ro-ro spaces (as described in 7.2.2). The use of those kinds of decks is dedicated to the transport of cargo, mainly constituted by containers, cars, buses, trucks or lorries. In addition, it should be noted that inside trucks or lorries, there are often all possible kinds of items/goods.

From this assumption, a possible fire starting within cargo, and its detection, is influenced by several factors. In fire safety engineering the fire load density, representing the available combustibles per square meter, can be used to represent the potential development of fire. By coupling the fire load and the amount of available fresh air (oxygen), a fire can be described as fuel controlled in case of a high amount of fresh air, or ventilation controlled if the available fresh air limits the fire development. If the fire is driven by the combustibles, the heat release rate of the fire can be assumed dependent on the nature and quantity of fuels. Such scenarios are expected on weather deck and open ro-ro space.

For detection, the most important factor for a fire in open ro-ro space and weather deck is not cargo influences on the fire development, but how the cargo influences the fire products (smoke and heat). Those influences are in this case quite straightforward and can be presented in two groups: the geometric configuration of the cargo and the fuel type of the cargo.

10.2.2 *Influence of the type of cargo (fuel)*

The type of cargo may affect detection for some special fire scenarios. For example, leakage of flammable gases or liquids could cause a rapid flaming fire scenario and there could be need for gas detection or flame detection. The density of different gases compared to air could affect optimum position of gas detectors. Further, special liquids such as clean burning methanol may cause problems for smoke detection and visual flame detection. However, these are special scenarios and regardless of type of cargo, a slow growing fire

[7] This detection time is not based on the real fire ignition time but on the first sign of fire detected by CCTV during the investigation phase.

(smouldering fire) should be expected initially for most cases. Gas detection can be a good complement though, especially with an increasing number of Alternative Fuel Vehicles which could release gases before a potential fire.

10.2.3 *Influence of the geometric configuration of the cargo*

The cargo geometric configuration has two main influences.

The first one is the cargo height, which will affect the field of view of flame and video detectors. Indeed, a high cargo will block the view angle of flame or video detectors. A good example of this scenario is given in Figure 3.

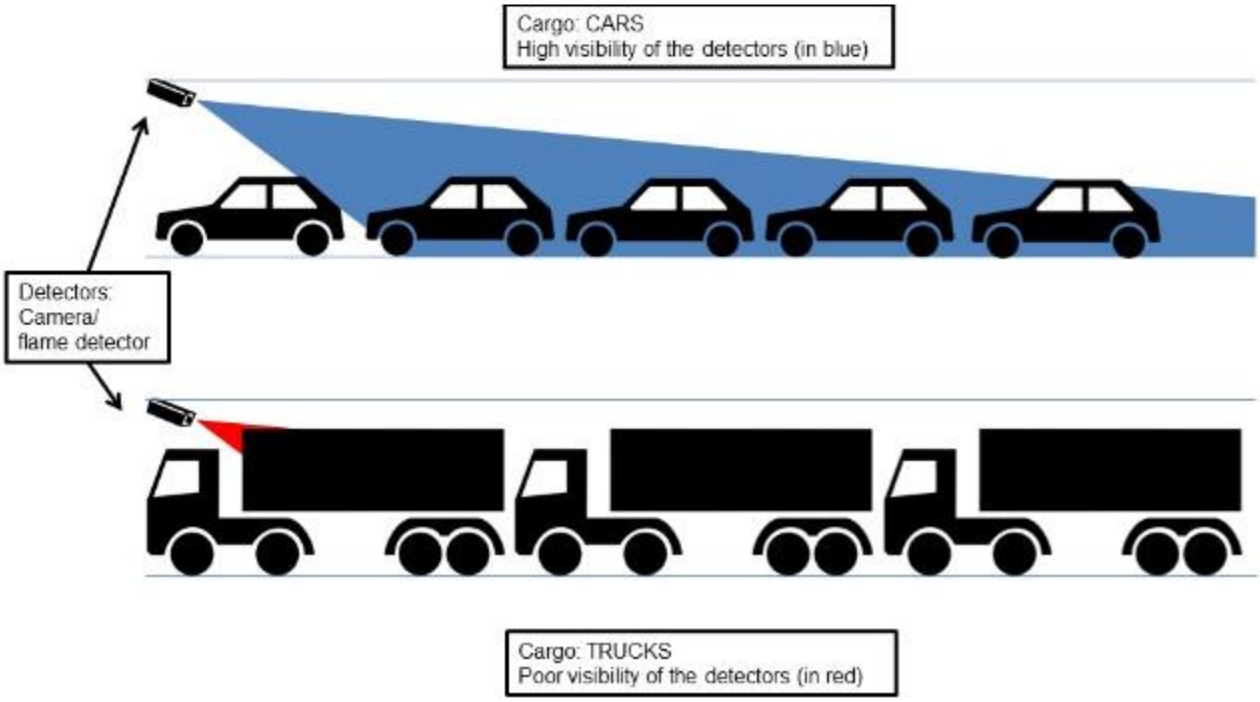

Figure 3. Example of video blockage due to high cargo.

Configurations with, for instance, dedicated areas for cars only would either give enough space between cargo and ceiling such that flame or video detectors can be suitable, or the possibility to have dedicated decks with lower ceiling height, which is beneficial for smoke and heat detectors with respect to activation time, as described in Figure 4. The traveling time of heat and smoke and its concentration in air (dilution effect) are reduced in case of a low ceiling height (blue arrow) compared to a high ceiling high (red arrow).

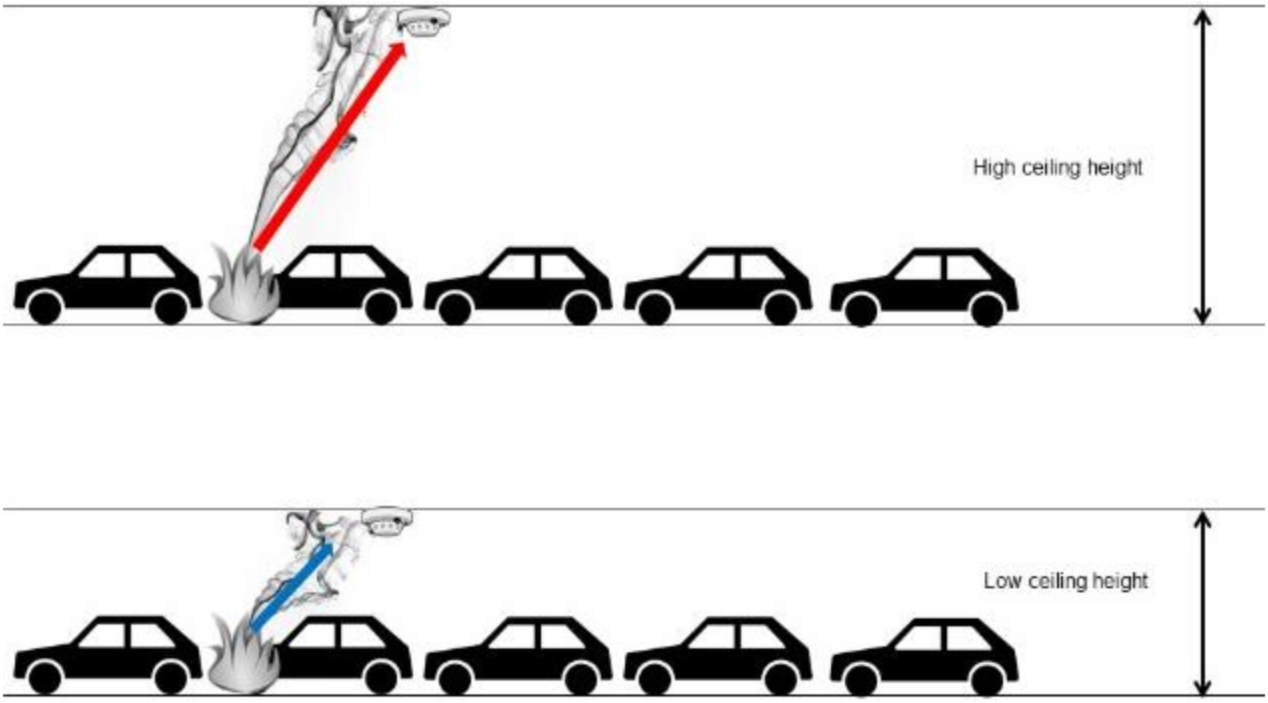

Figure 4. Example of smoke-detector traveling time for two deck heights.

Another aspect of the cargo height and cargo spacing is that high cargo (in relation to ceiling height) reduces the cargo-ceiling space, which can accelerate airflow (as presented in the Figure 5). High airflow affects most detection technologies, except flame and video detection (which are unsuitable due to field of view). However, for instance ASD has been proven to be less sensitive to airflow compared to point smoke detection.

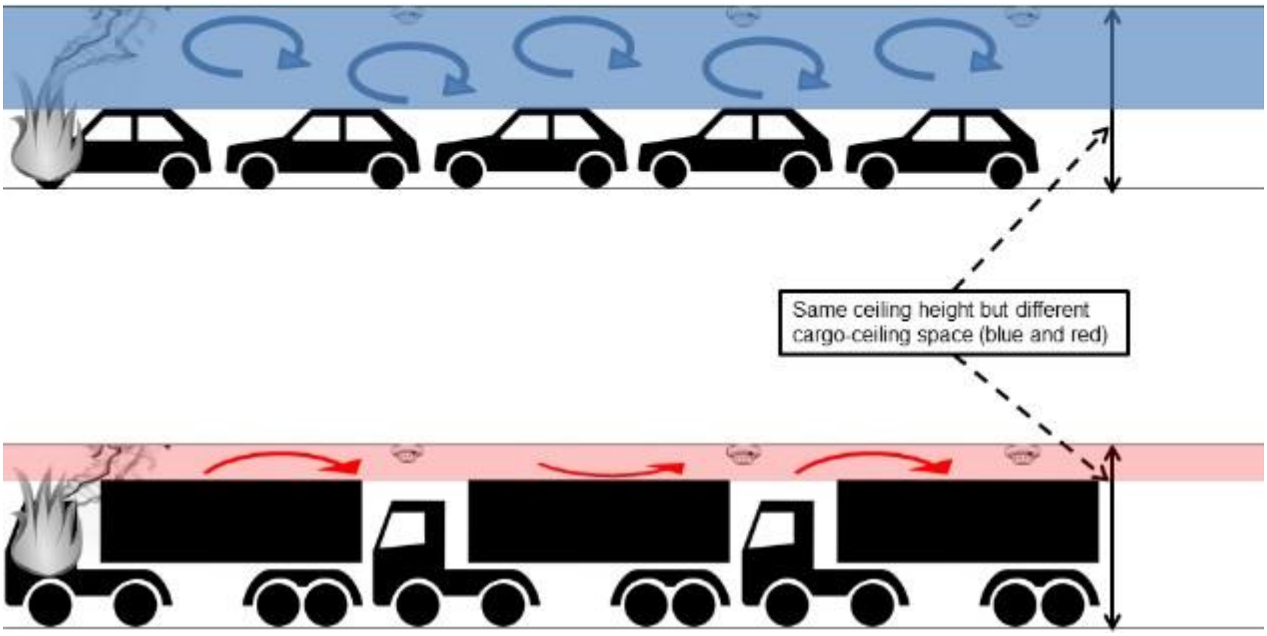

Figure 5. Example of accelerated air flow in case of high height cargo.

11 EVALUATION OF COSTS

The last evaluation done for the desk study on the relevant alternative fire detection system is a cost study. In order to perform the most accurate study, the evaluation of cost was performed with the ships chosen for the FIRESAFE II study as basis (Interested readers can refer to section 7.5 of FIRESAFE II Part 1 report [18] for a description of the generic vessels). All systems were evaluated as add-on systems covering the relevant deck and bringing the signal to the main fire panel on the bridge. As concluded in paragraph 8.3, no alternative fire detection system is optimal for both open and weather decks. Consequently, the evaluation of cost is divided by the type of deck. And two ships with those particular deck types were chosen, the *Standard RoPax* for open ro-ro spaces and the *Cargo RoPax* for weather decks.

Since it is expected that the equipment costs would be the same for newbuildings and existing ships (installation costs would be slightly less), the cost evaluations were made only for existing ships.

In order to make this result generally applicable to the world fleet of ro-ro passenger ships, scalability according the deck size is discussed.

Maintenance costs in the maritime context could not be retrieved. However, it was considered during the selection process.

11.1 Description of the decks used for the cost evaluation

11.1.1 *Ship with open ro-ro space*

As described previously, in order to consider the costs of implementing the alternative fire detection systems, an open ro-ro space of a real ship was selected, that of the *Standard RoPax*, illustrated in Figure 6.

Figure 6. Picture of the *Standard RoPax*.

Since Deck 4 of this ship was considered to represent well the open ro-ro spaces, this ship was selected. This deck is:

- enclosed by deckhead and side shell bulkheads;
- naturally ventilated through large openings in the ship side and has an open aft (no mechanical ventilation); and
- largely exposed to the ambient environment (temperature, wind, humidity …)

All costs presented are based on installations and systems applied for this open ro-ro space, deck 4 of the *Standard RoPax*. The deck is approximately 3 500 m^2 over a length of 155 m. Further details can be found in Figure 7.

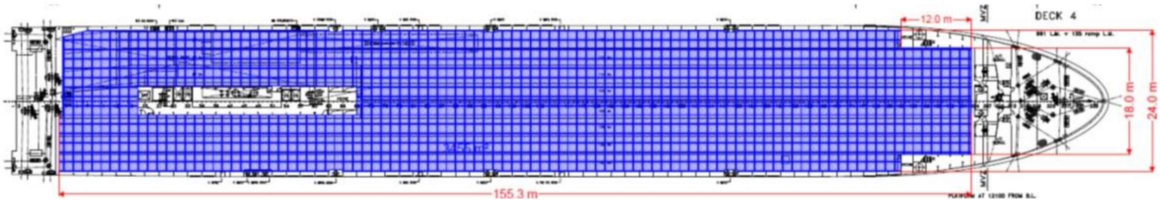

Figure 7. General arrangement of the open ro-ro space (deck 4) of the *Standard RoPax*.

11.1.2 *Ship with weather deck*

Similar to above, a ship was also selected with a representative weather deck, in order to produce a cost evaluation of alternative fire detection system. The selected ship was the *Cargo RoPax*, presented in Figure 8, with the weather deck shown in Figure 9.

Figure 8. Picture of the *Cargo RoPax*.

Figure 9. View of the weather deck of the *Cargo RoPax*.

The weather deck of the *Cargo RoPax* is approximately 1800 m^2, with the dimensions 93 m long and 23.5 m wide. It should be noted that the most forward part of this deck is enclosed and not relevant for this evaluation. Only the part with no deckhead (structure above) was considered, as illustrated (blue) in Figure 10.

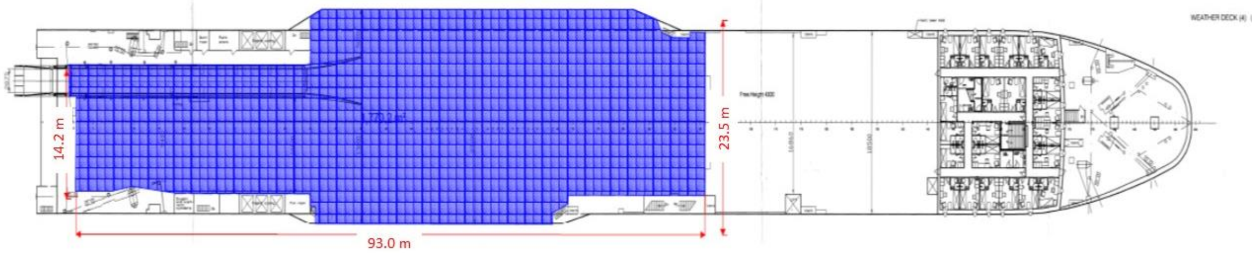

Figure 10. General arrangement of deck of the *Cargo RoPax*.

11.2 Cost estimations of alternative fire detection systems

In this paragraph are presented the estimated costs of relevant alternative fire detection systems. As described in paragraph 8.3, alternative fire detection systems relevant for open and weather decks were identified, including the following technologies:

- Fibre optic linear heat detection – **Open ro-ro space**
- Aspirating smoke detection – **Open ro-ro space**
- Gas detection, only in combination with ASD – **Open ro-ro space**
- Video detection: Smoke and combined smoke and flame detection – **Weather deck**
- Video detection: Thermal imaging camera – **Weather deck**
- Video detection: Flame video detection – **Weather deck**
- Flame detection – **Weather deck**

Some of the presented costs are the result of two different quotations.

11.2.1 *Systems for open ro-ro spaces*

Systems judged as relevant for open ro-ro spaces are fibre optic linear heat detection, aspirating smoke detection and gas detection in combination with ASD.

In order to have a reference in terms of cost evaluation, a common fire detection system (conventional point smoke & heat detection system) was also studied.

11.2.1.1 Conventional point smoke & heat detection system as an add-on system

The present quote was based on addressable detectors with combined smoke and heat detection of IP55 class units. The deck will require about 50-60 detectors and the price was estimated based on 60 units.

<u>System cost estimation</u>

The estimated total cost is € 55 000.

<u>Components cost</u>

Components cost includes detectors and related equipment needed and is estimated to € 10 000.

<u>Installation cost</u>

Installation cost is estimated, based on ship owner experience, at € 40 000.

<u>Commissioning cost</u>

The commissioning cost, based on 5 days of system configuration and test work, is about € 5 000.

<u>System Scaling</u>

As mentioned above this deck will require between 50-60 detector units, subsequently a deck of half the size will require 25-30 units. Estimated cost is € 30 000 (30 units) for half the deck size.

11.2.1.2 Fibre optic linear heat detection

The below information is based on 2 quotes received from manufacturers.

<u>Estimated total price range</u>

The estimated total price ranges from € 50 000 to 80 000. The total price includes, when available, the component cost, the installation cost and the commissioning cost. Note however that it may be required to have two controller units instead of the currently quoted one unit. It must be mentioned since this is significant to the cost of the system. The total estimated price for such a system is estimated to € 70 000 – 125 000.

<u>Component cost</u>

Details on the component cost, ranging from € 20 000 to 45 000 are detailed below. Both quotes received included the following components:

Components	Units	Comments
Controller unit with 1 km range and dual channels	1	Allow cable to be looped for redundancy *1 quote did not specify the cable range*
Fibre optic cable - Plastic sensor cable with accessories	650 - 700 m	Mounting material not included
Modbus TCP	1	Allow the system output to be integrated into an existing control management system or PLC
Software package	1	**Optional and not included in component cost figure above.** Used for further analysis, storage and visualisation

Important differences in components costs have been identified but the technical specifications received from the manufacturers did not allow determining whether there were any profound differences between the systems. It may be so that the quote which did not specify the cable range for the controller unit considered larger controller units which have brought up the price.

Installation cost

The installation cost is about € 31 000, based on ship owner estimation.

Commissioning cost

Commissioning cost is based on two days of the system configuration and test work and has been quoted at € 2 000.

System Scaling

The system costs are governed by the cost of the controller unit. Scalability is based on information from one of the suppliers which states their controller units are available for cable ranges from 1 to 10 km, ranging in price from € 17 000 to 37 000. The quote received have been based on 650-700m of fibre optic cable for which a 1 km range controller can be used.

A system for half the deck size would cost more or less the same as the same controller unit would be used. Some cost could be saved of the required amount of cable, as only half the length would be necessary. Hence, for half a deck, the system cost was estimated to about € 40 000, as opposed to € 50 000 for a full deck.

Notable for this system is that it might become quite cost efficient if it is applied on larger or several decks. For example, a 2 km dual channel system with 2 km cable would cost about € 25 000 (component price for controller unit and cable) and could potentially cover at least three decks of the considered size.

11.2.1.3 Aspirating Smoke Detection

11.2.1.3.1 Aspirating Smoke Detection with NO addressability function

The aspirating smoke detector system considered here has no addressability function, which means that parallel systems would be needed if addressability is desired. The below quote is based on an 8 zone system, corresponding to the drencher zones. The detectors can be calibrated to different sensitivities (class A, B or C), class C being equivalent to the sensitivity of a conventional smoke detector (as explained in the paragraph 8.1.2).

Estimated total cost

The estimated total price is € 115 000, including (when available) the component cost, the installation cost and the commissioning cost.

Components cost

The component cost was estimated to a total of € 50 000, based on the required components detailed below.

Components	Number of units
Aspirating smoke detector units	8
Stainless IP66 detector enclosure	9
Power supply units	9
Sub-rack	2
Remote display	8
In-line filter	8
Water trap	8
Pipes, fittings and cables	Necessary amount for the installation

Installation cost

The installation cost is € 60 000, based on ship owner estimation.

Commissioning cost

The commissioning cost was estimated to € 5 000. It includes commissioning of the system, including all necessary tests and configurations, as well as crew training on the system functionality.

System Scaling

The system cost is highly dependent on addressability requirements, i.e. the number of detector zones. The current cost estimate is based on 8 detector and drencher zones. Subsequently, a system of half the size would use 4 detector units and the price would basically be half of that for a full deck system (likely a bit more since commissioning and crew training will be similar for both installations). The cost of a half deck was estimated to € 45 000.

11.2.1.3.2 Aspirating Smoke Detection with addressability function

The system cost is highly dependent on addressability requirements, i.e. the number of detector zones. The current cost estimate is based on 8 detector and drencher zones. Subsequently, a system of half the size would use 4 detector units and the price would basically be half of that for a full deck system (likely a bit more since commissioning and crew training will be similar for both installations). The cost of a half deck was estimated to € 45 000.

Estimated total cost

The estimated total price is about € 105 000 and includes, when available, the component cost, the installation cost and the commissioning cost.

Component cost

Details on the component cost are detailed below, totalling a cost of € 45 000.

Components	Number of units
Aspirating smoke detector	2
Relay modules STAX	2
High level interface	1
IP66 enclosure	3
Power supply unit	3
Remote display	1
Pipes, fittings and cables	Necessary amount for the installation

Installation cost

The installation cost is € 50 000, based on ship owner estimation.

Commissioning cost

The commissioning cost was estimated to € 12 000. It includes commissioning of the system, including all necessary tests and configuration, as well as crew training on the system functionality.

System Scaling

The system cost is highly dependent on addressability requirements, i.e. the number of detector zones. The current cost estimate is based on 38 detector zones, which corresponds approximately to a conventional point detection system. The detector can monitor 40 zones in its basis version, which can be extended to 80 or 120 zones by adding one or two expansion modules. The micro bore pipe has a maximum length limited to 100 meters and one detector has a maximum coverage area of 1 600 m^2, which is why the quoted system has two detector units. For a deck with an area less than 1600 m^2, almost half of the current deck size, the cost would thus be nearly half. This assumes the same zone density and results in a cost of approximately € 65 000.

11.2.1.4 Gas detection in combination with ASD

The cost evaluation of the present system, as explained previously *i.e.* paragraph 8.2.3, has been done as an add-on of the ASD system without addressability function.

Estimated total cost

The estimated total price is around € 82 000. The total price includes, when available, the component cost, the installation cost and the commissioning cost.

Here, are presented the cost for the gas detection system only, meaning that the cost of the entire system (gas detection system in combination with ASD) is around € 197 000.

Components cost

Details on the component cost are detailed below, for a cost of € 74 000.

Components	Number of units
Gas detector (Methane)	16
Gas detector (Propane)	16
Gas detector (Hydrogen)	16
Pipes, fittings and cables	Necessary amount for the installation

Installation cost

The installation cost is € 5000, based on ship owner estimation.

Commissioning cost

The commissioning cost is € 2500. It includes commissioning of the system including all necessary tests and configuration, as well as crew training on the system functionality.

System Scaling

System cost is highly dependent on addressability requirements, *i.e.* number of detector zones. Current cost estimate is based on 8 detector zones, same as the drencher zones. Subsequently a system of half the size would use 8 detectors and the price would be basically half of full deck system, likely a bit more as commissioning and crew training will have to be formed in similar fashion for both installations. Cost of half deck is estimated at € 45 000.

11.2.2 *Systems for weather deck*

Systems judged as relevant for the weather deck are video detection: smoke or combined smoke and flame detection, video detection: thermal imaging camera, video detection of flames only and conventional flame detection.

11.2.2.1 Video detection: Smoke or combined smoke and flame detection

For the detection system based on combined smoke and flame detection, two manufacturers have answered that this system is not suitable for open ro-ro space. Indeed, it seems that the system is not yet robust enough for an application in open ro-ro space, due to ambient conditions (light, light reflexion, etc.) causing a lot of false alarms.

11.2.2.2 Video flame detection: thermal imaging camera

The below information is based on 2 quotes received from manufacturers.

System cost estimation

The estimated total cost is € 95 000.

Component cost

Details on the component cost are detailed below for a cost of € 65 000.

Components	Number of units
thermal imaging cameras	3
camera houses	1
computer	1
software	1
software camera module	1

Installation cost

The installation cost was estimated to € 20 000, based on ship owner experience.

Commissioning cost

The commissioning cost was estimated to about € 8000, based on 3 days of configuration and test work.

System Scaling

The system is expandable with essentially an unlimited number of cameras, so changing the deck size only change the number of cameras which accounts for the majority of the component cost. The cost for a system covering half the deck size was estimated to € 50 000 using the same premises as for a full deck system.

11.2.2.3 Video flame detection

The system requires 6 cameras to cover the deck. Three of the cameras will have integrated CCTV output, which could be used for closer identification of the fire once the system has given alarm. Otherwise these detectors work as any conventional detector, with an alarm signal when a fire has been detected. The addressability precision is therefore the range/area one camera covers.

System cost estimation

The estimated total cost of the system is € 65 000.

Component cost

The component cost is detailed below, resulting in a cost of € 27 000.

Components	Number of units
Cameras	3
Camera (with CCTV output)	3
Address unit	6
VPT4 unit	6
End of line Unit	6

Installation cost

The installation cost was estimated, based on ship owner experience, to about € 35 000.

Commissioning cost

The commissioning cost was estimated to about € 4 000, based on configuration and test work, as well as installation spot check.

System Scaling

The system cost is highly dependent on the number of cameras required. A deck of half the size would likely require half the number of cameras, possibly some more since it is not necessarily easier to cover a smaller deck. It would also be desirable to have two cameras with CCTV. This system would then likely consist of 4 cameras (two of each type). Commissioning cost would be more or less the same, reaching a total estimation for half a deck of approximately € 47 000.

11.2.2.4 Flame detection

The below information is based on quotes received from two manufacturers. The basic difference between these quotes is the camera itself, while all other details are the same. The first system uses a triple frequency camera which will detect and analyse three different infrared (IR) frequencies to detect a fire. The second system uses a frequency band camera which will detect and analyse a band of IR frequencies. These cameras are more expensive and should be more robust in their detection. Both camera types will output, in addition to a detection signal, normal CCTV signal via NTSC or PAL.

System cost estimation

The estimated total cost ranges from € 95 000 to € 115 000

Component cost

The component cost is detailed below, resulting in a cost range between € 40 000 and € 60 000.

Components	Number of units
Cameras with fastening brackets	14

It should be noted here that CCTV is not a standard feature on conventional flame detectors, and this may affect component cost.

Installation cost

The installation cost was estimated, based on ship owner experience, to about € 45 000.

Commissioning cost

The installation cost was estimated, based on ship owner experience, to about 8 000 €.

System Scaling

The system cost is highly dependent on the number of cameras required. A deck of half the size would likely require half the number of cameras, possibly a little bit more as it is not necessarily easier to cover a smaller deck. The cost for a system installed on a deck with half the size was estimated to approximately € 55 000 to € 66 000, depending on the used camera type.

11.2.3 *Conclusion on the cost evaluation of alternative fire detection systems*

For an overview of the cost evaluation of the detection systems, Table 14 shows the deck type where each system can be installed, as well as the total cost, component cost, installation cost, commissioning cost and the total cost for a system installed on half the deck size.

Table 14. Summary table of the evaluation of costs of alternative fire detection systems

Type of deck	Detection system	Component cost (in k€)	Installation cost (in k€)	Commissioning cost (in k€)	Total Cost (in k€)	Total cost for a half deck (in k€)
Open ro-ro space	Conventional point smoke & heat detection	10	40	5	55	30
	Fibre Optic Heat	20 - 45	31	2	50 – 80 (70 – 125 in case of two controller units)	40
	Aspirating Smoke Detection (with NO addressability)	50	60	5	115	70
	Aspirating Smoke Detection (with addressability)	45	50	12	105	65
	Gas detection in combination with ASD*	74 (+*50*)	5 (+*60*)	2.5 (+*5*)	74 (+*115*)	45 (+*70*)
Weather Deck	Video: Thermal Imaging Camera	65 – 86	20 - 25	8	95 - 120	50 - 85
	Flame detector	40 - 60	45	8	95 – 150	55 - 66
	Video flame detection	27	35	4	65	47
	Video: Flame and smoke	Not suitable for weather deck, according providers				

*Costs in brackets for the Gas detection system belongs to the Aspirating Smoke Detection (with NO addressability).

The figures in the above table are applicable to existing ships only. It is expected that for newbuildings, the equipment costs would be the same, but installation costs would be slightly less.

12 SELECTION OF ALTERNATIVE DETECTION SYSTEMS FOR TESTING

Several alternative detection systems were identified and selected for an evaluation in terms of performance (relevance/applicability to weather decks and open ro-ro spaces and activation time) and in terms of costs.

The next step was to select, based on the previous evaluations, the systems (one for the weather deck and one for the open ro-ro space) that was expected to have the best performance in combination with a feasible cost.

12.1 Selection criteria

The selection of the systems was based on a decision-support matrix. This type of matrix allows the classification of solutions according to weighted criteria. One criterion can be twice as important as another. The judgement criteria are thus defined and prioritized according their importance given by each participant. Indeed, the underlying philosophy behind this approach is that effective problem solving must involve partnerships between all types of participants (in the present study: fire researchers, classification society, ship operator and flag states representative).

The selection process is finally the comparison of the sum of scores multiplied by the corresponding criteria weight for each system. The system with the highest sum is then the system that should be selected.

This selection is illustrated in the Table 15 .

Table 15. Illustration of the selection process by a decision-support matrix.

	System 1	**System 2**	**System 3**
Criteria 1 (weight = A)	Score 1	Score 3	Score 5
Criteria 2 (weight = B)	Score 2	Score 4	Score 6
TOTAL	(A x Score 1) + (B x Score 2)	(A x Score 3) + (B x Score 4)	(A x Score 5) + (B x Score 6)

In the present study, the criteria were defined according four main groups:

- Cost/burden of the system
- Main function of the system (e.g. time of detection)
- Other functions of the system
- And reliability of the system.

Each of these groups are subdivided into pertinent criteria based on previous evaluations (chapter 9, chapter and chapter 11), and are presented in Table 16.

Weights were given only for each main criterion and have been chosen by participants themselves. The range of weight is between 1 and 10.

Finally, the decision/support matrix for the selection of the two fire detection systems is presented in Table 16.

Table 16. Decision-support matrix for the selection of the detection systems.

Main criteria	Weight	Sub-criteria	Detection System 1	Detection System 2
Cost/Burden of the system	W1	Installation Cost		
		Addressability (possible at low cost)		
		Redundancy (possible at low cost)		
		Cleaning		
		Replacing		
		Accessibility		
		Expected lifetime		
Main function of the system	W2	Time of detection: Open Fire		
		Time of detection: Smouldering Fire		
Other functions of the system	W3	Confirmation of fire		
		Assessment of fire development		
		Pre-warning		
Reliability of the system	W4	False alarm rate		
		Faulty alarm rate		
		Robustness (regarding environment)		
TOTAL				

12.2 System selected for the weather deck

For the case of the weather deck, four alternative detection systems were selected for evaluations (chapter 9, chapter and chapter 11). These four systems are:

- Video detection: Smoke or combined smoke and flame detection (VDS)
- Video detection: Thermal imaging camera (VDT)
- Video detection: Flame video detection (VDF)
- Flame detection (FD)

The decision-support matrix resulting is not presented in the report but only the result of the selection process. The Table 17 shows the ranking result for each project's partner. Here the ranking is presented under the form of a ratio consisting in the total score of the system divided by the score of the system that has been ranked first.

Table 17. Results of the selection process for the alternative detection system for the weather deck.

	Rank 1		Rank 2		Rank 3		Rank 4	
Participant	**System**	**Ratio of the score**	**System**	**Ratio of the score**	**System**	**Ratio of the score**	**System**	**Ratio of the score**
1	VDT	1	VDF	0.93	VDS	0.85	FD	0.74
2	VDT	1	VDF	0.86	VDS	0.85	FD	0.77
3	VDT	1	VDF	0.84	FD	0.81	VDS	0.77
4	VDT	1	FD	0.96	VDS	0.92	VDF	0.88

The system unanimously selected by each participant is: Video detection: Thermal imaging camera (VDT), with an average relative score higher by 10%.

The alternative system ranked in second position i.e. the Flame video detection was ranked in this position by three of four participants with an average relative score of 0.88.

12.3 System selected for the open ro-ro space

For the case of the open ro-ro space, three alternative detection systems were selected for evaluations (chapter 9, chapter 10 and chapter 11). These three systems are:

- Fibre optic linear heat detection (FO)
- Aspirating smoke detection (ASD)
- Gas detection, only in combination with ASD (GAS)

The decision-support matrix resulting is not presented in the rapport but only the result of the selection process. The Table 18 shows the ranking result for each participant in the same manner that the Table 17.

Table 18. Results of the selection process for the alternative detection system for the open ro-ro space.

	Rank 1		Rank 2		Rank 3	
Participant	**System**	**Ratio of the score**	**System**	**Ratio of the score**	**System**	**Ratio of the score**
1	FO	1	GAS	0.93	ASD	0.88
2	FO	1	ASD	0.69	GAS	0.57
3	FO	1	GAS	0.84	ASD	0.82
4	FO	1	GAS	0.88	ASD	0.81

It should be noted that even if each participant used their own weights values for each main criterion, the system was unanimously selected. Indeed, the system selected by each participant is: Fibre optic linear heat detection (FO).

Fibre optic linear heat detection was ranked in first position with a clear advance (17%) on the system ranked in second position.

13 TESTING OF ALTERNATIVE FIRE DETECTION SYSTEMS

The selection process described in chapter 12 singled out two alternative detection systems (one for weather deck and one for open ro-ro spaces) based on their judged performance in relation to cost. The performance of the systems was further tested in real ship environments as described in this chapter. Onboard tests were carried out with a two-sided objective to investigate both the detection time and the risk for false alarms.

13.1 The test vessel - Stena Scandinavica

The tests were conducted on the vessel Stena Scandinavica which is a RoPax ship normally operating between Gothenburg and Kiel. This ship has a representative weather deck adjacent to a large open ro-ro space. This deck (7) is shown in Figure 11 and is illustrated in Figure 12.

Figure 11. The aft of the test vessel showing the weather deck of deck 7 and the aft opening of the open ro-ro space.

Figure 12. General arrangement of deck 7 of the test vessel.

The open ro-ro space on the test vessel had a fixed fire detection system with both (point) heat and smoke sensors. The open ro-ro space was only naturally ventilated (no mechanical ventilation), by an aft opening (seen in Figure 11) and side openings (visible in Figure 13).

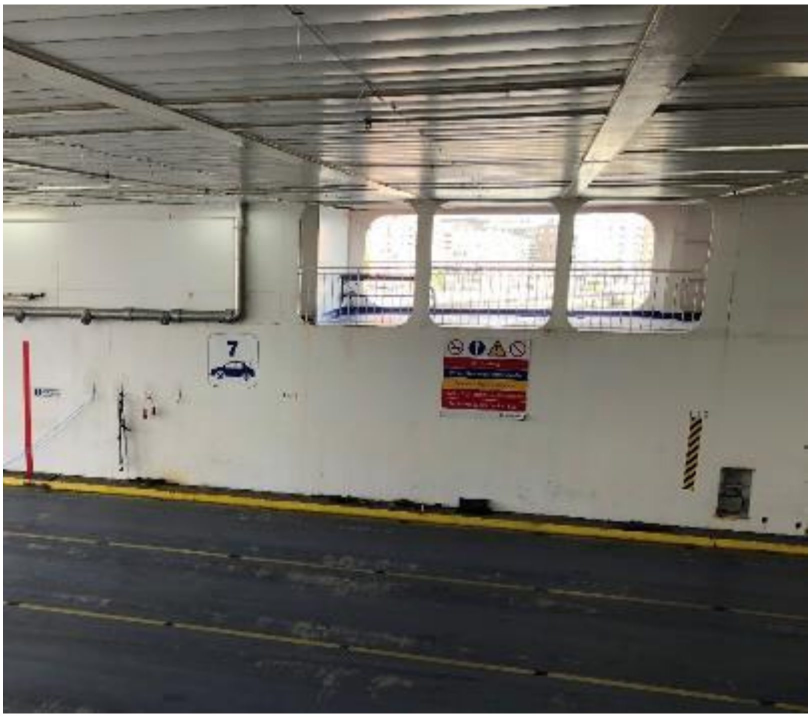

Figure 13. Side openings of the open ro-ro space.

13.2 Detection time test setup

The fire tests focusing on detection time were based on a simulated “cargo fire”. The simulated fire and the test setups for the two detection systems tested are described below.

13.2.1 *The simulated “Cargo fire”*

The fire tests were performed to reproduce a real fire on a weather deck or in an open ro-ro space. The main focus was to study the fire detection time for different fire detection systems. The simulated “cargo fire” was represented by a gas burner (LPG) using a 40x40 cm^2 burner filled with fine gravel. The heat release rate (HRR) of the fire was ramped following the standard fire growth rates “slow”, “medium” and “fast”, according to NFPA 204M [15]. These fire growth rates are based on the time to reach a fire effect of 1 MW (as detailed in Table 19) and can be described as:

$$\dot{Q} = \alpha t^2 \text{ or } \dot{Q} = \dot{Q}_0 \left(\frac{t}{t_0}\right)^2$$

$\dot{Q}: Heat\ release\ rate\ by\ the\ fire$

$\alpha: Fire\ growth\ rate$

$t: time$

$\dot{Q}_0 = 1MW$

$t_0: time\ to\ reach\ 1MW$

Table 19. Fire growth parameters

Type of fire	Fire growth rate (kW/s²): α	Time to reach 1MW (s)
Slow	0.0029	600
Medium	0.0117	300
Fast	0.0469	150

The test equipment used to simulate the fire growth in the fire test has a minimum pilot flame of about 80 kW. This initial fire load can be observed in Figure 14, representing the specified HRR based on NFPA 204M [15] and the measured HRR. The HRR was calculated based on the mass flow rate of LPG and its theoretical heat of combustion of 46.4 MJ/kg, assuming 92% combustion efficiency.

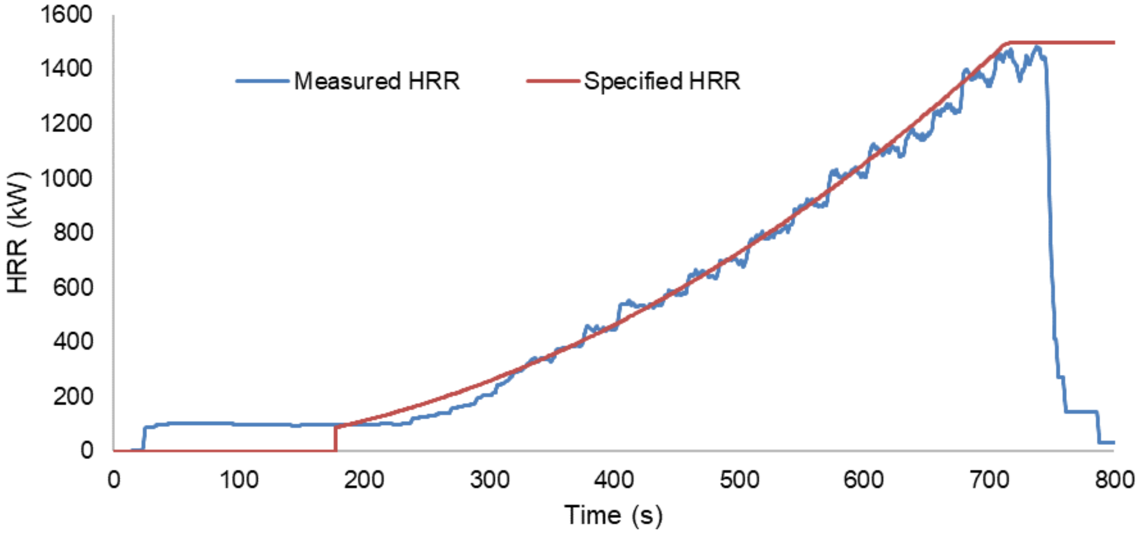

Figure 14. Measured and specified HRR

A “slow” fire growth rate was used to test the thermal imaging camera system. A slow fire is the most challenging for this system as the flame height is quite small during the first minutes of fire [16].

For the fibre optic cable system, all three fire growth rates were used. The production of smoke and heat correlates directly with the HRR.

13.2.2 *Thermal imaging camera system test arrangements on weather deck*

The fire detection system that was selected for testing on the weather deck consisted on a thermal imaging camera and software. A computer was used to process the images coming from the camera (component description in paragraph 11.2.2.2) together with fire detection algorithms in the software. The thermal imaging camera was positioned at a high level with a view of the aft part of the weather deck (Figure 15).

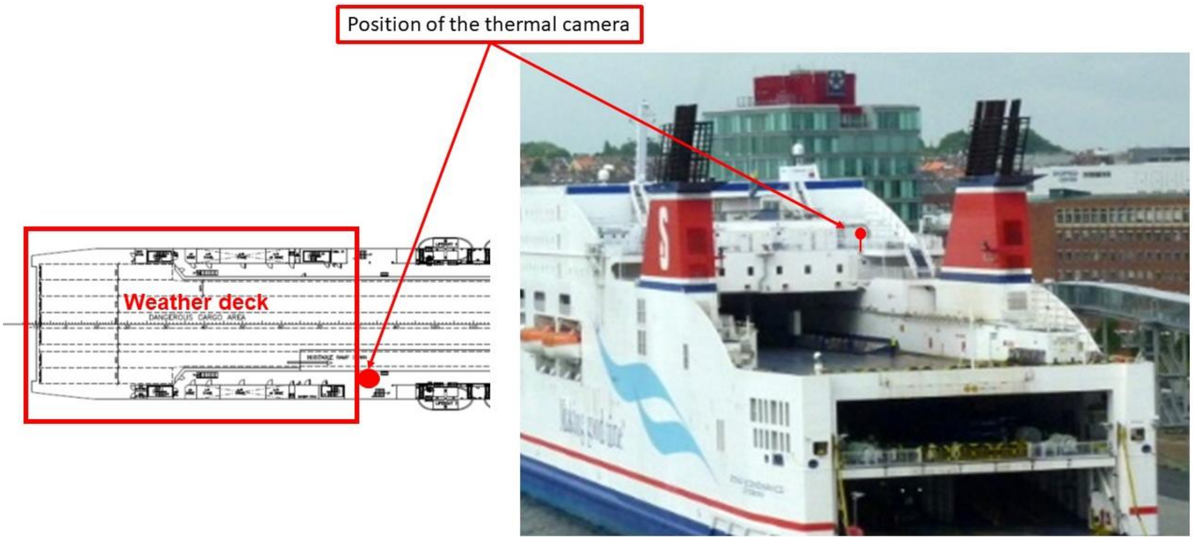

Figure 15. Position of the thermal imaging camera on the test vessel.

The main disadvantage of the thermal imaging camera is related to possible obstructions between the camera and the fire. To challenge the system, a container was placed on the weather deck to obstruct the field of view of the camera. The position of the container, relative to the camera and fire position, is illustrated in Figure 16.

Three positions of the fire were used in the tests, as shown in Figure 16, where Fire 1 was completely obstructed behind the container, one Fire 2 was half-obstructed and Fire 3 was unobstructed.

Another parameter that was evaluated was the effect of the distance between the camera and the fire. The maximum distance tested was 50 meters. The arrangement of the fire test for the thermal imaging camera on the weather deck is illustrated in Figure 16.

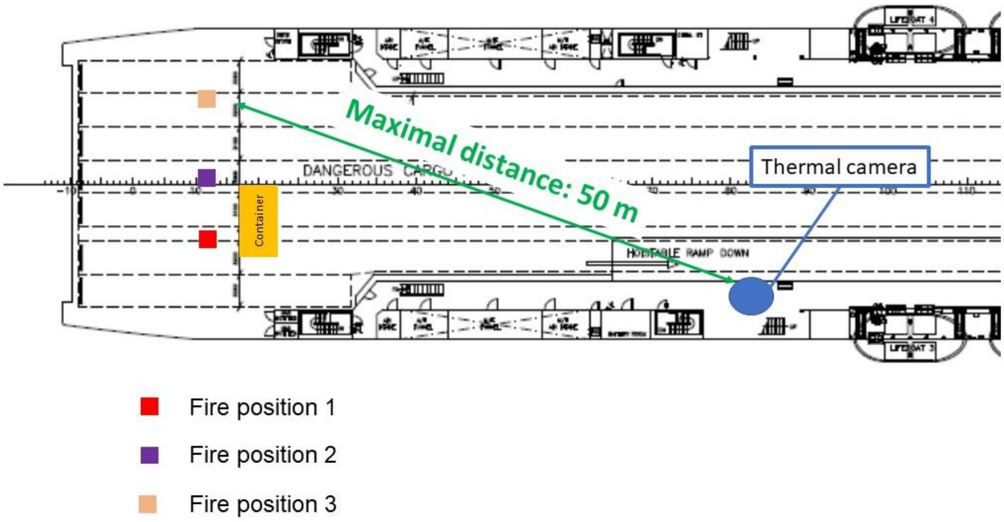

Figure 16. Fire test arrangement for the thermal imaging camera on the weather deck.

An additional parameter that was coarsely studied in the tests using the thermal imaging camera was the influence of rain on the time of detection. The weather deck of the test vessel was equipped with two water monitors and these were used to simulate heavy rain.

System criteria for fire detection

The fire detection criteria of the thermal imaging camera system were:

- Pre-warning alarm when $T_{measured}$ > 160°C; and
- Fire detection alarm when $T_{measured}$ > 175°C,

where $T_{measured}$ is the temperature calculated by the thermal imaging camera software in the designated alarm zone.

13.2.3 *Fibre optic linear heat detection system test arrangements in open ro-ro space*

The fire detection system that was selected for testing in the open ro-ro space was a fibre optic linear heat type fire detection system. The system consists of a fibre optic cable (the heat sensor) and a control unit (described in paragraph 11.2.1.2).

As reported in paragraph 11.2.1.2, one of the main advantages of the fibre optic cable is its coverage capacity. Conventional smoke and heat detectors are based on point detection but the fibre optic system is linear. This difference is shown on the Figure 17 where the position of the fibre optic cable and the positions of existing detectors are illustrated. Both systems were installed in the ceiling of the open ro-ro space, situated at a height of about 6 meters.

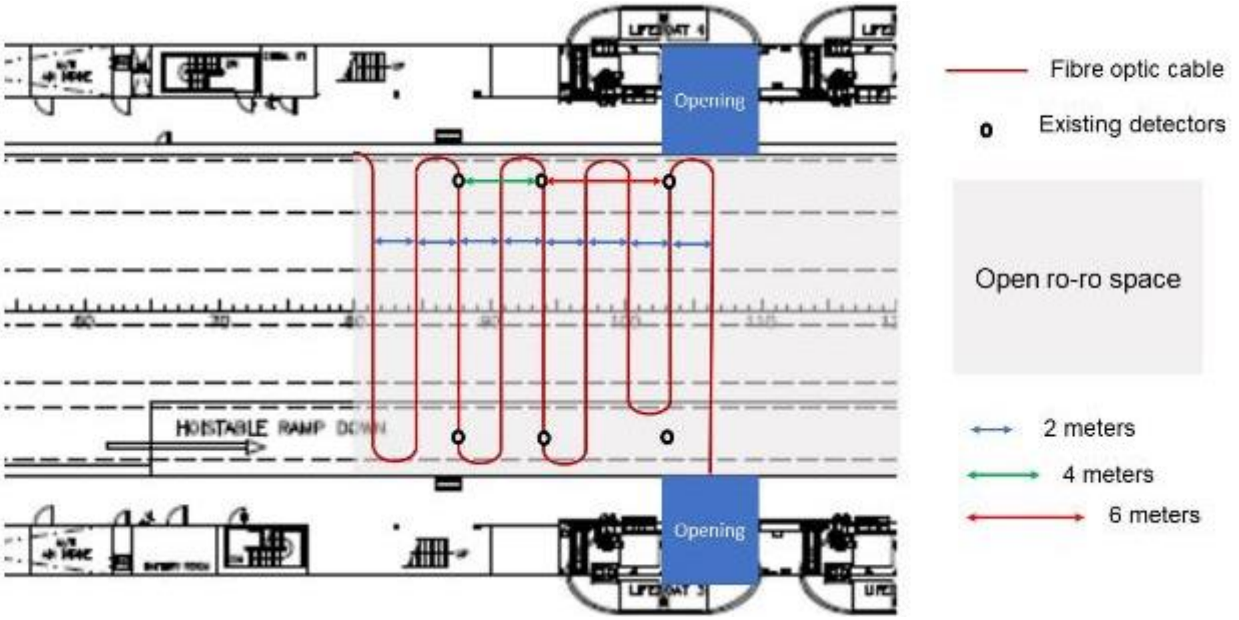

Figure 17. Positions of the fibre optic cable and existing conventional detectors in the ceiling of the open ro-ro space.

The fibre optic cable was installed to have several detection zones with a spacing of 2 meters. This distance was selected to provide at least one detection zone for each transversal line of existing detectors. The detection zones of the fibre optic system are shown in Figure 18.

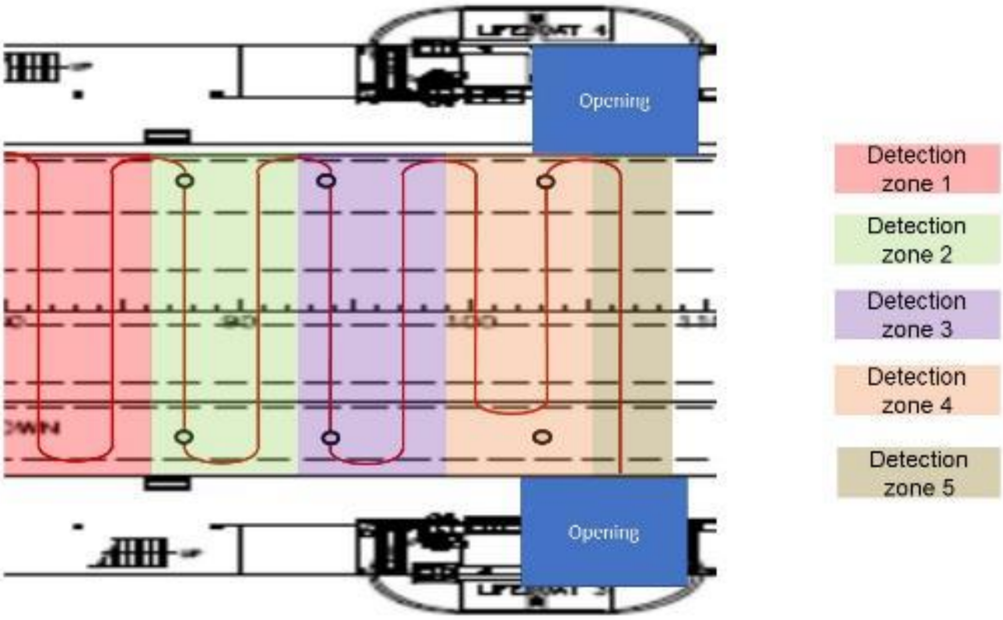

Figure 18. Illustration of the detection zones of the fibre optic linear heat detection system and existing detectors.

The fibre optic cable was positioned using a plastic plate that was glued directly to the ceiling of the ro-ro space. This is not the standard installation procedure, but it was valid for temporary installation for the fire tests. The passage of the cable fit the positions of existing detectors, as far as was practicable, as shown in Figure 19.

Figure 19. Position of the fibre optic cable in relation to existing conventional detectors.

As described in paragraph 9.1, one of the main foreseen issues of the fibre optic detection system was the influence of natural ventilation or wind. Conventional heat detection systems are generally only affected by heat convection and not by radiation, which means that detection of convected heat will likely be delayed since heat is transported with the smoke.

To verify this hypothesis, a portion of fibre optic cable was positioned close to a side opening at the same position as a conventional existing detector (see Figure 20).

Figure 20. Existing detector (circled in red) and fibre optic cable positioned at a side opening.

As one of the main challenges to be considered in the fire tests was the influence of natural ventilation, three fire positions were used (shown in Figure 21), each different in relation to the side openings.

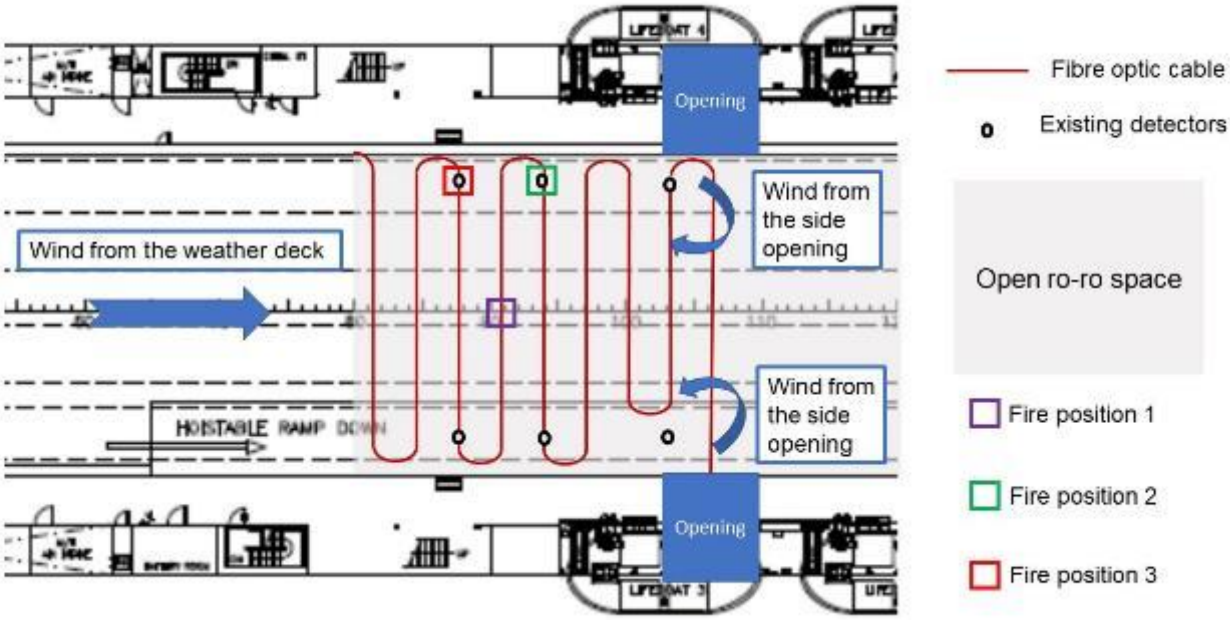

Figure 21. Positions of the fire in relation to existing detectors and wind influence.

Fire position 1 was considered to be the worst-case scenario for the existing detectors. The fire is positioned exactly in-between two existing detectors (in the longitudinal deck axis) and in the middle of the ro-ro space where the wind coming from the weather deck was assumed to be the strongest.

Fire position 2 was selected because an existing detector is directly over the fire. This is an interesting scenario for the existing detector in case of absence of wind. But in case of wind from the weather deck and/or the side opening, dilution of the smoke might delay the fire detection. Depending on the wind direction, two existing detectors are close to the fire, not considering the detector directly over the fire.

Fire position 3 was close to fire position 2 in case of wind but only one detector is close to the fire, not considering the detector directly over the fire.

During the tests, part of the fibre optic cable was also placed at the floor of the open ro-ro space in order to test the capacity of this system to detect a fire from the floor, this detection is considered as a 6th detection zone. Two distances between the fibre optic cable and the fire were used: 1 meter (illustrated in Figure 22) and 5 meters.

Figure 22. Position of the fibre optic cable on the floor.

System criteria for fire detection

The fire detection criteria were set in the fibre optic linear heat fire detection system:

- Criterion 1: Temperature: 60°C
- Criterion 2: Temperature gradient: 14°C in 120 seconds
- Criterion 3: Temperature gradient: 20°C in 240 seconds
- Criterion 4: Temperature gradient: 26°C in 360 seconds

The temperature in these criteria is the maximum temperature of one zone, measured by the fibre optic cable. A temperature gradient is an increase of temperature during a given time period.

For these tests, a fire detection alarm was activated when two consecutive measurement cycles (one measurement cycle was 10 seconds) have reached at least one criterion.

13.2.4 *Fire tests procedures*

The test started when the burner was ignited, and time was measured with a stop watch. The fire was allowed to grow to a maximum HRR of 1.5 MW (with varying fire growth rates) and then the HRR was kept constant.

Table 20 shows the tests procedures in terms of the fire curve used and fire position.

Table 20. Fire tests procedure

Test	System tested	Ro-ro space	Fire position	Fire curve	Other
1	Thermal imaging camera	Weather deck	Fire 1 (Figure 16)	Slow	[-]
2	Thermal imaging camera	Weather deck	Fire 2 (Figure 16)	Slow	[-]
3	Thermal imaging camera	Weather deck	Fire 3 (Figure 16)	Slow	[-]
4	Thermal imaging camera	Weather deck	Fire 3 (Figure 16)	Slow	Simulation of heavy rain
5	Fibre optic linear heat detection	Open ro-ro space	Fire 1 (Figure 21)	Slow	Distance FOC*-burner: 1 m
6	Fibre optic linear heat detection	Open ro-ro space	Fire 2 (Figure 21)	Medium	Distance FOC*-burner: 5 m
7	Fibre optic linear heat detection	Open ro-ro space	Fire 2 (Figure 21)	Fast	Distance FOC*-burner: 5 m
8	Fibre optic linear heat detection	Open ro-ro space	Fire 2 (Figure 21)	Slow	Distance FOC*-burner: 5 m
9	Fibre optic linear heat detection	Open ro-ro space	Fire 3 (Figure 21)	Slow	Distance FOC*-burner: 5 m

*FOC: Fibre Optic Cable (on deck floor)

As soon as a fire detection system (thermal imaging camera for the weather deck tests, existing smoke/heat detectors, and fibre optic linear heat system for the open ro-ro space) detected the fire, the test was stopped, and the gas feed to the fire was shut off. This was done to avoid damage to the ship. Furthermore, during tests, if the fire safety crew onboard judged that heat from the fire source could endanger the ship, a cooling procedure was initiated, consisting in water aspersion of adjacent bulkhead and deck by water from a fire hose.

13.3 False alarm test setup

One of the main issues with fire detection is the rate of false alarm of the system. The thermal imaging camera and the fibre optic linear heat detection system were left running onboard the test vessel for a period of 1 month to test their reliability. There was no satellite connection to the detection systems during this period so a weekly visit onboard the ship was needed to monitor them. The control units and computers dedicated to each system have recorded the possible presence of alarms. During this period, no fire has been reported by the test vessel, so any kind of alarm recorded during this period can be declared as false alarm. The results of this test are discussed in section 13.5.

13.4 Detection time test results

During the tests there was no way to moderate wind speed, which was gusty, especially on the weather deck. The average wind velocities measured were slightly less on the weather deck than in the open ro-ro space, 0.5-4 m/s at the fire locations on the weather deck compared to 3-6 m/s in the open ro-ro space. On the weather deck the wind direction varied a lot, however, in the open ro-ro space the wind was mainly coming from the weather deck (Figure 21).

13.4.1 *Results of thermal imaging camera on weather deck*

Four tests were performed with the thermal imaging camera with a slow fire growth. The results of the tests for this system are shown in the Table 21.

Table 21. Results of the fire tests for the thermal imaging camera.

Test	Challenging parameter(s)	Detection time	HRR at detection
1	Distance between fire and camera	Immediately at ignition	About 80 kW
2	Visibility of the fire: fire hidden behind a container	3 minutes	300 kW
3	Visibility of the fire: fire half-hidden behind a container	0.5 minutes	About 80 kW
4	Visibility of the fire: half-hidden fire + heavy rain	4 minutes	400 kW

The main parameter of interest in test 1 was the distance between the camera and the fire. The system detected fire quite fast.

For test 2, the fire was positioned behind a container to obstruct the direct view of the camera. The system detected the fire after 3 minutes. The detection was based on heat reflection from a rail situated at the aft of the weather deck (Figure 23).

Figure 23. Picture of fire detection for test 2 – Thermal imaging camera.

For test 3, the gas burner was half hidden by the container. The system detected the fire quite quickly (around 30 sec), which corresponds to the time when a flame reached the edge of the container.

For test 4, one fire monitor located on the weather deck was activated to simulate heavy rain.

Figure 24. Illustration of heavy rain from the fire monitor.

The system was able to detect the fire after 4 minutes for a HRR of 400 kW and a detection temperature of 204.4°C. The system detected the fire through the water flow, the detection point used by the system is shown in Figure 25.

Figure 25. Screen shot at the detection time for test 4.

13.4.2 *Results of fibre optic linear heat system in open ro-ro space*

Five tests were performed with the fibre optic linear heat detection system. The results of the tests for this system are shown in the Table 22, with a note on the criterion causing detection and the temperature upon detection.

Table 22. Results of the fire tests for fibre optic linear heat detection system.

Test	Fire position	Fire curve	Detection time – Detection criterion	HRR at detection
5	Fire 1 (Figure 21)	Slow	Fibre optic system at the ceiling	
			8.5 min (zone 3) - Criterion 2 (43°C) *10 min (zone 2) - Criterion 2*	*800 kW* *1050 kW*
			Fibre optic system at the floor (1 m from fire)	
			6 min - Criterion 2	*400 kW*
			Existing detectors (smoke/heat)	
			No detection (Z4: 85% obscuration, 22°C)	*[-]*
6	Fire 2 (Figure 21)	Medium	Fibre optic system at the ceiling	
			6.5 min (zone 4 & 5) - Criterion 2 (38°C)	*1400 kW*
			Fibre optic system at the floor (5 m from fire)	
			No detection	*[-]*
			Existing detectors (smoke/heat)	
			No detection (Z4: 88% obscuration, 32°C)	*[-]*
7	Fire 2 (Figure 21)	Fast	Fibre optic system at the ceiling	
			3 min (zone 4 & 5) - Criterion 2 (36°C)	*1600 kW*
			Fibre optic system at the floor (5 m from fire)	
			No detection	*[-]*
			Existing detectors (smoke/heat)	
			No detection (Z4: 88% obscuration, 30°C)	*[-]*
8	Fire 2 (Figure 21)	Slow	Fibre optic system at the ceiling	
			7.5 min (zone 4) - Criterion 2 (37°C) *8 min (zone 3 & 5) - Criterion 2*	*650 kW* *750 kW*
			Fibre optic system at the floor (5 m from fire)	
			No detection	*[-]*
			Existing detectors (smoke/heat)	
			No detection (Z4: 98% obscuration, 37°C)	*[-]*
9	Fire 3 (Figure 21)	Slow	Fibre optic system at the ceiling	
			9.5 min (zone 2 & 3) - Criterion 2 (44°C) *10.5 (zone 4) - Criterion 2*	*900 kW*

			13 min (zone 1) - Criterion 2	*1100 kW* *1500 kW*
			Fibre optic system at the floor (5 m from fire)	
			No detection	*[-]*
			Existing detectors (smoke/heat)	
			13 min – Smoke (Z3: 100% obscuration, 72°C)*	*1500 kW*

*For the conventional system, only the highest records are stated, at the time of the first detection with the alternative system (for port side detectors in zone (Z) 1, 2, 3, 4 or 5). This excepts the record for test 9, in which the fire source was left burning until detection was achieved by the conventional system – here the record upon detection is noted.

13.5 False alarm test results

13.5.1 *Results of thermal imaging camera on weather deck*

Left onboard the Scandinavica, the thermal imaging camera system recorded a large number of pre-alarms and alarms. For instance, between the 26th August and the 30th August, a total of 935 alarms were recorded as listed below:

- 26/08, 58 alarms between 7:00 – 17:32
- 28/08, 474 alarms between 10:42 – 17:56
- 29/08, 365 alarms between 10:20 – 17:00
- 30/08, 35 alarms between 10:19 – 11:24

The interesting point is that all these periods correspond on the time of loading/unloading the cargo on the weather deck of the Scandinavica.

Indeed, as recorded and illustrated in the Figure 26, all these pre-alarms and alarms are due to exhaust fumes or the mufflers of trucks moving the cargo on the deck.

Figure 26. Screen shot for an alarm during loading of cargo.

13.5.2 *Results of fibre optic linear heat system in open ro-ro space*

No alarm was triggered during the one-month period when the system was installed and functioning.

13.6 Discussion of fire detection tests

13.6.1 *Thermal imaging camera on the weather deck*

The alternative fire detection system tested for the weather deck was the thermal imaging camera. The system was considered to perform relatively well in the fire detection tests, as it quickly detected fire in all of the scenarios considered. The thermal imaging system was able to detect a fire at 50 meters (test 1). When the view of camera was totally obstructed by a container, the system was able detect a fire using radiant heat reflection on surrounding elements (test 2). When fire was partially hidden, the system could detect the fire as soon as a flame was visible by the camera (test 3).

One of the questions about the capability of this system was the influence of rain on the time of detection. Indeed, the detection method here is based on the heat radiation transmitted by the fire to the camera but water drops are capable of absorbing a large amount of this radiation [17]. It is expected that a fire should be relatively large in the presence of rain to be detected by the system.

The present system needed only 1 minute longer to detect a fire with “heavy rain” compared to the same fire without rain. This minute corresponds to an increase of 100 kW (33%) of the HRR by the fire.

Regarding the false alarm tests, the thermal imaging camera system showed difficulties. With the settings used for the fire tests, the system revealed a large amount of false alarms during loading/unloading of cargo. This nuisance might be avoided by:

- A change of sensitivity settings, but this solution would have a serious impact on the capability of fire detection.
- A change of fire detection alarm criterion. The manufacturer of this system is running another test onboard a ship. The solution adopted for this other study is to adapt the detection criteria according to the schedule of the ship. When the ship is sailing, the criterion is kept the same as for the fire test, but another criterion ($T_{measured}$ > 180°C for a period of 60 seconds) is adopted during loading/unloading of cargo.

In conclusion, the thermal imaging camera performs well for fire detection but suffers from a high false alarm rate with the current settings.

Pending the results of the additional study mentioned above, it is recommended to repeat fire tests for the thermal imaging camera with settings (better detection criteria for instance) that avoid false alarms.

13.6.2 *Fibre optic linear heat system in the open ro-ro space*

The alternative fire detection system tested for the open ro-ro space was the fibre optic linear heat detection system. This system performed relatively well within the frame of the fire tests in terms of detection and what can be expected from conventional systems.

Figure 27 shows the different positions of the fire and conventional detectors, and the fire zones of the fibre optic system in the open ro-ro space.

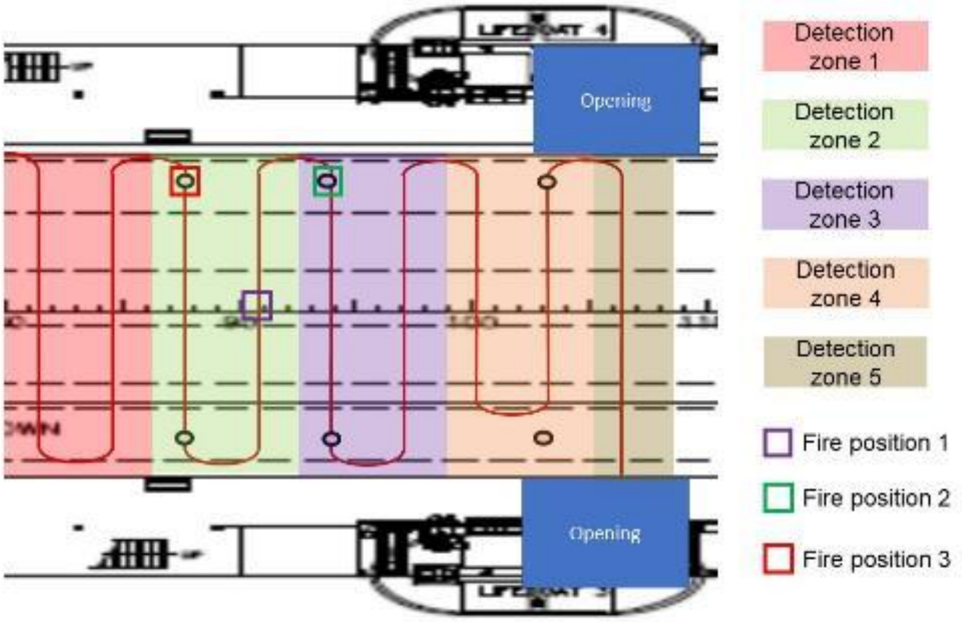

Figure 27. Fire positions, conventional detectors positions and fire zone of the fibre optic system.

As explained above, one of the main issues with heat detection systems is that wind can reduce and blow away the hot gases from the detectors. This effect will be increased by a large deck height and was demonstrated in the tests, where a wind was apparent from the stern. In test 5, the fire was situated in zone 2 and the wind was about 3-6 m/s. The system detected this fire in zone 3 after 8.5 minutes (800 kW) and in zone 2 after 10 minutes (1 050 kW). This result shows the advantage of a system having widespread and continuous detection coverage. During this test, the conventional system (heat and smoke detectors) did not detect the fire before the fibre optic system. The combined smoke and heat detection system onboard showed a level of obscuration of 85% (where 100% corresponded to alarm) and a temperature of 22°C. However, it should be noted that the test series was not set up to evaluate smoke detection (the fire source was not producing a representative amount of smoke).

Test 8 was similar to test 5, but the position of the fire was different. For test 8, the fire was situated directly below a conventional detector and closer to a side opening, but the result was similar to that of test 5. The fibre optic system detected the fire first in zone 4 in 7.5 minutes (fire situated in zone 3) and then in zone 3 in 8 minutes, while the conventional system did not detect the fire (98% obscuration and 37°C). Tests 5 and 8 showed that the fibre optic system can detect a fire even in windy conditions with the detection zone offset in the direction of the wind from the position of the fire.

Tests 6 and 7 represent the capacity of this system to detect fast fire growth (medium growth fire gave a detection time of 6.5 minutes and fast growth fire gave a detection time of 3.5 minutes). Again, for these tests, the conventional detection system did not trigger the alarm (test 2: 88% obscuration and 32°C, test 3: 88% obscuration and 30°C).

The longitudinal distance between the conventional detectors in zone 3 and zone 4 was larger than the longitudinal distance between the conventional detectors in zone 2 and zone 3. For test 9, the fire was situated right below the conventional detector in zone 2 in order to reduce the time of detection for the conventional detector in zone 3 (due to the influence of wind). Due to the great influence of the wind (greater at fire position 3 than in fire position 1), the time of detection of the fibre optic system was 9.5 min in zone 2, which was 3.5 minutes longer that the detection time in test 5 (with the same slow fire growth). For this test, the fire was not shut down at the first detection of the fibre optic system, but the HRR was kept constant at 1.5 MW until the conventional system detected the fire. This occurred after 13 minutes and was due to smoke (100% obscuration and 73°C).

The primary conclusion of the tests was that the fibre optic linear heat detection system appears to be functional and suitable in the relevant ro-ro space environment. Further verification tests would need to be performed to ascertain this performance also after long-term installation and exposure to the, often harsh, environment onboard.

The tests showed varying differences in temperature in the records between the conventional point heat detection system and the new alternative fibre optic linear heat detection system. In test 5, the fire source was not in line with the conventional detectors, considering the longitudinal wind and flow of gases, which gave the lowest temperature recording by the conventional system (22°C). Slightly higher temperatures were recorded in test 8, where the fire source was in line with the conventional detectors, but the temperature increase was still relatively small (37°C) and shifted, due to the wind, deck height and the distance to the detectors. The highest records for the conventional system were noted in test 9, in which the fire source was closer to the conventional detectors. Hence, even though the data is not enough for generalized conclusions, the test results indicate that a risk reduction is achieved by the fibre optic linear heat detection system, thanks to increased (and transversally continuous) detection coverage. It should be noted that the recorded differences in temperature cannot be separated from influences from differences in sensitivity of the heat sensors used for the different technologies.

Furthermore, each detection by the fibre optic linear heat detection system was caused by criterion 2 (rate of temperature rise). The differences in actual temperature recorded upon detection between the conventional and alternative systems can mainly be explained by the improved coverage, as concluded above. However, even larger differences can be noted between the recorded temperatures and criterion 1 (60°C). The test results thus indicate that the earlier detection can primarily be dedicated to the use of criterion 2 (temperature gradient of 14°C in 120 seconds) by the detection system. It seems that this criterion is more reactive than the conventional criterion 1.

A limitation of the test arrangement was the fact that the open ro-ro space was totally empty from cargo. This arrangement might be an advantage for the fibre optic linear heat system compared to a conventional point smoke detection system, where an empty space facilitate smoke dilution.

Another limitation explaining the ability of the fibre optic system to detect the fires earlier than the conventional smoke detection system was the burner, which produced a cleaner fire in terms of smoke production compared to a typical cargo fire. This means that the heat compared to the smoke produced was high in the tests, although there was smoke visible, as seen in Figure 28. Hence, if the objective is to compare the detection time of a fibre optic linear heat detection system with conventional point smoke detectors, it is recommended to perform additional fire tests with a fire source producing a more suitable amount of smoke.

An unknown limitation of the results related to the records made for the conventional smoke and heat detection system is related to the cooling down of the system. The initial temperatures of the heat sensors in the conventional detectors are unknown (after the initial test in which it can be assumed to have been of ambient temperature). However, it should be noted that the fibre optic linear heat detection system cooled down to ambient temperature between the tests and that higher initial temperatures for the conventional system would only have implied earlier detection by the latter. The same conclusion cannot be made for the smoke part of the conventional system, for which the starting value of the obscuration in the detection chamber is unknown. The test results show increasing obscuration in the test series, which is in line with the increasing severity of the tests but also cannot exclude effects from un-calibrated obscuration chambers. It should although be noted that the results in some cases relate to different detectors.

It should be noted that the fire safety crew onboard engaged in cooling of the ship surfaces adjacent to the fire source by water aspersion when deemed necessary, which might have slightly reduced the detection time for the conventional smoke detection system (test 9) and avoided heat detection on the floor. However, in tests 5 and 6, no wetting of the floor was made, which showed that detection 1 away from the fire was possible but that detection 5 m away from the fire was not possible. It was considered unlikely that the steam from the water had more than a marginal effect on the detection time for the conventional system in test 9.

Figure 28. Illustration of the smoke (circled in red) produced by the burner.

13.7 Fire detection test acknowledgements

The FIRESAFE II consortium would like to thank the manufacturers who provided the two alternative detection systems: AP Sensing (Deutschland) and ALPHATRON Marine (Netherlands).

14 RISK REDUCTION FROM SELECTED ALTERNATIVE SYSTEMS

The tests performed pointed out the key items to address in the quantification of the risk reduction associated with implementation of the two selected alternative detection systems in chapter 12. The methodology for the risk reduction quantification is presented in this chapter, starting with a review of the main fire risk model used in FIRESAFE II Part 1 [18] and Part 2 [19] and followed by a review of the results of the analysis.

14.1 Translation of tests in term of detection failure probabilities

14.1.1 *Main fire risk model*

This risk model is based on the one developed in FIRESAFE. The main modification for this work was the expansion of the former *Decision* node into two nodes, covering *Decision* and *Detection*.

The definition of *Early/Late Decision* has remained the same as in FIRESAFE [20]. An “Early” or “Late” decision should be understood in relation to the fire growth rate, where “Early” means that the decision to activate the system has been taken early enough to potentially extinguish the fire and “Late” means that the fire has already developed beyond the ability to extinguish it. However, the fire can still be suppressed upon system activation if the decision is Late.

The concept of *Early/Late Detection* was introduced and extensively discussed in section 9.2 of the report Detection and Decision of the FIRESAFE II project [18].

A diagram of the updated Main Fire Risk Model for the *Standard RoPax Newbuilding* (*Open ro-ro spaces* part only) is shown in Figure 29. The entire Main Fire Risk Model, including the three parts: *Closed ro-ro spaces*, *Open ro-ro spaces*, and *Weather Deck* and the event tree for the *Cargo RoPax* and the *Ferry RoPax* are shown in the Appendixes of the report Detection and Decision of the FIRESAFE II project [18].

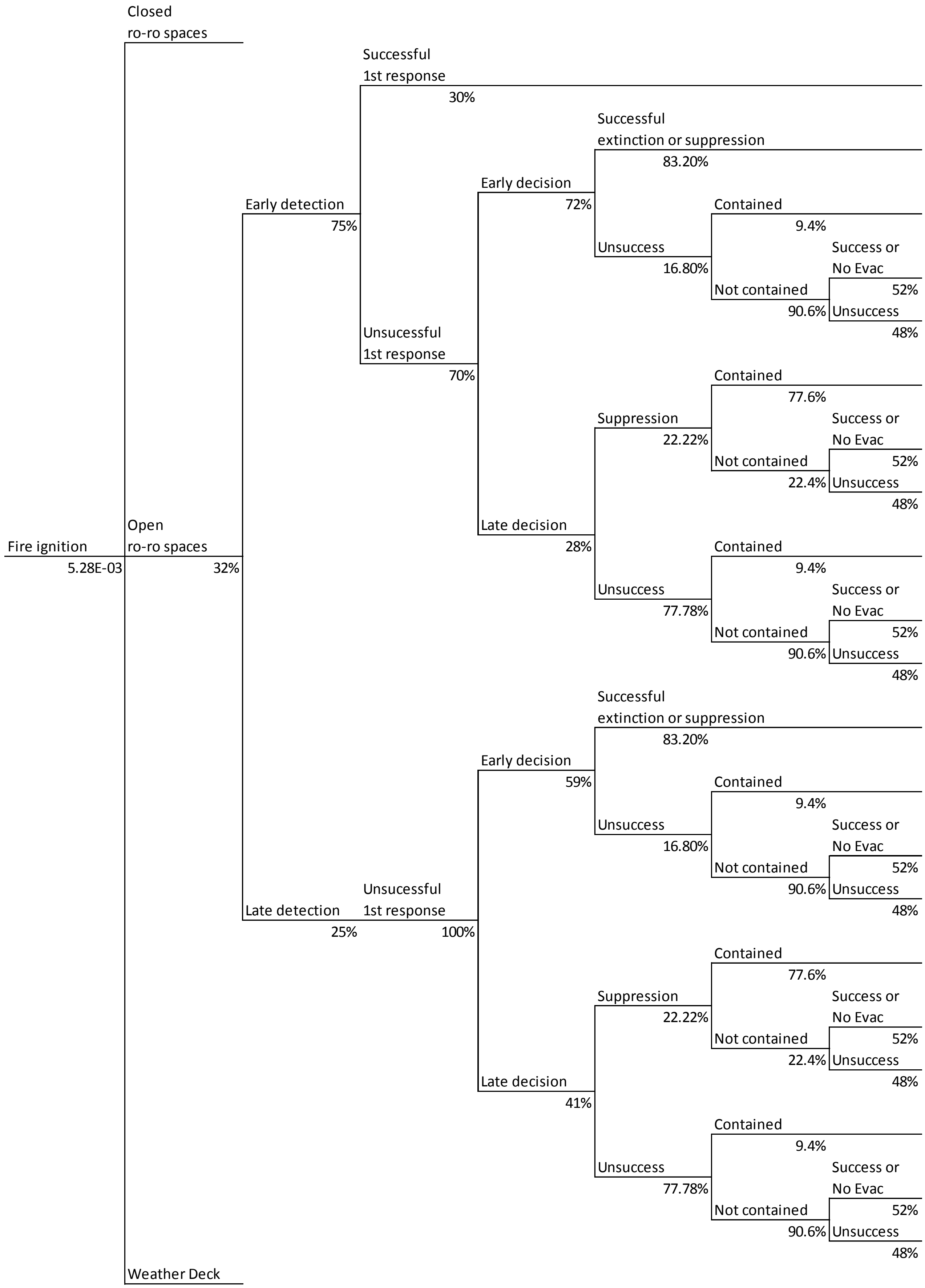

Figure 29. Updated Main Fire Risk Model for the *Standard RoPax Newbuilding* (*Open ro-ro spaces* part)

A fault tree was developed to model early detection failure, meaning that unsuccessful first response is probable due to no or late detection. For *late detection* to occur, both *system detection failure* and *manual detection failure* are necessary. The failure probabilities are dependent on the deck type. While the structure of the tree remains the same for both closed and open ro-ro spaces, the quantification differs. In the absence of any fixed detection system on the weather deck, the structure of the tree was adapted to model the early detection failure for the particular type of deck.

The structure of the fault tree for closed and open ro-ro spaces is illustrated in Figure 30 to Figure 32. In order to maintain readability, the fault tree was divided into two sub-fault trees.

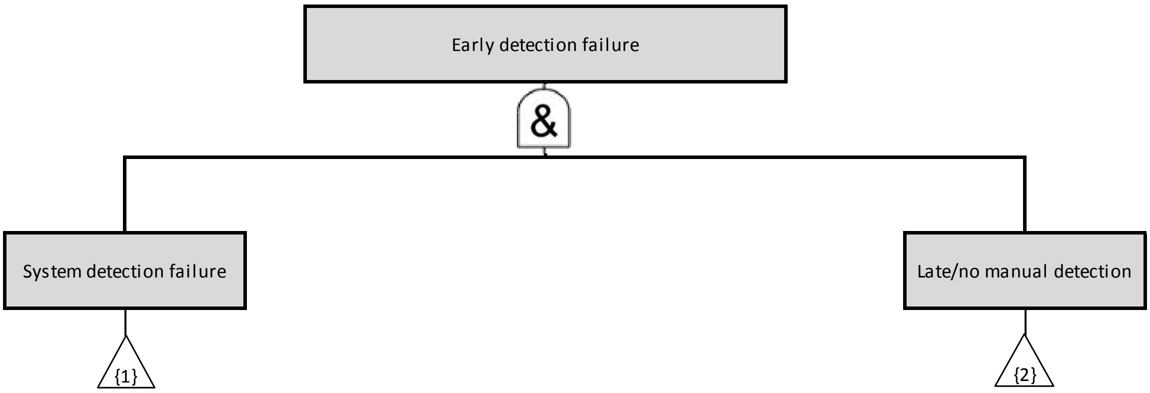

Figure 30. Detection fault tree (closed and open ro-ro spaces).

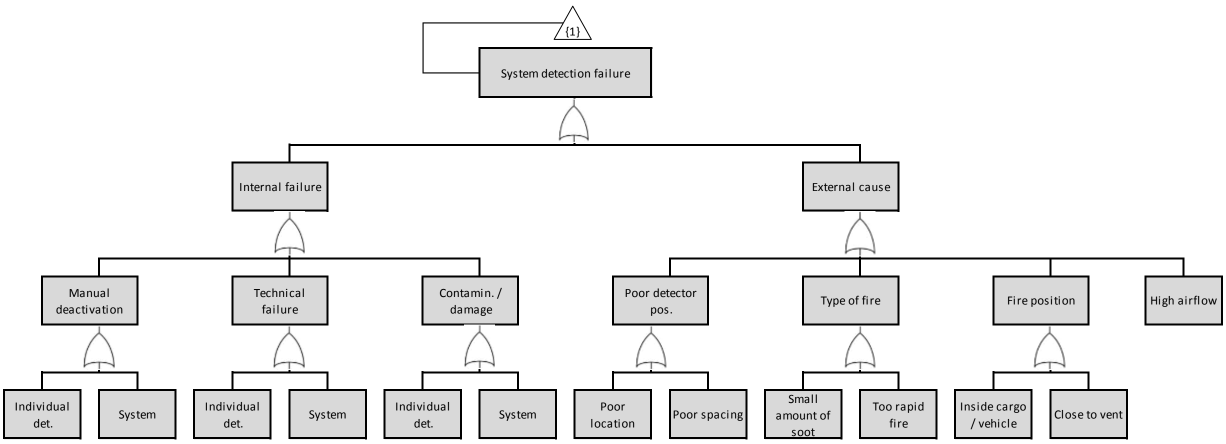

Figure 31. Sub-tree for *System detection failure* (Closed and open ro-ro spaces).

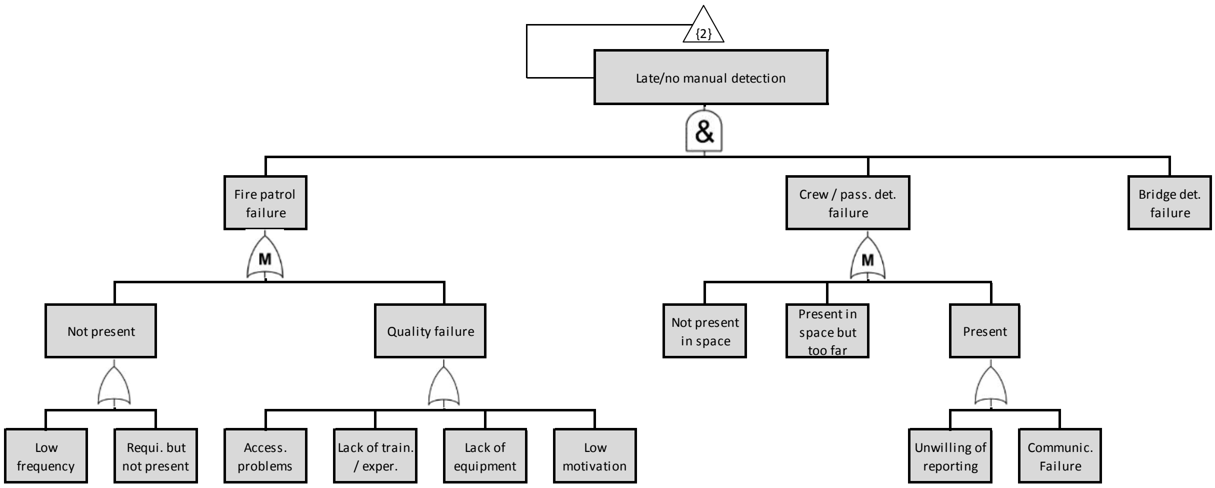

Figure 32. Sub-tree for *Late/no manual detection* (closed and open ro-ro spaces).

A full description of the detection fault tree is available in the report Detection and Decision of the FIRESAFE II project [18].

For the quantification of the risk reduction of the alternative system installed in the open ro-ro space, the impacted part of the detection fault tree is the sub-tree for *system detection failure*.

For the case of the alternative system on the weather deck, a new detection fault tree was developed.

14.1.2 *Updated quantification of the detection fault tree for Fibre optic linear heat system in the open ro-ro space*

The quantification of the risk reduction associated to the fibre optic linear heat system is similar to the risk reduction done in the report Detection and Decision of the FIRESAFE II project for the Risk Control Option: *combined heat and smoke detection* [18].

Experts first quantified the benefits of having the fibre optic linear heat system without considering the detection time. The reasoning for this approach is reported in the column 'Affecting factors' of Table 23. The probability of an early detection was then calculated to obtain the risk reducing effect of the detection system.

This factor was deducted from Fire Dynamic Simulator simulations run for the Detection and Decision part of the FIRESAFE II study [18]. Several fire scenarios were simulated in an open ro-ro space to obtain the detection time and the probability of an early detection. Scenarios can be split into two groups: presence of wind when the ship is at sea, and no wind when the ship is at port. For each group different fire positions and different fire growth rates were applied. Using the temperature gradient criterion (Criterion 2: Temperature gradient: 14°C in 120 seconds), the simulations showed early detections for the no wind cases. For cases with wind, the probability of having an early detection is estimated at 10% (results from the Detection and Decision part of the FIRESAFE II study, concerning the Risk Control Option: *Combined heat and smoke detection* [18]). The temperature gradient criterion for the simulations of the closed ro-ro space showed that an early detection was reached when a slow or medium fire growth rate was applied but no early detection occurred for cases having fast fire growth.

From the previous results, the risk reduction was explained by:

- Open ro-ro spaces: [P(slow and medium fire growth) x P(fire on ship at port)] + [10% x P(fire on ship at sea)] = [66% x 25%] + [10% x 75%] = 24%
- Closed ro-ro spaces: P(slow and medium fire growth) = 66%.

where

P(slow or medium fire growth): probability to have a slow or medium fire growth in case of fire. This probability was estimated to be 66%.

P(fire on ship at port): probability that there is a fire on the ship while she is at port. The time in port versus time at sea varies greatly between ships, generally from 1:1 to 1:7. Statistics based on 39 reported fires indicate that one out of four fires occurs while in port or just after leaving port. Based on these statistics, the probability was estimated at 25%.

P(fire on ship at sea) = 100% - P(fire on ship at port).

It should be noted that as the fibre optic linear heat detection system could be considered for closed ro-ro spaces, the risk reduction methodology was applied for this type of ro-ro spaces.

In the case of open ro-ro spaces, for the nodes *manual deactivation-Individual det.* and *manual deactivation-System*, the factor is taken at 66% as these nodes apply to the ship at port.

Table 23. Reduction of the failure probabilities for the nodes impacted by the criterion based on temperature gradient and use of the linear fibre optic heat detection system for closed (CRS) and open (ORS) ro-ro spaces.

Affected nodes	*Affecting factors*	*CRS*	*ORS*
System detection failure - Internal failure - **Manual deactivation - Individual det.**	Linear Fibre Optic detection remains activated during these activities.	65.67%	65.67%
System detection failure - Internal failure - **Manual deactivation - System**	Linear Fibre Optic detection remains activated during these activities.	65.34%	65.34%
System detection failure - Internal failure - **Technical failure - Individual det.**	Smoke & Linear Optic Fibre detection system are two separated systems. Unlikely that both will be faulty at the same time. No common cause of failure.	65.34%	23.76%
System detection failure - Internal failure - **Technical failure - System**	Smoke & Linear Optic Fibre detection system are two separated systems. Increased reliability of the linear fibre optic system but output integrated into the existing system.	33.00%	12.00%
System detection failure - Internal failure - **Contamin. / damage - Individual det.**	Contamination will not impact the heat detection. Damage is not likely to affect both Linear Optic Fibre detection system and smoke detection system.	65.34%	23.76%
System detection failure - Internal failure - **Contamin. / damage - System**	Contamination will not impact Linear Optic Fibre detection system. Damage is not likely to affect both Linear Optic Fibre detection system and smoke detection system.	33.00%	12.00%
System detection failure - External cause - Poor detector pos. - **Poor spacing**	Fiber optic system is expected to be installed with the same horizontal spacing as the smoke detectors in one direction. However, fibre optic is a linear system (opposed to a point system), giving continuous detection possibility in the other direction.	33.00%	12.00%
System detection failure - External cause - Type of fire - **Small amount of soot**	Soot is not a determining factor for Linear Optic Fibre detection system.	66.00%	24.00%
System detection failure - External cause - Type of fire - **Too rapid fire**	Only a small proportion of "rapid" fires will benefit from heat detection (compared to smoke detection).	9.90%	4.80%
System detection failure - External cause - Fire position - **Close to vent**	According to the fire tests, the Linear Fibre detection system might detect a fire close to vent.	33.00%	12.00%
System detection failure - External cause - **High airflow**	Heat transport is not affected by high flow, contrary to particulates transport, especially in case of solid (detector) disturbances.	66.00%	24.00%

14.1.3 *New detection fault tree and its quantification for the Thermal imaging camera on the weather deck*

As no fixed fire detection system is required on the weather deck, and as the implementation of this system brings new failure modes, a sub-tree for *system detection failure* was developed in order to capture. This sub-tree is based on the fault tree developed for the smoke detection system and is presented in Figure 33.

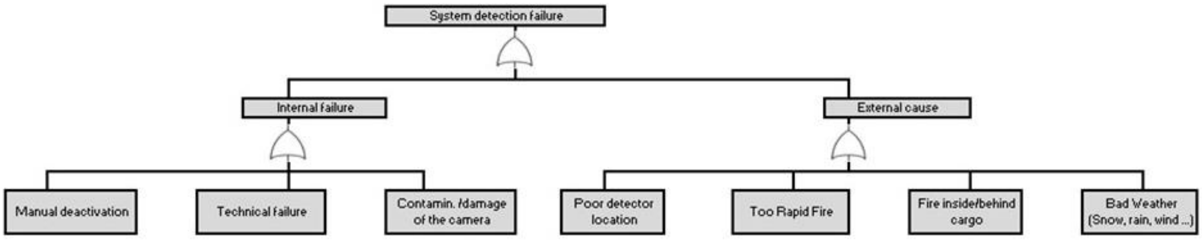

Figure 33. Sub-tree for *System detection failure* for weather deck.

System detection failure is divided into *internal failure*, which implies late detection despite favourable detection conditions, and *external cause*, which implies unfavourable detection conditions due to fire/sensor position, airflow or fire scenario.

Internal failure:

- Manual deactivation

  The thermal imaging camera system has shown a high rate of false alarms while cargo is loaded and unloaded during the test period. With the current settings tested, it was decided that the current system should be deactivated during loading and unloading. The time in port versus time at sea varies greatly between different ships, generally from one out of 1:1 to 1:7. Statistics (based on 39 reported fires) indicate that one out of four fires occur while in port or just after leaving port. Based on those statistics, the probability of detection failure due to manual deactivation was estimated at 25%.

- Technical failure

  Technical failure includes all technical problems affecting the performance of the thermal imaging camera system. Technical failures will generally result in a fault signal, implying that faults that could lead to late detection must be fixed as soon as possible. As no data are available on technical failure for the thermal imaging system, the quantification of this failure mode is the same as for the smoke detection system i.e. 0.3%.

- Contamination or damage of the camera

  Contamination of the camera due to e.g. dirt, dust or salt deposition on the lens could be relatively common in this environment but will most often cause fault alarms (classified as technical failure) or false alarms. However, if dirt or dust degrades the camera view it will cause late detection. Such failures can be hard to realize without frequent cleaning procedures or without lens supervision. The probability of this failure node was estimated at 2.0%.

External cause:

It is assumed that early detection is achieved when the detection system is not affected by internal failures and there is no effect of the following failure conditions.

- Poor detector position

  Poor detector position considers the case where the camera has been badly positioned during installation. The probability of this failure node was estimated at 0.3%.

- Too rapid fire

  According to FIRESAFE [20], around 60% of the fires in ro-ro spaces are electrical fires, but there are many other types of possible fires as well. A fire could cause late detection if it grows too rapidly, thus growing beyond the threshold of possible extinguishment during the time between detection and fire confirmation by the crew. Any liquid or gas fire has the potential to grow too rapidly. The probability of this failure node was estimated at 4.0%.

- Fire inside/behind cargo

The fire position has great influence on the response time. Fire tests performed during the study have shown that the early detection time of a fire *behind cargo* will be delayed by approximately 3 minutes. *Fire inside cargo* is considered to be the most problematic with respect to early detection. A fire inside a container can develop into a large fire but will be not be detected until the container wall reaches the critical temperature of thermal imaging detection. According to FIRESAFE [20], 19% of fires originate inside a cab. Since the thermal imaging system can detect these fires, the probability of this failure node was estimated at 10%.

- Bad weather

The thermal imaging camera system is intended to be installed on weather deck, it will be exposed to bad weather. The thermal camera can have detection difficulties if the field of view includes a large amount of cold surfaces or water, or if the lens is physically blocked. The case of heavy rain was tested during the fire tests and the system overcame this issue. In case of snow, the lens of the camera might be covered by snow or frozen, even if a heating system is built to avoid this issue. The probability of this failure node was estimated at 1 %.

In conclusion, the probability of detection failure for the thermal imaging camera system was calculated to be 37.51%.

14.2 Estimation of Risk Reduction by the implementation of the selected systems

The relative risk reductions induced by the implementation of the selected systems were estimated on the ships the systems have initially been considered for in the Desk study (i.e. linear fibre optic: A/*Standard RoPax* and thermal imaging camera: B/*Cargo RoPax*).

The above quantifications/translation were integrated into the respective main fire risk models, from which effects on the total risk could be calculated. These results are presented in Figure 34.

The results are presented in terms of relative risk reductions to standardize the impact (reduction) on the PLL, which is different for the reference ships, for example due to different effects (described above) and depending on their varying passenger capacity.

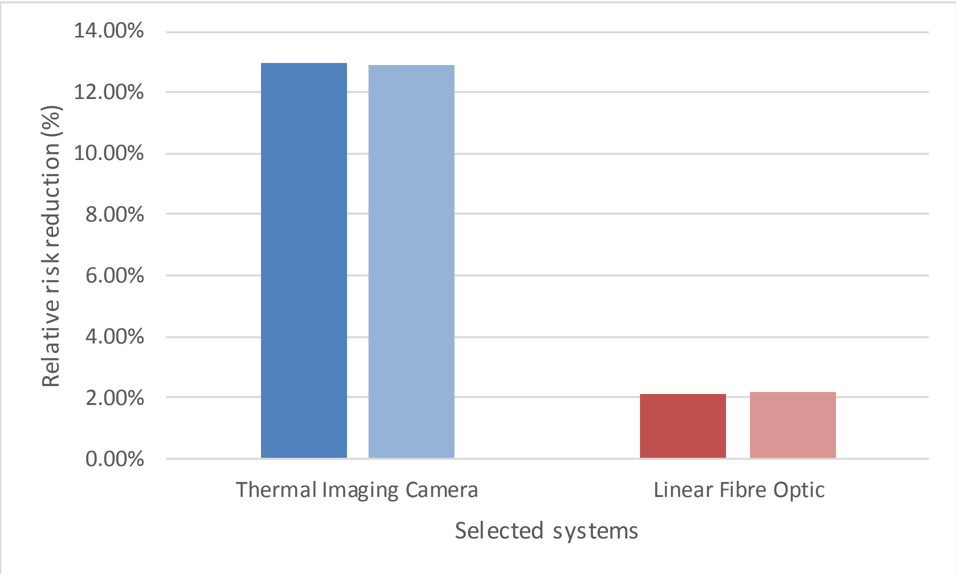

Figure 34. Relative Risk Reduction of the two selected systems on Newbuildings (lighter blue and red corresponds to Existing ships)

Regardless of the system considered, the relative risk reduction is not significantly impacted by the ship status (Newbuildings vs. Existing ships).

The Potential Loss of Life after the implementation of the thermal imaging camera is 5.80E-03 fatalities per shipyear for Newbuildings and 5.83E-03 fatalities per shipyears for Existing ships (compared to a PLL before the implementation of the system of 6.66E-03 fatalities per shipyears and 6.69E-03 fatalities per shipyears for Newbuildings and Existing ships respectively).

The Potential Loss of Life after the implementation of the linear fibre optic in the open ro-ro space is 2.27E-02 fatalities per shipyear for Newbuildings and 2.29E-02 fatalities per shipyears for Existing ships (compared to a PLL before the implementation of the system of 2.32E-02 fatalities per shipyears and 2.34E-02 fatalities per shipyears for Newbuildings and Existing ships respectively).

14.2.1 *Extension to FIRESAFE II Generic Ships*

As an additional output of this study, the estimated risk reduction induced by the implementation of the selected systems were also estimated for the three generic ships considered in the Part 1 [18] and Part 2 [19] of FIRESAFE II project.

Although the linear fibre optic detection system was initially considered for use in open ro-ro spaces only, [in accordance to the scope of the study], its use on both open and closed ro-ro spaces was considered realistic from a technical point of view and expected to bring additional risk reduction effects. Therefore, this was further investigated, and estimated risk reductions were assessed considering the installation of the linear heat detection system on both types of decks, taken into account the results from the section 14.1.2

These results are presented in Figure 35 for Newbuildings and Figure 36 for Existing Ships.

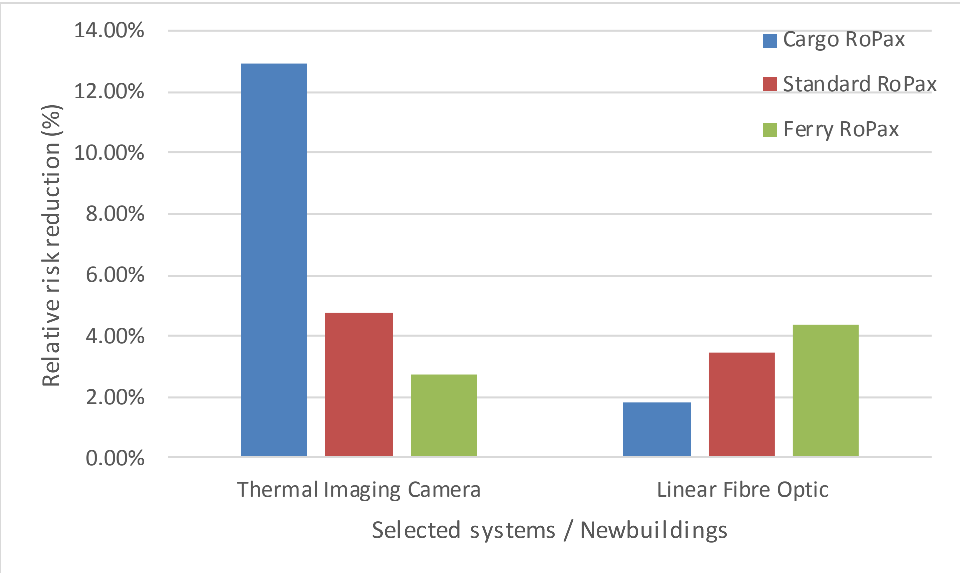

Figure 35. Relative Risk Reduction of the two selected systems on Newbuildings

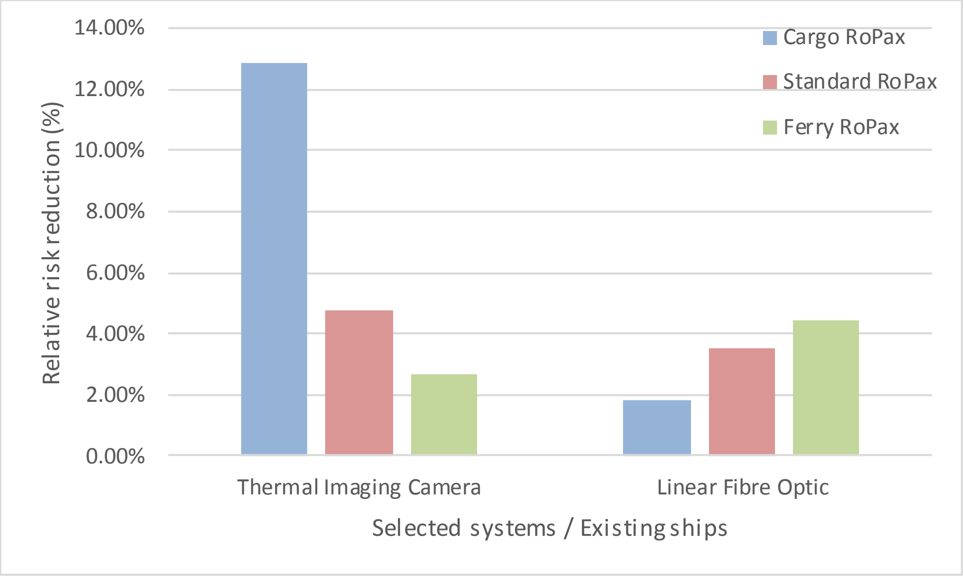

Figure 36. Relative Risk Reduction of the two selected systems on Existing ships

The relative risk reduction induced by the thermal imaging camera is directly correlated to the area of weather deck of each ship considered.

With regard to the linear fibre optic, correlation between the relative risk reduction and the total areas of Closed / Open ro-ro spaces can also be observed. For the *Standard RoPax*, the relative risk reduction reached 3.45% when considering the impact of the system for both open and closed ro-ro spaces (compared to 2.14% when only the impacts on the open ro-ro spaces are considered).

14.2.2 *Consideration of side effects*

It should be noted that the relative risk reductions presented and discussed above only take into account the effects of the system on the Detection node in the main fire risk model event tree.

14.2.2.1 Linear fibre optic

As a heat detection system, complementing the smoke detection system, the implementation of the linear fibre optic would bring similar benefits on the other parts of the main fire risk model as the ones induced by the RCO *Combined Heat and Smoke detection* (e.g. improved decision, allowing tactical fire-fighting and better informed boundary cooling). These were extensively discussed in the Combined Assessment report of FIRESAFE II [21].

No negative side effects induced by the implementation of this system were identified. As a consequence, the relative risk reduction presented and discussed above should be seen as a lower bound.

14.2.2.2 Thermal imaging camera

Installing a fixed detection system in the weather deck (where no fixed fire detection system is required as per the regulations) would increase the Early Detection probability but also increase the Late Decision probability (due to system-induced failure modes, such as *Late deployment of runner* or *Delayed acknowledgment*).

As a first approximation for the purpose of quantifying this negative side effect, the Decision fault trees (and associated conditional probabilities) that were developed for the Closed and Open ro-ro spaces (where both manual and system detection are required/possible) were applied to the weather deck.

No other side effects (positive or negative) were identified. Figure 37 presents the difference in the relative risk reduction according to whether or not the side effects are considered.

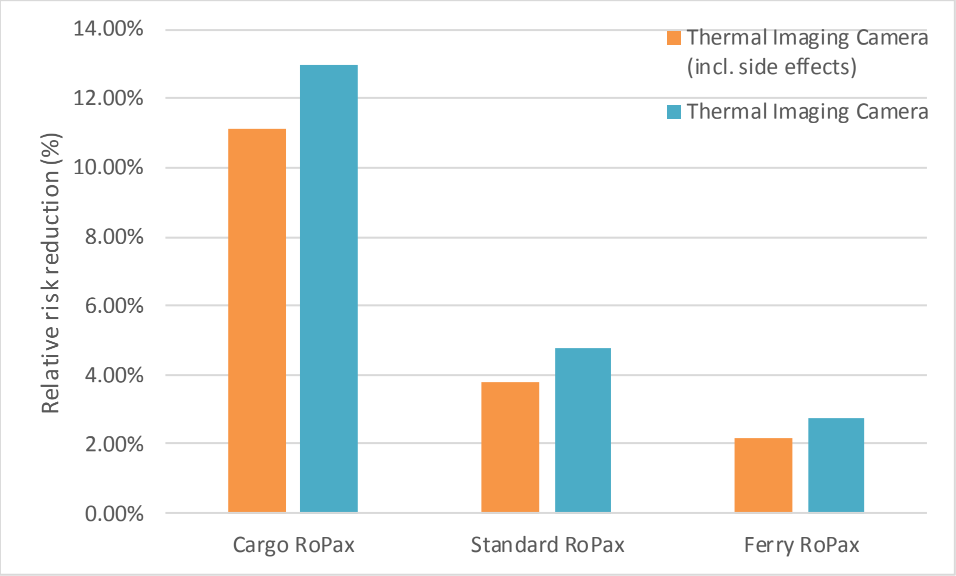

Figure 37. Relative risk reduction induced by the *thermal imaging camera* – with and without considering the side effects of its implementation (on the other parts of the main fire risk model)

15 COST-EFFECTIVENESS ASSESSMENT OF THE SELECTED SYSTEMS

15.1 Cost-effectiveness assessment – background

A cost-effectiveness of the selected system was performed taking into account the expected costs identified in section 11.2 and the expected risk reduction quantified in section 14.

Background and assumptions for the cost-efficiency assessment were provided in the Part 1 report of FIRESAFE II [18]. Only the main information is reported below.

It was proposed to use 7 000 000€ as the cost effectiveness criterion in FIRESAFE II. The expected lifetime (T) of a RoPax was set to 40 years, whereas the average age of the fleet was estimated to 20 years old. The delta cost and benefits were calculated in Net Present Value (NPV) with a depreciation rate of 3.5% for the period of years 1 – 30 and 3.0% for the period of years 31 – 40 [22].

15.2 Estimation of costs

Costs of relevant alternative fire detection systems were estimated in section 11.2. These costs are used for the purpose of performing the cost-effectiveness assessment.

In order to perform an extended cost-effectiveness assessment on the three generic ships considered in Parts 1 [18] and Part 2 [19] of FIRESAFE II, the costs estimated in section 11.2 were derived for each of the generic ships based on the respective areas of the different ro-ro spaces and decks, also considering the scaling arguments discussed in section 11.2.

15.2.1 *Fibre optic linear heat system*

The initial cost estimation in section 11.2 was performed taking as the basis the open ro-ro space of the *Standard RoPax*.

15.2.1.1 Existing ships

15.2.1.1.1 Standard RoPax

Considering the installation of the system in the open ro-ro space of the *Standard RoPax*, the estimated total cost ranged from 50 000 € to 80 000 €. The average (65 000€) was taken as the basis for the cost-effectiveness assessment.

No maintenance cost was considered, and this system would be installed in addition to the current fixed detection system. Therefore, the marginal lifetime cost corresponds to the investment cost (i.e. 65 000€).

If installed in both closed and open ro-ro spaces, component costs increases up to 25 000€, as described in paragraph 11.2.1.2.

Considering that half of the installation cost is driven by the installation of the cable itself, and that the total area of the closed and open ro-ro spaces are 2.5 larger than the area of the open ro-ro space only, installation cost are expected to increase by 25 000€. Commissioning costs were kept identical. This led to a marginal lifetime cost of 98 000€.

15.2.1.1.2 Ferry RoPax

The total area of closed and open ro-ro spaces are almost identical on *Standard RoPax* and on *Ferry RoPax*, 7 830 m² (closed and open ro-ro spaces) and 7990m² (closed ro-ro spaces only) respectively. Therefore, the marginal lifetime cost of 98 000€ estimated for *Standard RoPax* was considered applicable for the *Ferry RoPax.*

15.2.1.1.3 Cargo RoPax

The total area of closed ro-ro spaces of *Cargo RoPax* is identical to the size of the open ro-ro space of *Standard RoPax*, 2 930m² (closed ro-ro spaces) and 2 990m² (open ro-ro space) respectively. Therefore, the marginal lifetime cost of 65 000€ estimated for the installation of the system in the open ro-ro space of the *Standard RoPax* was considered applicable.

15.2.1.2 Newbuildings

As indicated in section 11.2, it is expected that the equipment costs would be the same for newbuildings and existing ships. Installation costs would be slightly less. However, this minor effect was not considered in the study.

Therefore, the same costs as estimated above were applied.

15.2.2 Thermal imaging camera

The initial cost estimation was performed taking as the basis the weather deck of the *Cargo RoPax*.

15.2.2.1 Existing ships

15.2.2.1.1 Cargo RoPax

For the *Cargo RoPax*, the estimated total cost is 95 000 €.

However, maintenance costs were not considered in this total cost. As a first approximation, the maintenance costs were considered the same as a CCTV system (for which the yearly service costs were estimated to 1 000€ in FIRESAFE [20]).

This led to a marginal lifetime cost of 109 000€.

15.2.2.1.2 Standard RoPax

The area of the weather deck on the *Cargo RoPax* and *Standard RoPax* are almost identical (1 440m² and 1 450m² (spread over two decks), respectively). Therefore, the marginal lifetime cost of 109 000€ estimated for *Cargo RoPax* was considered applicable for the *Standard RoPax.*

15.2.2.1.3 Ferry RoPax

The cost for a system covering half of the deck size of the *Cargo RoPax* was estimated to € 50 000 in section 11.2. Given that the size of the weather deck of the *Ferry RoPax* (450m²) is approximately the third of the size of the *Cargo RoPax* weather deck, the lower bound of the cost estimation range (50 000€) was selected.

Taking into account the maintenance costs, this led to a marginal lifetime cost of 64 000€.

15.2.2.2 Newbuildings

As indicated in section 11.2, it is expected that the equipment costs would be the same for newbuildings and existing ships. Installation costs would be slightly less. This effect was not considered in the study. However, the lifetime marginal costs increased due to the longer expected lifetime of the vessels.

Therefore, the marginal lifetime costs are as follows:

- Cargo RoPax: 116 000€
- Standard RoPax: 116 000€
- Ferry RoPax: 71 000€

15.3 GCAF ratio for the selected systems

Table 24 to Table 27 summarize the inputs value for the calculation of the GCAF (as defined in [23]).

The ΔRisk is difference of the potential loss of life over the expected lifetime of the vessel after and before the implementation of the selected systems. The ΔCost, in present value, is the difference of the lifetime costs between reference vessel and the vessel equipped with the alternative system. The ΔBenefits, in present value, is the lifetime economic benefits (reduced loss of cargo and reduced loss of ship) that follow the implementation of the system.

These tables also present the result of the cost benefit analysis and assessment by providing the GCAF.

The GCAF Factor is the ratio between the GCAF as calculated and the CAF criterion of €7.00M that was selected in the first part of FIRESAFE II [18] and indicates a cost efficiency with values less or equal to 1.00.

15.3.1 *Newbuildings*

Table 24 lists the input values ΔRisk and ΔCost, as well as the resulting cost effectiveness ratios GCAF, and GCAF Factors for the selected systems on the reference vessels (Newbuildings).

Table 24. ΔRisk, ΔCosts, GCAF and GCAF Factor values for the selected systems on reference vessels (Newbuildings)

		ΔRisk	ΔCost	GCAF		
Newbuildings	Systems investigated	Averted fat.	Present Value	GCAF	GCAF Factor	Cost effective
Cargo RoPax	Thermal Imaging Camera	3.45E-02	116 000 €	3 361 515 €	0.48	Yes
Standard RoPax	Linear Fibre Optic (open ro-ro space only)	1.98E-02	65 000 €	3 274 803 €	0.47	Yes

The systems were found cost-effective on the reference ships (*Cargo RoPax* ship for the thermal imaging camera system and *Standard RoPax* ship for the linear fibre optic heat detection system), with calculated GCAF factors of about 0.5.

A simple sensitivity analysis of the GCAF Factor for the linear fibre optic heat detection system showed that a variation of the cost between 50 000€ and 80 000€ gave GCAF Factors between 0.36 and 0.58, while varying the “success factor” between 0.36 and 0.12 gave a small impact, with GCAF Factors varying between 0.46 and 0.48. An uncertainty analysis showed that the probability of a GCAF Factor<1 was 84.2%, assuming a triangle distribution (0.12; 0.24; 0.36) for the “success factor” and a uniform distribution (50 0000; 80 000) for the cost.

For the thermal imaging camera, a simple sensitivity analysis of the GCAF Factor showed that a variation of the cost between 96 000€ and 136 000€ gave GCAF Factors between 0.40 and 0.56. An uncertainty analysis showed that the probability of a GCAF Factor<1 was 89.7%, assuming a uniform distribution (96 000; 136 000) for the cost.

Furthermore, a more extensive cost-effectiveness assessment was performed, taking into account the risk reduction estimated for the three generic ships considered in the Part 1 [18] and Part 2 [19] of FIRESAFE II (section 14.2.1) and the costs of implementation of the systems in these ships (section 15.2). The results of the extended cost-effectiveness assessment are provided in Table 25.

Table 25. Extended cost-effectiveness assessment: ΔRisk, ΔCosts, GCAF and GCAF Factor values for the selected systems on generic ships (Newbuildings)

		ΔRisk	ΔCost	GCAF		
Newbuildings	Systems investigated	Averted fat.	Present Value	GCAF	GCAF Factor	Cost effective
Cargo RoPax	Thermal Imaging Camera	3.45E-02	116 000 €	3 361 515 €	0.48	Yes
	Linear Fibre Optic	4.76E-03	65 000 €	13 641 256 €	1.95	No
Standard RoPax	Thermal Imaging Camera	4.43E-02	116 000 €	2 616 056 €	0.37	Yes
	Linear Fibre Optic (open ro-ro space only)	1.98E-02	65 000 €	3 274 803 €	0.47	Yes
	Linear Fibre Optic	3.20E-02	98 000 €	3 066 912 €	0.44	Yes
Ferry RoPax	Thermal Imaging Camera	3.86E-02	71 000 €	1 839 815 €	0.26	Yes
	Linear Fibre Optic	6.16E-02	98 000 €	1 591 546 €	0.23	Yes

Apart from the linear fibre optic in the *Cargo RoPax*, all of the systems achieved cost-effectiveness on all the generic ships investigated.

It is worth noting that the results of the extended cost-effectiveness assessment tend to confirm the initial expert judgement mentioned in section 11.2.1.2 about the cost-effectiveness of the linear fibre optic ("this system is that it might become quite cost efficient if it is applied on larger or several decks"). However, due to the uncertainties in the calculation of the increased installation and component costs, the cost effectiveness of the system can be considered not sensitive to the size of the system (as long as only one controller unit is necessary).

15.3.2 *Existing ships*

Table 26 lists the input values ΔRisk and ΔCost, as well as the resulting cost effectiveness ratios GCAF, and GCAF Factors for the selected systems on the reference vessels (Existing ships).

Table 26. ΔRisk, ΔCosts, GCAF and GCAF Factor values for the selected systems on reference vessels (Existing ships)

Existing ships	Systems investigated	ΔRisk	ΔCost	GCAF		
		Averted fat.	Present Value	GCAF	GCAF Factor	Cost effective
Cargo RoPax	Thermal Imaging Camera	1.73E-02	109 000 €	6 317 329 €	0.90	Yes
Standard RoPax	Linear Fibre Optic (open ro-ro space only)	1.02E-02	65 000 €	6 393 276 €	0.91	Yes

For the Existing ships, both systems were found cost-effective on the *Cargo RoPax* with a GCAF ratio around 0.9.

A simple sensitivity analysis of the GCAF Factor for the linear fibre optic heat detection system showed that a variation of the cost between 50 000€ and 80 000€ gave GCAF Factors between 0.70 and 1.12, while varying the "success factor" between 0.36 and 0.12 gave a small impact, with GCAF Factors varying between 0.89 and 0.94. An uncertainty analysis showed that the probability of a GCAF Factor<1 was 48.2%, assuming a triangle distribution (0.12; 0.24; 0.36) for the "success factor" and a uniform distribution (50 0000; 80 000) for the cost.

For the thermal imaging camera, a simple sensitivity analysis of the GCAF Factor showed that a variation of the cost between 89 000€ and 129 000€ gave GCAF Factors between 0.73 and 1.06. An uncertainty analysis showed that the probability of a GCAF Factor<1 was 50.9%, assuming a uniform distribution (89 000; 129 000) for the cost.

Furthermore, a more extensive cost-effectiveness assessment was performed, taking into account the risk reduction estimated for the three generic ships considered in the Part 1 [18] and Part 2 [19] of FIRESAFE II (section 14.2.1) and the costs of implementation of the systems in these ships (section 15.2). The results of the extended cost-effectiveness assessment are provided in Table 27.

Table 27. Extended cost-effectiveness assessment: ΔRisk, ΔCosts, GCAF and GCAF Factor values for the selected systems on generic ships (Existing ships)

Existing ships	Systems investigated	ΔRisk	ΔCost	GCAF		
		Averted fat.	Present Value	GCAF	GCAF Factor	Cost effective
Cargo RoPax	Thermal Imaging Camera	1.73E-02	109 000 €	6 317 329 €	0.90	Yes
	Linear Fibre Optic	2.44E-03	65 000 €	26 620 449 €	3.80	No
Standard RoPax	Thermal Imaging Camera	2.22E-02	109 000 €	4 916 381 €	0.70	Yes
	Linear Fibre Optic (open ro-ro space only)	1.02E-02	65 000 €	6 393 276 €	0.91	Yes
	Linear Fibre Optic	1.64E-02	98 000 €	5 987 431 €	0.86	Yes
Ferry RoPax	Thermal Imaging Camera	1.93E-02	64 000 €	3 316 850 €	0.47	Yes
	Linear Fibre Optic	3.15E-02	73 000 €	2 314 478 €	0.33	Yes

Apart from the linear fibre optic in the *Cargo RoPax*, all the systems achieved cost-effectiveness on all the generic ships investigated.

However, on the *Cargo RoPax,* it should be noted that the thermal imaging camera reached a GCAF factor quite close to 1. This system may not be found cost effective considering the side effects discussed in section 14.2.2.2.

16 PROPOSALS FOR RULE-MAKING / DISCUSSION

In view of the above, it was investigated whether the selected systems could be implemented onboard ro-ro passenger ships and how regulations and rules could be modified to make them mandatory.

16.1 Analysis of regulations for fire detection system for weather deck

Currently, there is no regulation forbidding thermal imaging cameras or any other detection system on ro-ro weather decks. However, it is noted that this is not required either since SOLAS II-2/20 does not include any requirement for fire detection on weather decks.

In order to make fixed fire detection mandatory on ro-ro weather decks, the following modifications of SOLAS II-2/20.4.1 were foreseen:

> **4.1 Fixed fire detection and fire alarm systems**
>
> 4.1.1 Except as provided in paragraph 4.3.1, there shall be provided a fixed fire detection and fire alarm system complying with the requirements of the Fire Safety Systems Code in open and closed ro-ro and vehicle spaces. The fixed fire detection system shall be capable of rapidly detecting the onset of fire. The type of detectors and their spacing and location shall be to the satisfaction of the Administration, taking into account the effects of ventilation and other relevant factors. After being installed, the system shall be tested under normal ventilation conditions and shall give an overall response time to the satisfaction of the Administration.
>
> 4.1.2 There shall be provided a fixed fire detection and fire alarm system on weather decks intended for the carriage of vehicles. The fixed fire detection system shall be capable of rapidly detecting the onset of fire anywhere on the weather deck. The type of detectors and their spacing and location shall be to the satisfaction of the Administration, taking into account the effects of ventilation, cargo obstruction and other relevant factors. Several settings may be used for specific operation sequences, such as during loading or unloading and during voyage, in order to reduce the rate of false alarms.

Besides, dedicated guidelines or an approval standard would need to be developed by IMO to cover fire detection systems for weather decks intended for the carriage of vehicles. Such guidelines could be either performance-based, i.e. specifying verification tests to be performed to ensure sufficient performance (e.g. including detection of a fire hidden by a container, detection of a fire as far as possible from the detector, etc.) or prescriptive requirements (i.e. specifying a technology such as thermal imaging cameras as well as technical and spacing requirements, etc.).

As an additional output, it was identified that the above proposed amendment should also lead IACS to revise UI SC73 accordingly, possibly as per the below proposal:

> The requirements for a fixed fire extinguishing system, ~~fire detection,~~ foam applicators and portable extinguishers need not apply to weather decks used for the carriage of vehicle with fuel in their tanks.

16.2 Analysis of regulations for alternative fire detection system

Currently, there is no regulation forbidding the use of a linear heat detection system for open or closed ro-ro spaces. However, it should be noted that such system is not considered in the FSS Code, Ch 9, which covers the fixed fire detection and fire alarm system required by SOLAS II-2/20.4.1.

Nevertheless, it was noted that fiber optics / linear heat fire detection systems are covered by EN 54-22, which is part of the EN 54 series, i.e. the reference approval standard for fire detectors as per the FSS Code, Ch 9 §2.3. Therefore, the following amendment of FSS Code Ch 9 §2.3.1.1 was foreseen:

> 2.3.1.1 Detectors shall be operated by heat, smoke or other products of combustion, flame, or any combination of these factors. Detectors operated by other factors indicative of incipient fires may be considered by the Administration provided that they are no less sensitive than such detectors. Detectors may be of point or linear type.

It was further noted that the FSS Code, Ch 9 §2.3.1.3 may also be considered applicable for linear heat detectors.

2.3.1.3 Heat detectors shall be certified to operate before the temperature exceeds 78ºC but not until the temperature exceeds 54ºC, when the temperature is raised to those limits at a rate less than 1ºC per min, when tested according to standards EN 54:2001 and IEC 60092-505. Alternative testing standards may be used as determined by the Administration. At higher rates of temperature rise, the heat detector shall operate within temperature limits to the satisfaction of the Administration having regard to the avoidance of detector insensitivity or oversensitivity.

The following amendment of FSS Code, Ch 9 §2.4.2.2 was also foreseen as a complement:

2.4.2.2 The maximum spacing of point detectors shall be in accordance with the table below:

Table 9.1 - Spacing of detectors

Type of detector	Maximum floor area per detector (m^2)	Maximum distance apart between centres (m)	Maximum distance away from bulkheads (m)
Heat	37	9	4.5
Smoke	74	11	5.5

The maximum spacing between two lines of a linear heat detection system shall not exceed 9 m. The spacing between a bulkhead and a line of a linear heat detection system shall not exceed 4.5 m.

The Administration may require or permit other spacing based upon test data which demonstrate the characteristics of the detectors. Detectors located below moveable ro-ro decks shall be in accordance with the above.

16.3 Analysis of regulations for new criterion for heat type fire detectors

In view of the conclusion of section 13.6.2, it was believed that one of the reasons why fibre optic linear heat system performed relatively well in detecting fire in the full scale ro-ro space fire detection tests was that a temperature variation criterion was used instead of a minimum temperature threshold (the criterion used in the tests was a temperature rate of rise of 14°C within 120 s). It was investigated whether such a criterion is currently permitted and how the regulations could be modified to make it mandatory use such a criterion in addition to a minimum temperature criterion.

The FSS Code, Ch.9 §2.3.1.3 requires that heat detectors are type tested according to EN 54-5:2001, which includes several criteria for detectors, including a maximum application temperature criterion and a rate of temperature rise criterion. However, the FSS Code in Ch.9 §2.3.1.3 specifically states that the temperature range (54-78°C) in which fire detectors should detect fire only applies “when the temperature is raised to those limits at a rate less than 1ºC per min”. This is a very slow temperature rise and means that only a fixed temperature criterion must be considered. To include a requirement to also consider the rate of temperature rise, the following amendment of FSS Code Ch 9 §2.3.1.3 was foreseen:

2.3.1.3 Heat detectors shall be certified to operate before the temperature exceeds 78ºC but not until the temperature exceeds 54ºC, when the temperature is raised to those limits at a rate less than 1ºC per min, and within the response limits defined in Table X for the rate of temperature rise, when tested according to standards EN 54:2001 and IEC 60092-505. Alternative testing standards may be used as determined by the Administration. ~~At higher rates of temperature rise, the heat detector shall operate within temperature limits to the satisfaction of the Administration having regard to the avoidance of detector insensitivity or oversensitivity.~~

For the purpose of defining “Table X” and the range of response limits to be required for the added rate of temperature rise criterion of heat type fire detectors, reference can be made to “Table 4” in clause 5.4 of EN 54-5:2001, here reproduced in Table 28. However, note that the upper limits in this table may need to be lowered to ensure quick detection based on the rate of temperature rise but may not be suitable to apply directly as a criterion.

Table 28. Response time limits for the rate of temperature rise of different classes of heat type fire detectors

Rate of rise of air temperature	Class A1 detectors				Class A2, B, C, D, E, F & G detectors			
	Lower limit of response time		Upper limit of response time		Lower limit of response time		Upper limit of response time	
K min^{-1}	min	s	min	s	min	s	min	s
1	29	0	40	20	29	0	46	0
3	7	13	13	40	7	13	16	0
5	4	9	8	20	4	9	10	0
10	1	0	4	20	2	0	5	30
20		30	2	20	1	0	3	13
30		20	1	40		40	2	25

It was further noted that the FSS Code, Ch 9 §2.3.1.3 may be considered applicable for linear heat detectors. However, it should be noted that Table 28 comes from EN54-5 which is dedicated to point heat detectors, while no equivalent table is found in EN54-22, applicable for fibre optics linear heat detection. The criteria and test definition may thus need to be adapted for linear heat type fire detectors.

17 CONCLUSION

One of the main issues with regard to fire safety of open ro-ro spaces and weather decks is that fire detection systems may not be as efficient as in closed ro-ro spaces.

Available and emerging fire detection technologies for use in open ro-ro spaces and on weather decks of ro-ro passenger ships were evaluated with a view to select systems for further evaluation in fire tests. This will support discussions on specific proposals for new regulations, if the systems are found to be cost-effective.

SOLAS requires a fixed fire detection and fire alarm system to be fitted in all ro-ro spaces. However, no fixed fire detection and fire alarm system is required for weather decks. Even though any detection system operated by heat, smoke or other products of combustion, flame, or any combination of these signatures are allowed in open ro-ro spaces, in practice the most common type of detection system relies on smoke detectors.

Among nine identified technologies, seven were further evaluated and their expected efficiency was discussed in terms of activation time and sensitivity to weather conditions, loading conditions and deck configuration:

- Fibre optic linear heat detection;
- Aspirating smoke detection;
- Gas detection in combination with ASD;
- Video detection: Smoke or combined smoke and flame detection;
- Video detection: Thermal imaging camera;
- Video detection: Flame video detection; and
- Flame detection.

No system was judged optimal for both open ro-ro spaces and weather decks.

The evaluation of activation time was primarily based on a literature review of performed detection system tests. Especially tests in tunnels were of interest, since tunnels have high airflows and high ceilings, similar to ro-ro spaces, and since it is also a vehicle related environment. Linear heat detection, including fibre optic linear heat detection, is often used in tunnels thanks to robustness and immunity to false alarms, but it has generally slower response time than smoke, flame and video detection. Flame detectors have the possibility to activate within a few seconds from the point of visible flames, while most other technologies need 30-60 seconds also with “suitable” conditions, due to smoke and heat transport and detector processing time. The processing time, sampling delay time, thermal inertia etc. are relevant when comparing detectors of the same type and functionality, but when comparing different technologies, the detector location relative to the fire, the fire scenario and the airflow will have more effect on the activation time.

Costs of the evaluated systems were estimated through quotations from relevant system manufacturers. While the cost of a conventional point smoke and heat detection system for open ro-ro spaces was estimated to € 55 000, the estimated total costs for the identified new systems varied from € 50 000 to € 105 000. For the systems considered for weather decks, the costs varied from € 65 000 to € 150 000.

Based on the theoretical evaluation of the identified systems, a selection process was carried out to select two alternative detection systems to be tested for open ro-ro space and weather deck. The process was based on a decision-support matrix and resulted in the selection of Fibre Optic Linear Heat detection for the open ro-ro space, and thermal imaging camera detection for the weather deck. Both alternative systems were tested onboard a commercial RoPax vessel, in terms of fire detection capacities and false alarms rate. Both systems were found functional and suitable for the relevant ro-ro space environments. The fibre optic linear heat detection system detected faster than a conventional point heat detection system. The improved performance was judged to be mainly attributed to the used detection criterion, based on a rate of temperature rise instead of a given critical temperature. Furthermore, the new system also provided improved coverage. The thermal imaging camera detected fire on weather deck at a distance of 50 meters. It also detected a fully obstructed fire and even a fire behind simulated heavy rain. The thermal imaging camera system recorded many false alarms when it was left onboard for one month, but all alarms were recorded during cargo loading and unloading. The fibre optic linear heat detection system recorded no false alarms.

Based on the fire detection tests onboard as well as on simulation studies performed in the FIRESAFE II study, the reduced risk of detection failure was estimated based on the main fire risk model and the detection fault trees developed within the study. Effects on each failure node probability of the fault tree were assessed. For weather deck, a new detection fault tree had to be developed since this had not been considered before

A cost-effectiveness assessment was performed, and the two selected systems were found cost-effective, assuming a Gross Cost of Averting a Fatality (GCAF) of € 7 M.

Thermal Imaging Camera detection was found cost-effective for all types of RoPax (Existing ships and Newbuildings), and Fibre optic linear heat detection was found cost-effective for *Standard* and *Ferry RoPax* (Existing ships and Newbuildings).

Sensitivity and uncertainty analyses reinforced the cost-effectiveness of implementing Fibre optic linear heat detection or Thermal imaging camera detection for Newbuildings. However, for Existing ships the analyses highlighted that the cost-effectiveness results of both RCOs are more uncertain, and sensitivity to unexpected cost increases.

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19 LIST OF ABBREVIATIONS

AFV:	Alternatively Fuelled Vehicles
ASD:	Aspirating Smoke Detection
BV:	Bureau Veritas
CCTV:	Closed-circuit television
CLIA:	Cruise Lines International Association
CNG:	Compressed Natural Gas
EMI:	Electro-Magnetic Interference
EMSA:	European Maritime Safety Agency
EN:	European Norm
FBG:	Fibre Bragg Gratings
FD:	Flame detection
FO:	Fiber Optic linear heat detection
FSS:	Fire Safety Systems (Code)
GCAF:	Gross Cost of Averting a Fatality
HRR:	Heat Release Rate
IACS:	International Association of Classification Societies
IEC:	International Electrotechnical Commission
IMO:	International Maritime Organization
IR:	Infrared
LEL:	Lower Explosive Limit
LHD:	Linear Heat Detection
LLL:	Low Location Lighting
LNG:	Liquefied Natural Gas
LPG:	Liquefied Petroleum Gas
MOCP:	Manually Operated Call Point
MSC:	Maritime Safety Committee
MVZ:	Main Vertical Zone
MW:	Megawatt
NPV:	Net Present Value
RCO:	Risk Control Option
SOLAS:	International Convention for the Safety Of Life At Sea
UI:	Unified Interpretation
UV:	Ultraviolet
VDF:	Video detection: Flame video detection
VDS:	Video detection: Smoke and combined smoke and flame detection
VDT:	Video detection: Thermal Imaging Camera

A1 ANNEXES

A1.1 List of the participants of the workshop for the selection of relevant alternative fire detection systems

In order to cover a wide spectrum of expertise, nine participants participated in the workshop for the selection of relevant fire detection systems.

The list of the participants as well as their areas of expertise are presented below:

From Stena:

- Lisa Gustin (Naval Architect)
- Fredrik Efraimsson (Naval Architect)

From Bureau Veritas:

- Stephane Quievreux (Technical Advisor Fire & Safety)
- Philippe Le-Foll (Electrical/Automation Engineer)
- Jérome Leroux (Risk Analysis Engineer)

From RISE:

- Ola Willstrand (Expert in Fire Detection)
- Peter Karlsson (Expert in Fire Detection)
- Franz Evegren (Research Scientist in Fire Safety Engineering)
- Pierrick Mindykowski (Research Scientist in Fire Safety Engineering)