Horizon 2020

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Deliverable D04.4

Holistic risk model

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Abstract

The Formal Safety Assessment (FSA) carried out in LASH FIRE requires the development and quantification of a holistic risk model describing the fire growth and response in ro-ro spaces. The objective is to compute the risk levels in terms of life, cargo and ship loss for the three generic ships (one for ro-ro passenger ship fleet, ro-ro cargo ship fleet and vehicle carrier fleet) as well as to assess the impact of each solution proposed by the D&D WPs on these safety levels.

For this purpose, a risk model mainly based on the risk model from the FIRESAFE studies was developed and quantified. It was then implemented using Microsoft Excel and split into three files, one for each type of ro-ro ship. These files return the risk indicators, also called safety levels, of human (PLL), cargo (PLC) and ship (PLS) for the corresponding generic ship. The values used to quantify these files can be later modified to assess the impact of a proposed solution on the safety levels mentioned above.

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Co-authors:	Eric De Carvalho, Antoine Cassez		
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Approved by	Bernard Porterie on 2022-02-03	Stina Andersson on 2022-01-28	Maria Hjohlman on 2022-01-21

Involved partners

No.	Short name	Full name of Partner	Name and contact info of persons involved
1	RISE	Research Institutes of Sweden	Stina Andersson – stina.andersson@ri.se Kujtim Ukaj Sixten Dahlbom – sixten.dahlbom@ri.se
8	BV	Bureau Veritas Marine & Offshore Registre International De Classification De Navires Et De Plateformes Offshore	Eric De Carvalho – eric.de-carvalho@bureauveritas.com Antoine Cassez – antoine.cassez@bureauveritas.com Léon Lewandowski – leon.lewandowski@bureauveritas.com

Document history

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02	2022-01-04	Léon Lewandowski	Draft of final report, circulated to reviewers
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Content

1 Executive summary

1.1 Problem definition

The LASH FIRE project aims to develop solutions to enhance fire safety in ro-ro spaces by the development of innovative technologies as well as by the modification of operations and applications. An evaluation of each solution, in line with IMO Formal Safety Assessment (FSA) procedures, will be carried out within the project. This implies the creation and quantification of a risk model, which will be used to compute the safety levels in term of life, cargo and ship loss for the three generic ships as well as to assess the impact of each solution proposed by the D&D WPs on these safety levels.

The main challenges were to select the best type of risk model amongst existing ones, and then to quantify it as accurately as possible. As requested by the IMO FSA guidelines [1], the quality and validity of the information and data used to build the model are a paramount. Furthermore, as stated in the LASH FIRE Grant Agreement [2], the development should benefit from the risk model developed in the EMSA-funded FIRESAFE studies.

1.2 Technical approach

To address the described problems above, the following report describes the holistic risk model as a tool:

- Choice of the software to implement the risk model;
- Architecture of the risk model (repartition of the different elements);
- Link of the different parts to each other; and
- Implementation of the formulas to get requested information (safety levels) as an output.

This deliverable is a description of the final risk model as a tool and how it works. To have more insights about its development, its quantification and the analysis of the results obtained, please refer to the LASH FIRE deliverable D04.5 “Development of holistic risk model report” [3].

1.3 Results and achievements

The structure and the quantification of the risk model were, as far as practicable, kept from the FIRESAFE studies. As mentioned previously, more details about the modifications and improvements made by the LASH FIRE study are available in the LASH FIRE deliverable D04.5 [3].

The risk model was implemented using Microsoft Excel and split into three files, one for each type of ro-ro ship: ro-ro passenger ship, ro-ro cargo ship and vehicle carrier. Each Excel file includes several sheets (for the global event tree, for the fault trees, etc.) linked to each other. These files return the risk indicators, also called safety levels, of human (PLL), cargo (PLC) and ship (PLS) for the corresponding generic ship.

The values used to quantify these files can be later modified to assess the impact of a proposed solution on the safety levels mentioned above.

1.4 Contribution to LASH FIRE objectives

The IMO strategic plan for 2018-2023 highlights the importance of integrating new and advancing technologies in the regulatory framework. One of the objectives of LASH FIRE is to support the aforementioned strategic plan, in part through this deliverable. This deliverable will furthermore lay the groundwork for achieving the LASH FIRE objective 3:

> LASH FIRE will provide a **technical basis** for future revisions of regulations by **assessing risk reduction and economic properties of solutions**.

This deliverable is the last step to fulfil the action 4-A:

> **Development of a holistic ro-ro ship fire risk assessment** model and tool for consequence quantification of fires originating in ro-ro spaces.

1.5 Exploitation and implementation

The risk model will be used within LASH FIRE first to determine the most promising solutions in term of risk reduction. Then, with the help of costs estimated by WP05 for the implementation of the solutions on board the three generic ships, the model will be used to assess more precisely their cost-effectiveness, as requested by the IMO FSA guidelines [1].

2 List of symbols and abbreviations

BV	Bureau Veritas
D&D	Development and Demonstration
EMSA	European Maritime Safety Agency
ET	Event Tree
FSA	Formal Safety Assessment
FT	Fault Tree
IMO	International Maritime Organization
PLC	Potential Loss of Cargo
PLL	Potential Loss of Life
PLS	Potential Loss of Ship
RISE	Research Institute of Sweden
WP	Work Package
WP04	Work Package on Formal Safety Assessment

3 Introduction

Main author of the chapter: Léon Lewandowski, BV.

3.1 Background

The risk assessment constitutes the step 2 of a Formal Safety Assessment (FSA) [1]. A risk assessment is a "systematic process to comprehend the nature of risk, express and evaluate risk, with the available knowledge" [4]. The IMO FSA guidelines [1] defines risk as: "The combination of the frequency and the severity of the consequence" [1]. A risk model, which is a tool able to estimate the frequency and consequence of each important accident scenario identified in hazard identification, needs to be developed using suitable methods. The risk model developed in the LASH FIRE study is called "holistic" because it takes into account all the steps of a fire in a ro-ro space.

From 2016 to 2018, the EMSA-funded FIRESAFE studies [5], [6] and [7] investigated cost-effective measures for reducing the risk from fires on ro-ro passenger ships using a risk model developed specifically for this purpose. The FIRESAFE studies and its risk model were reviewed and commented by the IMO FSA Experts Group [8].

Starting in 2019, the LASH FIRE project funded by the European Union's Horizon 2020 research and innovation programme is the logic continuation of FIRESAFE. The risk models developed in FIRESAFE and FIRESAFE II should be used as input for LASH FIRE.

In addition to LASH FIRE's specific objective 3, i.e. "providing a technical basis for future revisions of regulations by assessing risk reduction and economic properties of solutions", LASH FIRE is a research and innovative project. Therefore, while developing the risk model, new modelling techniques should be investigated.

3.2 General description of the developed holistic risk model

With regard to the requirements settled by the Grant Agreement, the lessons learnt from the FIRESAFE studies, as well as other considerations, it was decided to keep as much as practicable the same risk model structure as FIRESAFE II, i.e. a Risk Contribution Tree.

This type of risk model consists of an event tree, of which each branch point is quantified using a fault tree. A scenario is linked to the end of each branch of the event tree, and consequences (in terms of life loss, cargo loss, ship loss) are associated with each scenario. An example of this structure is provided in Figure 1. For more details on how this type of risk model works (how the compounds are mathematically related to each other), please refer to the LASH FIRE deliverable D04.5, "Development of holistic risk model report" [3].

In brief, the risk model for each reference case is composed of an event tree, several fault trees and a list of consequences associated to each scenario.

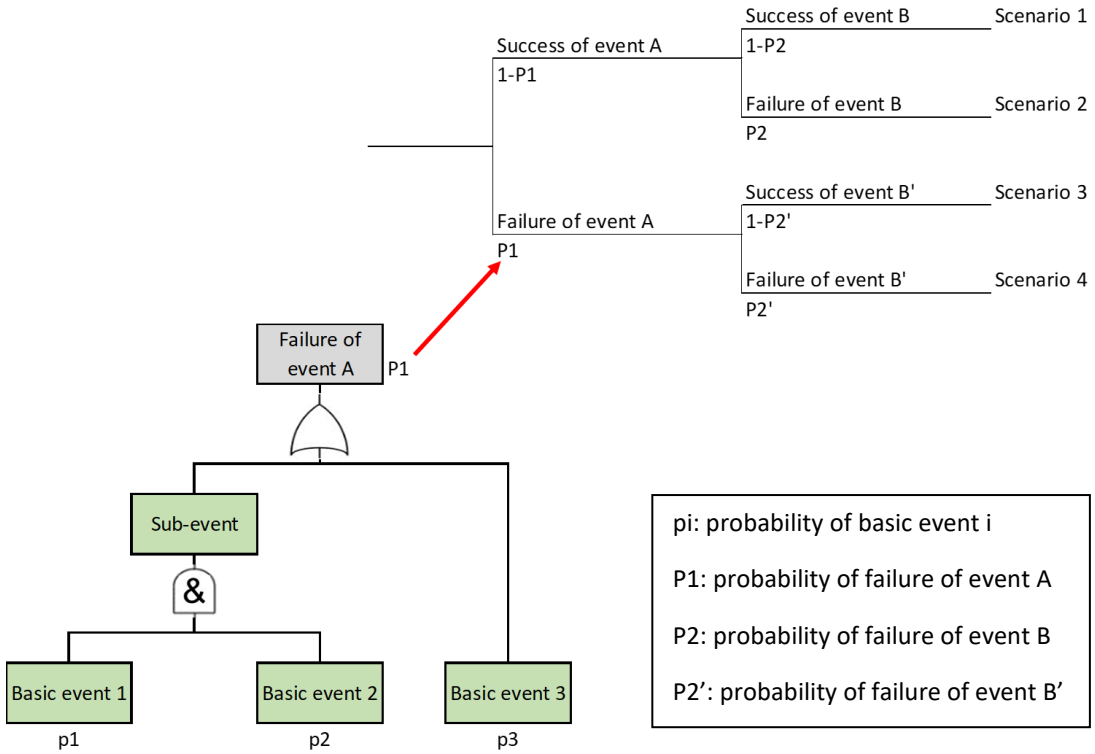

Figure 1. Structure of the risk model: example of link between the event tree (top-right) and a fault tree (bottom-left).

4 Description of the risk model

Main author of the chapter: Léon Lewandowski, BV.

This section provides information about the risk model architecture and its implementation as a tool. It describes the structure of each part, and their connections to each other.

4.1 Global structure of the risk model

The risk model basically takes as inputs probabilities for basic events (also known as “bottom nodes”) of fault trees and consequences for end branches of event trees, and returns the risk indicators: Potential Loss of Life (PLL), of Cargo (PLC) and Ship (PLS) for the generic ships.

As required in the LASH FIRE Grant Agreement, for continuity and consistency with the FIRESAFE studies, the new risk model was based as much as practicable on the FIRESAFE model.

Microsoft Excel was used to implement the risk model for the several reasons:

- It is easy to handle;
- Any part of the risk model can be easily edited at any time; and
- It is used by the vast majority of the WP04 actors, so it facilitates collaborative work.

The risk model is currently split in three Excel files: one for each ro-ro ship type. It will later be split between “newbuildings” and “existing ships” (for the purpose of the cost-effectiveness assessment).

Each file is split into several sheets, as it is illustrated in in Figure 2.

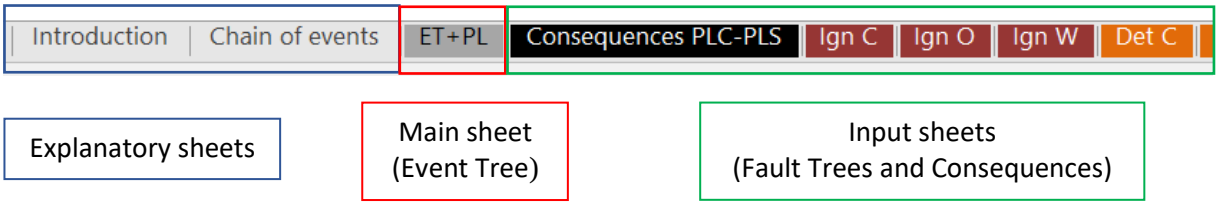

Figure 2. Nature of sheets in the risk model Excel file.

- The two sheets “Introduction” and “Chain of events” are only for information purposes (about the abbreviations, the colour code used, the course of events in case of a fire in a ro-ro space) and are not used in the actual risk calculation;
- The event tree is included in the main sheet “ET+PL” (for “Event Tree and Potential Losses”);
- The consequences in terms of cargo and ship loss for several degrees of severity are expressed in the sheet named “Consequences PLC-PLS”. The consequences in terms of life loss are directly expressed in the main sheet “ET+PL”; and
- Each fault tree is implemented on its own sheet. There can be several fault trees for a single tier: for instance, the sheet “Dec-Early det O” deals with the decision-making tier (“Dec”) after an early detection (“Early det”) for a fire started in an open ro-ro space (“O”).

The different sheets are coloured to enable an easy navigation into the file.

The sheets are linked as is shown in Figure 3.

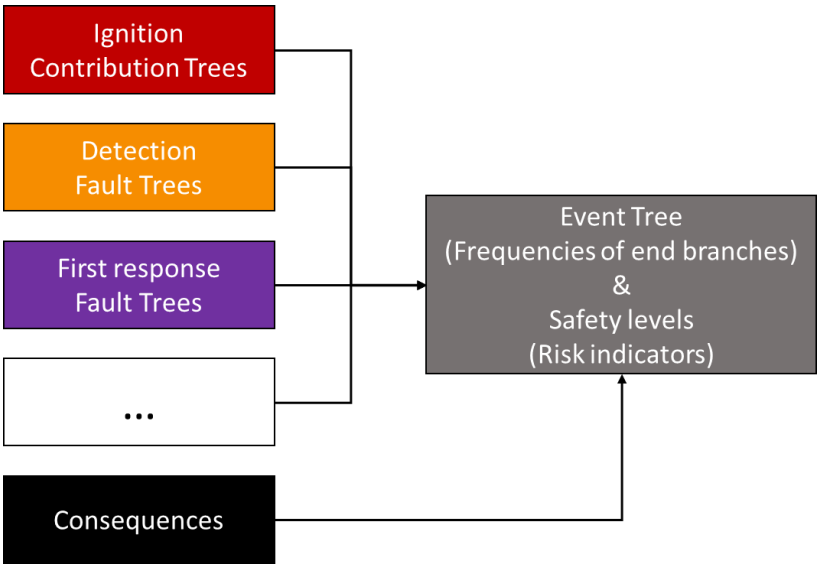

Figure 3. Flow of information in the risk model Excel file.

4.2 The main Event Tree sheet

The main sheet includes the Event Tree as well as the risk calculations (Potential Loss of Life, of Cargo and Ship). It works in the following way (see also Figure 4, note: for a better visualisation, only PLC is illustrated):

1. Information about the generic ship (POB, ro-ro space distribution, etc.) is given manually. It is used to compute the ignition frequency (a) and the number of equivalent fatalities.
2. The event tree branch points probabilities (b) are imported from corresponding "Fault Tree" sheets. At the end of each branch of the event tree is the frequency (c) corresponding to each scenario.
3. Consequences in terms of cargo and ship loss of each scenario are imported from the "Consequences PLC-PLS" sheet. The severity of the consequences (d) for each scenario (in euro per shipyear for cargo loss) is returned.
4. To compute the global loss (f) for the generic ship, all the products (e) of frequency and the severity of the consequence previously computed are summed. The risk results are summarised in a table and a graph.

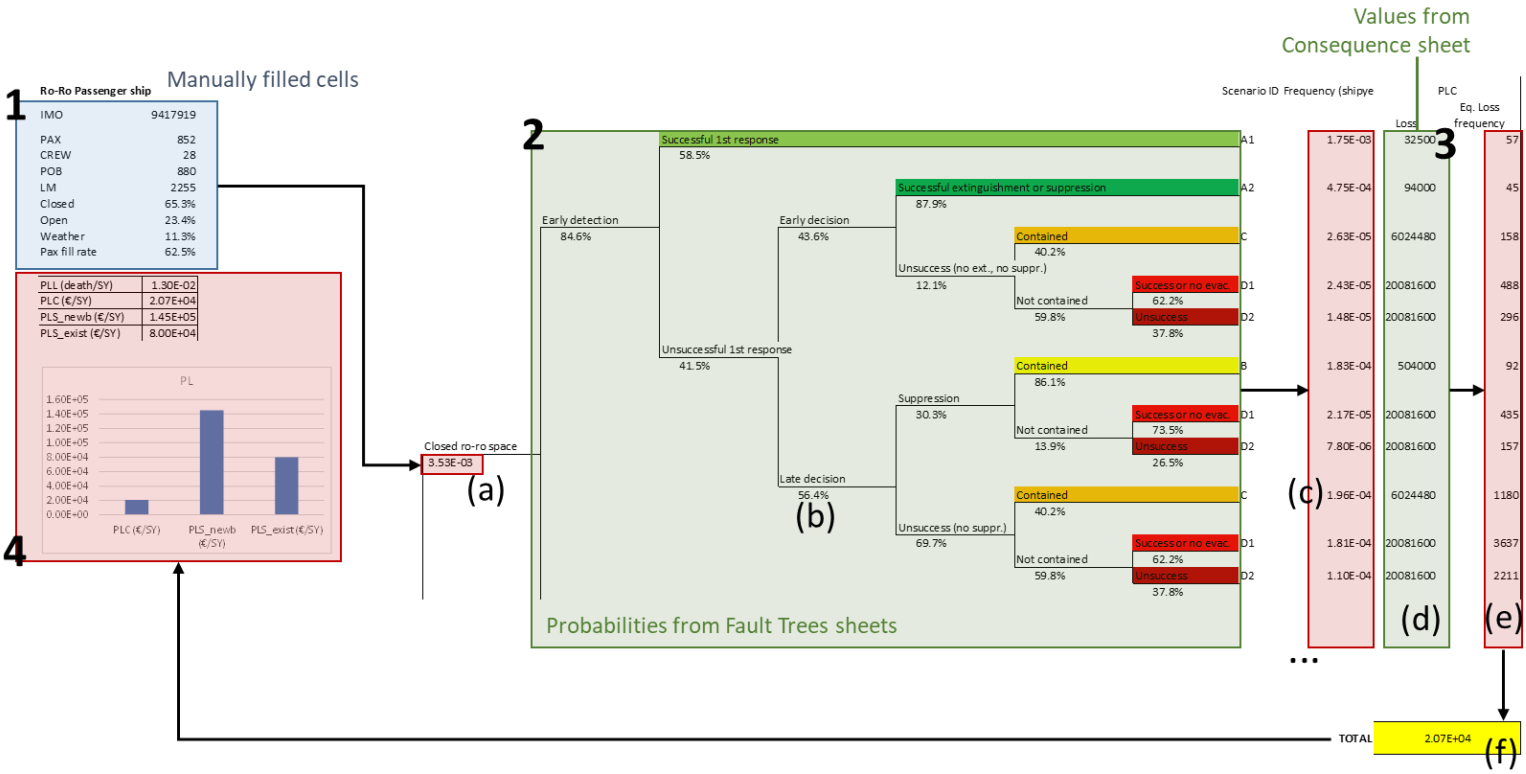

Figure 4. Screenshot and workflow of the Event Tree sheet.

4.3 The Fault Tree sheets

Each of the "Fault Tree" sheets includes a unique fault tree, where the bottom nodes are expected to be filled or modified by the user of the risk model (Figure 5). The upper nodes are then calculated automatically (with "and", "or" and "exclusive or" functions), and the top node is linked to the "Event Tree" sheet, in the corresponding branch of the tree.

The fault trees used and their quantification are, as far as practicable, taken from the FIRESAFE II studies. For more details about the modifications brought by the LASH FIRE study, please refer to the LASH FIRE deliverable D04.5 [3].

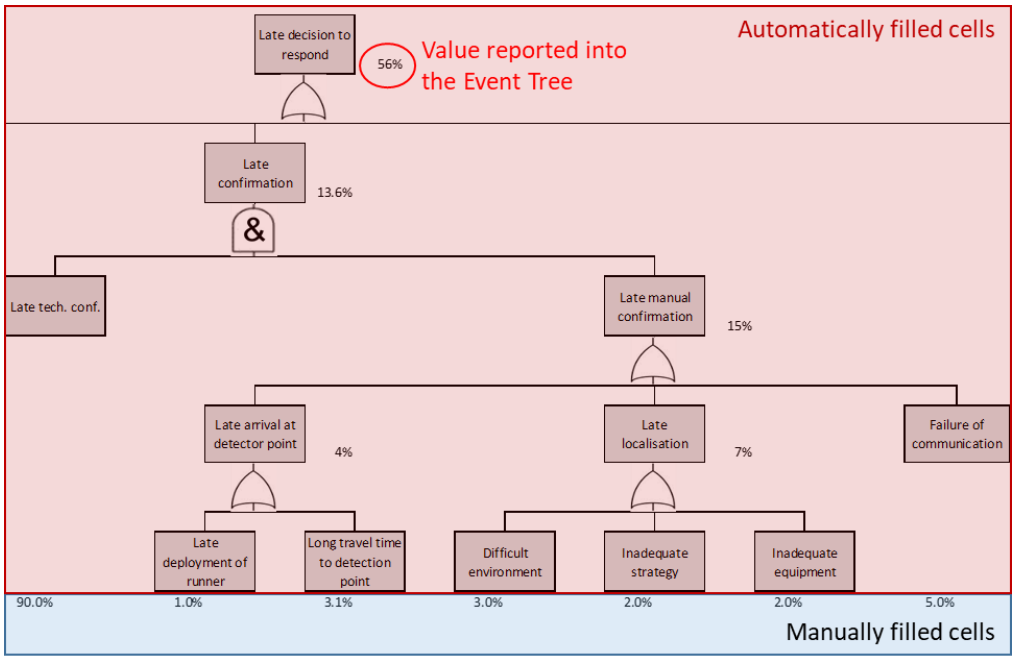

Figure 5. Screenshot of a Fault Tree sheet.

4.4 The Consequences PLC-PLS sheet

This sheet includes a table grouping the consequences in terms of cargo and ship loss for all scenarios. The cost of cargo and ship loss for each of them has to be filled manually, and are linked to the corresponding end branches in the event tree.

ID	Scenario	General Narrative	Cargo Loss Narrative	Cargo Loss Cost		
				Ro-Pax	Ro-Ro Cargo	Vehicle Carriers
A1	"Small fire"	Fires extinguished by portable extinguisher	Damage to 1 vehicle 50% (no damage to goods)	32 500 €	55 000 €	65 648 €
A2	"Small fire"	Fire extinguished by firefighting	Damage to 1 vehicle 100% (damage to goods)	94 000 €	168 000 €	131 295 €
B	"Medium fire"	Fires suppressed and contained	If drencher system: Damage to 1 vehicle 100% + 4 vehicles 50% If CO2 system: Damage to 13 vehicles 100% + 12 vehicles 50%	504 000 €	504 000 €	2 494 605 €
C	"Fire to one deck"	Fires not suppressed but contained	Damage to cargo of 1 entire deck + 50% above deck, 70% of cargo capacity	6 024 480 €	10 451 700 €	22 974 000 €
D1	"Total loss"	Fires not contained and evacuation success	100% loss of cargo, 70% of cargo capacity	20 081 600 €	27 871 200 €	183 792 000 €
D2	"Total loss"	Fires not contained and evacuation unsuccess	100% loss of cargo, 70% of cargo capacity	20 081 600 €	27 871 200 €	183 792 000 €

Manually filled cells

Figure 6. Screenshot of the Consequences PLC-PLS sheet.

5 Conclusion

Main author of the chapter: Léon Lewandowski, BV.

A risk model focusing on fires originating in ro-ro spaces was developed and quantified.

It was decided to keep the same structure as the FIRESAFE studies, though as they only focused on ro-ro passenger ships, the structure was enhanced to take into account ro-ro cargo ships and vehicle carriers. The structure of the model was also improved to include new failure modes affected by new solutions proposed by the D&D WPs in LASH FIRE.

The risk model was then implemented into three Microsoft Excel files, one for each type of ro-ro ship, each file including several sheets for the event tree, the consequences of each defined scenario and the fault trees. The structure and usage of these files are explained in this deliverable. The use of Microsoft Excel allows an easy sharing of the files amongst WP04 members, as well as an easy editing of the risk model.

The risk model will also be used in the next steps of the FSA led by WP04. For the selected solutions, using quantitative risk reduction on affected nodes provided afterwards by the D&D WPs and the costs provided by WP05 (T04.6), it will be possible to assess the cost-effectiveness of each solution (T04.7). These new features will be implemented later in the project.

This deliverable is, together with the LASH FIRE deliverable D04.5, the conclusion of task T04.4, *'Holistic ro-ro ship fire risk model'* [2]. It contributes to the strategic objective:

> "To provide a **recognized technical basis** for the revision of international **IMO regulations**, which greatly **enhances fire prevention** and **ensures independent management of fires** on ro-ro ships in current and **future** fire safety challenges";

and to the specific objective 3:

> "LASH FIRE will provide a **technical basis** for future revisions of regulations by **assessing risk reduction and economic properties of solutions**".

6 References

[1] IMO, *Revised Guidelines for Formal Safety Assessment (FSA) for the use in the IMO rule-making process, MSC-MEPC.2/Circ.12/Rev.2,* 2018.

[2] LASH FIRE, *LASH FIRE Grant Agreement,* 2019.

[3] L. Lewandowski, *Development of holistic risk model report (D04.5),* LASH FIRE, 2022.

[4] Society for Risk Analysis, *Glossary,* 2018.

[5] J. Wikman, *Study investigating cost effective measures for reducing the risk from fires on ro-ro passenger ships (FIRESAFE), EMSA/OP/01/2016,* EMSA, 2016.

[6] J. Leroux, *FIRESAFE II Detection and Decision, Final Report, Version 1.1, 2017/EMSA/OP/17/2017,* EMSA, 2018.

[7] J. Leroux, *FIRESAFE II Containment and Evacuation, Final Report, Version 1.1, 2017/EMSA/OP/17/2017,* EMSA, 2018.

[8] IMO, *Review of SOLAS Chapter II-2 [...] to minimize the incidence and consequences of fires on ro-ro spaces [...], Report of the intersessional meeting of the Experts Group on Formal Safety Assessment (FSA), SSE 7/6,* 2019.

7 Indexes

7.1 Index of tables

No table.

7.2 Index of figures