RO5 ro-ro space fire ventilation
Literature study
Anna Olofsson and Elin Ranudd
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Abstract

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A fire in a ro-ro space can grow intensely large and statistics show that the number of fire accidents in these spaces are not decreasing over the last years. The different types of ro-ro spaces defined in SOLAS has different requirements for fire extinguishing systems, natural and mechanical ventilation and fire detection system. RO5 aims to clarify how the ro-ro space ventilation affects the development and management of a fire and to recommend appropriate fire protection measures for ro-ro space with different ventilation conditions. This report gives the reader the background of the project with the review of literature together with review of accident investigation reports, inventory of ventilation design and a documentation of the performed hazard identification workshop that was held with suppliers, authorities, crew and ship owners.

The final report of RO5 will present overall project result from tests, computer simulations including recommendations and concept solutions.

The accident investigation review shows that the most common way to operate the ventilation system in case of a fire onboard was to shut it down. From the workshop the comments from crew was the interest to learn more how to use the ventilation system onboard. Densely stowed cars, which made it hard for the fire fighters to approach the fire, was mentioned as a problem in 7/10 accident reports with closed ro-ro spaces and in 3/4 reports with open ro-ro spaces.

The intention with the SOLAS regulations is to structurally divide passenger ships so that a fire cannot spread, and that fire extinguishing system or horizontal divisions should exist to control a fire in the space of origin. While on the other hand the principle of large ro-ro spaces is an important part of the maritime industry. Some of the accident investigations reveal that the large spaces such as open ro-ro spaces make it difficult to meet the functional requirements of the regulations and that open ro-ro spaces may be prohibited. The same conclusion is made from the two zone fire simulations conducted in the project. The simulations show that both increased natural ventilation and increased mechanical ventilation results in larger fire development. The conducted parameter simulation study shows that if natural ventilation is nevertheless required, the openings should, in terms of fire development, preferably be constructed as wide as possible and with as low sill and soffit height as possible.

Key words: ventilation, accident investigation, fire, regulation review, ro-ro space, ro-ro deck, SOLAS, hazard identification, hazid, IMO
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Preface

A fire protection engineering work to contribute to a safe, developing and working society. A sailor knows the feeling of the endless fresh air and view of the horizon. Ships with ro-ro spaces carry families with their cars, truck drivers with their goods, campers with their caravans, all crew working onboard and many more. To work for a safe and secure ro-ro space where a fire can be handled before growing to big is what RO5 is about.

RO5 is the short name of the research project Ro-ro space fire ventilation. The project is carried out by RISE Research Institutes of Sweden financed by The Swedish Transport Administration (Trafikverket) and The Swedish Mercantile Marine Foundation (Stiftelsen Sveriges Sjömanshus), great acknowledgement to them.

Support has also come from the in-kind partners providing expert knowledge, important comments and participation in workshop. Thanks to:

- David Götvall and Anton Gustafsson at MacGregor;
- Henrik Johansson at Johnson Control Internationals;
- Nils Nordström at Destination Gotland;
- Lisa Gustin, Joacim Lottkärr and Mats Nilsson at Stena;
- Sebastian Norén at Fläkt Marine;
- Rikard Sjölander at Fläkt Group; and
- Mattias Hörnquist at Transportstyrelsen.

Three fire protection engineer students have been part of the RO5 project and contributed with inspiration and work. Thanks to:

- Elin Ranudd from Lund University for the ventilation inventory and accident investigation review and for being an author of these chapters in the report; and
- Andreas Lilja and Martin Lindgren from Luleå University of Technology for conducting their Bachelor thesis in the project and carried out loads of two zone fire simulations at RISE.
Summary

This is one part of the RO5 research project carried out by RISE Research Institutes of Sweden. This part is the first part of the project, the background study. Two other reports will be produced within the project: a test & simulation report including result and discussion about fire tests and computer simulations that has been performed, and an overall project report summarizing this report together with the test & simulation report and giving an overall conclusion, recommendations and conceptual solutions.

Ro-ro spaces are an important component in Swedish and international marine industry. A significant number of fire incidents on ro-ro spaces and lacking signs of falling numbers indicate that fire protection must be improved. As recently as in August 2018, a short circuit in a motor of a truck started a fire on the Greek ferry Eleftherios Venizelos was sailing with 875 passengers and 141 crew onboard. Based on a proposal from the European Commission, the IMO has adopted a new agenda item for the Maritime Safety Committee in November 2016, called "Fire Safety of Ro-ro Passenger Ship" (MSC 97/19/3).

There are three groups of ro-ro spaces depending on how open/close they are:

Weather deck - are completely exposed to weather and wind;

Open ro-ro spaces - 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; and

Closed ro-ro spaces - are other ro-ro spaces, which are neither open ro-ro spaces nor weather decks.

The literature study was conducted to clarify the directions for ventilation and coupled fire protection requirements for different types of ro-ro spaces as well as how these can affect and have influenced the fire performance in the event of previous accidents. This will be the basis for identifying fire safety deficiencies for different types of ro-ro decks as well as suggestions for fire protection measures. The identification was carried out in a workshop with authorities, ship owners and system suppliers and will be further worked on in the tests and simulations. A study visit onboard together with studying the ventilations drawings of two ships with ro-ro spaces has given a reference to how it can look like in reality, even though the world fleet of ro-ro spaces have a varied design.

The International Convention for the Safety of Life at Sea (SOLAS), 1974, with its amendments has been studied together with the Swedish ratification of SOLAS, TSFS 2009:98.

The interpretation made in this study is that ro-ro spaces are a type of cargo space and that ro-ro spaces include special category spaces and vehicle spaces. The interpretation is also that there are three categories of ro-ro spaces (open, closed and weather deck). Since this is open for interpretation the following clarifications are proposed to be added in the regulations and guidelines:

- “Ro-ro spaces” should be defined as “ro-ro cargo spaces”, the definition should state that “ro-ro spaces are cargo spaces not normally subdivided...”;

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“Vehicle spaces” should be defined as “Vehicle spaces are ro-ro cargo spaces intended for carriage of motor vehicles with fuel in their tanks for their own propulsion”;
- that a definition of “side” or “space sides” should be added and that the definition shall include what is a side, and how high a side needs to be to be a side; and
- to avoid misunderstanding in how to calculate the openness of a ro-ro space (that for an open ro-ro space shall be 10% of the space sides) introducing a guidance of how to calculate it in SOLAS. Are ends and decks included in the calculation, or only hull sides, for example.

RO5 aims to clarify how the ro-ro space ventilation affects the development and management of a fire and to recommend appropriate fire protection measures for ro-ro space with different ventilation conditions. The most common way to use the ventilation during fire, according to the accident investigations, is to shut the ventilation system off after detecting a fire. Crew at the workshop mentioned that it is up to individuals to learn and practise with the ventilations systems to earn knowledge about the effects in different scenarios, which is also mentioned in the MSC.1/Circ.1515 Design guidelines for ventilation systems in ro-ro cargo spaces. The ventilation system today is not designed to work with hot gases from a fire. From the accident investigation it can be noticed that some crew try to use it to evacuate smoke from the ro-ro space. Some ships have reversible fans installed making it more possible to use the fans in a flexible way depending on the situation. Dense smoke and tight parked vehicles are troubles that the fire patrols onboard often meet when a fire starts in ro-ro space. The first two zone simulations indicate a rapid increase in fire development if the ventilation is remained on or turned on during a fire in a closed ro-ro space. These simulations also imply that that the geometry of a natural opening has an impact on the fire development.
1 Introduction

This report is one of three reports in the research project RO5. This report is documenting the review of literature, review of accident investigation reports, inventory of ventilation design, a documentation of the hazard identification workshop and a summary of the Bachelor thesis carried out in the project by Andreas Lilja and Martin Lindgren (Lilja & Lindgren, 2019).

1.1 Background

Ro-ro spaces are an important component in Swedish and international shipping. The concept is simple; vehicles and other load can be rolled on and rolled off with their own propulsion. However, a significant number of fire incidents on ro-ro ships and lacking signs of diminishing numbers indicate that fire protection must be improved. As recently as in August 2018, a short circuit in a motor of a truck started a fire on the Greek ferry Eleftherios Venizelos sailing with 875 passengers and 141 crew onboard (The Greek Reporter: transport, 2018).

Ro-ro spaces are often the entire length of the ship without division into vertical fire zones and are loaded with vehicles with fuel in their tanks. A fire in such a space can potentially grow big and be difficult to handle, it shows accident statistics from 1994 and onwards. There are open ro-ro spaces, closed ro-ro spaces and weather decks. The three different types have different conditions regarding ventilation (natural or mechanical) as well as fire protection requirements. Ventilation conditions on open ro-ro decks are problematic in a fire scenario, as there is free access to oxygen for growth and continued fire, while much of the hot smoke is contained. A weather deck has also free access to oxygen and no required fire protection. Closed ro-ro spaces need mechanical ventilation, and this is mainly shut off when a fire is detected. There are differences in the fire protection between (and within) the different categories of ro-ro spaces.

How the different conditions for ro-ro spaces affect the development of a fire and how it affects the handling of a fire are the main issues of the RO5 project. The project has been initiated with a literature review of regulations and accident reports to clarify the conditions. Thereafter, a workshop was conducted with partners to discuss hazards for the various ro-ro spaces and potential safety measures. Some potential safety measures are included in computer simulations and tests at different ventilation conditions for further analyse and shall be used when working on concept solutions and recommendations. The tests and simulations are documented in separate report (Olofsson, o.a., 2019).

Concept solutions will be developed by system manufacturers together with shipowners and fire experts. Recommendations on appropriate fire protection measures for different types of ro-ro spaces will be communicated to IMO through the Swedish Transport Agency, for dissemination of knowledge and to introduce proposals for regulatory changes.
1.2 Objective

The overall project objective in RO5 was to clarify how the ro-ro space ventilation affects the development and management of a fire and to recommend appropriate fire protection measures for ro-ro space with different ventilation conditions.

The aim with the literature study was to clarify and discuss the ventilation requirements and the design of ventilation systems for ro-ro spaces together with coupled fire protection requirements.

The aim with the accident investigation analysis was to achieve a better understanding of what can cause fires onboard ro-ro spaces and to get a better view of the range of accidents that can occur.

The aim with the workshop was to include partners interested in the research in a dialogue about the hazards and possible solutions for ro-ro space fires.

1.3 Delimitation

Accident investigation reports studied was only including ro-ro passenger ship. Only investigation reports that could be found online and were free to read has been studied.
2 Literature study

The literature review and accident investigation analysis were conducted to clarify the ventilation requirements and the design of ventilation systems together with coupled fire protection requirements for different types of ro-ro spaces. The literature study also include discussion on how these can affect and have influenced the fire development in the event of previous accidents. This will form the basis for identifying fire safety deficiencies for different types of ro-ro spaces as well as suggestions for fire protection measures. The safety deficiencies identification is carried out in a workshop with authorities, ship owners and system suppliers which is documented last in this report.

2.1 Regulation review

The regulations and documents that mainly have been studied are SOLAS and IMO circulars related to fire protection and ventilation for ro-ro spaces, for example SOLAS II-2/20 Protection of vehicle, special category and ro-ro spaces (IMO, 1974) and MSC.1/Circ.1515 Design guidelines for ventilation systems in ro-ro cargo spaces (IMO, 2015).

TSFS 2009:98, Transportstyrelsens föreskrifter och allmänna råd om brandskydd, branddetektering och brandsläckning på SOLAS-fartyg byggda den 1 juli 2002 eller senare (Transportstyrelsen, 2009:98), is the Swedish ratification of SOLAS and are included in the literature study to compare SOLAS with the Swedish regulations.

UIISC, Interpretations of the International Convention for the Safety of Life at Sea (SOLAS), 1974 and its Amendments (International Association of the Classification Societies, 2018) has also been used to clarify some terminology.

2.1.1 Definitions

Definitions of terms relevant to the project have been studied and a comparison of definitions has been made between SOLAS (IMO, 1974) and TSFS 2009:98 (Transportstyrelsen, 2009:98). The definitions are summarized in Table 1 below, along with comments to the comparison in conjunction with each term.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition in SOLAS</th>
<th>Definition in TSFS 2009:98</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle spaces/</td>
<td>are cargo spaces intended for carriage of motor vehicles with fuel in their tanks for their own propulsion</td>
<td>lastutrymmen som är avsedda för transport av motorfordon med bränsle i tankarna för egen framdrivning</td>
</tr>
<tr>
<td>Fordonsutrymmen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cargo ship/</td>
<td>is any ship which is not a passenger ship</td>
<td>ett fartyg som inte är ett passagerarfartyg</td>
</tr>
<tr>
<td>Lastfartyg</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Comment: No difference in interpretation of the definition.
**Comment:** No difference in interpretation of the definition.

<table>
<thead>
<tr>
<th>Cargo spaces/Lastutrymme</th>
<th>are spaces used for cargo, cargo oil tanks, tanks for other liquid cargo and trunks to such spaces</th>
<th>sådana utrymmen som används för last, lastoljetankar, tankar för andra flytande laster och trunkar till sådana utrymmen</th>
</tr>
</thead>
</table>

**Comment:** No difference in interpretation of the definition.

<table>
<thead>
<tr>
<th>Passenger ship/Passagerarfartyg</th>
<th>is a ship which carries more than twelve passengers</th>
<th>ett fartyg som medför fler än 12 passagerare</th>
</tr>
</thead>
</table>

**Comment:** No difference in interpretation of the definition.

<table>
<thead>
<tr>
<th>Ro-ro spaces/Rorolastutrymmen</th>
<th>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</th>
<th>utrymmen för last och fordon som kan lastas och lossas av andra fordon eller på egen hand, normalt i horisontell riktning</th>
</tr>
</thead>
</table>

**Comment:** The Swedish translation of ro-ro space implies that a ro-ro space is a cargo space, which is not as clear in the terminology of SOLAS. If you read the definitions of cargo spaces and ro-ro spaces, it can nevertheless be interpreted that ro-ro space is a type of cargo space since vehicles can be seen as cargo.

Proposedly, ro-ro spaces in SOLAS should be called "ro-ro cargo spaces" or the definition should state that 'ro-ro spaces are cargo spaces not normally subdivided...'.

<table>
<thead>
<tr>
<th>Ro-ro passenger ship/Roropassagerarfartyg</th>
<th>means a passenger ship with ro-ro spaces or special category spaces</th>
<th>passagerarfartyg med ro-ro lastutrymmen eller utrymmen av särskild kategori</th>
</tr>
</thead>
</table>

**Comment:** No difference in interpretation of the definition.

<table>
<thead>
<tr>
<th>Closed vehicle spaces/Slutna fordonsutrymmen</th>
<th>are vehicle spaces which are neither open vehicle spaces nor weather decks</th>
<th>fordonsutrymmen som varken är öppna fordonsutrymmen eller väderäck</th>
</tr>
</thead>
</table>
**Comment:** No difference in interpretation of the definition. Closed vehicle spaces are defined as closed ro-ro spaces. See below.

<table>
<thead>
<tr>
<th><strong>Closed ro-ro spaces</strong>/ <strong>Slutna rorolastutrymmen</strong></th>
<th>are ro-ro spaces which are neither open ro-ro spaces nor weather decks</th>
<th>Ro-ro lastutrymmen som varken är öppna rorolastutrymmen eller väderdäck</th>
</tr>
</thead>
</table>

**Comment:** No difference in interpretation of the definition. Closed ro-ro spaces are defined as closed vehicle spaces. See above.

<table>
<thead>
<tr>
<th><strong>Special category spaces</strong>/ <strong>Utrymmen av särskild kategori</strong></th>
<th>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</th>
<th>de slutna fordonsutrymmen till och från vilka fordon kan köras och till vilka passagerarna har tillträde; utrymmen av särskild kategori får uppta fler än ett däck om den totala fria höjden för fordonen inte överstiger 10 m</th>
</tr>
</thead>
</table>

**Comment:** SOLAS has a reference to the bulkhead deck (the uppermost deck up to which the transverse watertight bulkheads are carried) which is not in the Swedish translation. In SOLAS, it is written 'those enclosed vehicle / ro-ro spaces ...' and not closed vehicle / closed ro-ro spaces, which opens up for interpretation. In this case, however, closed space and enclosed space should aim at the same type of closedness. A more unambiguous definition would be 'those closed vehicle spaces ... ', which also clarifies that there are only closed vehicle spaces that may be special category spaces. Enclosed also appears in other definitions referring to closed space, see, for example, SOLAS II-2 / 19.3.4 "Adequate power ventilation shall be provided in enclosed cargo spaces”.

<table>
<thead>
<tr>
<th><strong>Weather deck</strong>/ <strong>Väderdäck</strong></th>
<th>is a deck which is completely exposed to the weather from above and from at least two sides</th>
<th>ett däck som är fullständigt utsatt för väder och vind ovanifrån och från minst två sidor</th>
</tr>
</thead>
</table>

**Comment:** No difference in interpretation of the definition. Weather decks are not referred to as a space but as a deck, as there is no limit in volume / space. A weather deck can have multiple applications, see for example the definition of closed ro-ro spaces. However, it is unclear what is a side, and how high a side needs to be to be a side. According to the Swedish Transport Agency, the Authority's interpretation has been that 10% is related to the hull sides of the ship, i.e. excluding the ends, and that a deck height of 150 cm maximum can be allowed alongside the sides of the vessel for a side on weather deck for a weather deck to be considered open.

<table>
<thead>
<tr>
<th><strong>Open vehicle spaces</strong>/ <strong>Öppna fordonsutrymmen</strong></th>
<th>are those vehicle spaces either open at both ends, or have an opening at one end and are provided with adequate natural ventilation</th>
<th>sådana fordonsutrymmen som antingen är öppna i båda ändarna eller är öppna i ena änden och har tillräcklig ventilation</th>
</tr>
</thead>
</table>

© RISE Research Institutes of Sweden
<table>
<thead>
<tr>
<th><strong>Comment:</strong> No difference in interpretation of the definition. Interpretation question arises as to how calculations of 10% of the total area of the space are; are there only hull sides? Are the ends and decks included? The Swedish Transport Agency's interpretation is that the openings should be 10% of the hull sides, with the ends not being included in the calculation. In SOLAS, no interpretation has been found for what is meant by space sides.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Open ro-ro spaces/Öppna rorolastutrymmen</strong> are those ro-ro spaces that are either open at both ends or have an opening at one end, and are provided with adequate natural ventilation effective over their entire length through permanent openings distributed in the side plating or deckhead or from above, having a total area of at least 10% of the total area of the space sides.</td>
</tr>
<tr>
<td><strong>sådana rorolastutrymmen som antingen är öppna i båda ändarna eller är öppna i ena änden och har tillräcklig naturlig ventilation i hela utrymmet genom permanenta öppningar i sidobordläggningen eller i det ovanliggande däcket eller ovanifrån som har en total area av minst 10 procent av den totala arean av utrymmets sidor</strong></td>
</tr>
</tbody>
</table>

See comment for open vehicle spaces.

### 2.1.1.1 Interpretations and suggestions

The interpretation of the above definitions, in Table 1, is that ro-ro spaces are a type of cargo space and that ro-ro spaces include special category spaces and vehicle spaces. The interpretation is also that there are three categories of ro-ro spaces (open, closed and weather deck). The interpretation is schematically shown in Figure 1.
That ro-ro spaces include special category spaces and vehicle spaces are in accordance with the interpretation of ro-ro spaces made by IACS in SC85 (International Association of the Classification Societies, 2018), see Figure 2. The Swedish translation of ro-ro spaces to ro-ro cargo spaces indicates that the Swedish Administration consider it as a type of cargo space. This is not entirely apparent in SOLAS and clarifying definitions would be appropriate. The following new and clarified definitions are hereby proposed:

- “Vehicle spaces are ro-ro cargo spaces intended for carriage of motor vehicles with fuel in their tanks for their own propulsion”
- “Ro-ro spaces are cargo spaces not normally…”

If these interpretations are valid, it is possible to remove the definition of open and closed vehicle spaces, as they are exactly the same as the definitions for open and closed ro-ro spaces.

Thus, there are three groups of ro-ro spaces depending on how open/close they are:

- Weather deck are completely exposed to weather and wind
- Open ro-ro spaces 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.
- Closed ro-ro spaces are other ro-ro spaces, which are neither open ro-ro spaces nor weather decks.

Closed ro-ro spaces can thus have openings with an area of up to 9% of the space’s sides, and one end open. A vessel with a ro-ro space of 200 m length, 20 m width and the height of the hull sides 6.5 m can thus have 234 m² (9%) openings and be classified as a closed
ro-ro space. An open ro-ro space with the corresponding dimensions and with 10% openings and one end open gives an opening area of 390 m². Typically for closed ro-ro spaces is that they have at least one open end or openings around the moorings. The opening area for such a closed space with the corresponding dimensions as stated above will be 364 m². Openings to the atmosphere gives a potential fire free access to oxygen and thus the opportunity to continue burning as long as there is fuel. Free access to oxygen and a fully loaded vessel with vehicles therefore has the potential to result in a fire lasting for a long time. How differences in opening areas affect the development of a fire will be studied in computer simulations and tests further into the project. Some preliminary simulations have been implemented by RISE earlier (European Maritime Safety Agency, SP Technical Research Institutes of Sweden AB, Bureau Veritas, Stena Rederi AB, 2016), which indicates that a fire can be extensive even with a small proportion of openings (less than 10%). The theoretical and structural difference between open and closed ro-ro spaces is sometimes peripheral, but in spite of this there is a difference in the fire protection requirements for the different categories of ro-ro spaces. A compilation of the requirements can be found in section 2.1.3.

When discussing the different types of ro-ro spaces, we need to include the discussion of side, what is a side? An uncertain definition is what is meant by "sides" in the definition of open ro-ro space:

"...having a total area of at least 10% of the total area of the space sides."

Also, the definition of weather deck is to some extent related to the term "sides". In SOLAS II-2/3.50 it says:

“Weather deck is a deck which is completely exposed to the weather from above and from at least two sides.”

This interpret RISE implicitly that the ends are counted as "sides" because otherwise it should not have been "from at least two sides" if there were only two sides. If "sides" should have a consistent meaning in the definitions, RISE interprets that even the ends should be included in the calculations for open ro-ro spaces. According to the Swedish Transport Agency, the Authority’s interpretation has been that 10% is related to the hull sides of the ship, i.e. excluding the ends, and that a side height of maximum 150 cm can be allowed alongside the sides of the vessel for a weather deck to still be considered exposed. In order to avoid misunderstandings, a definition of "sides" in SOLAS would be good.

2.1.2 Regulations

The regulations that have been studied are the currently applicable and may not be applicable to older ships.

The study of regulations aims at identifying and analysing the regulations and circulars associated with ventilation, fire detection and fire alarm systems, fire extinguishing systems and fire integrity for ro-ro spaces.

2.1.2.1 Ventilation

In the planned experimental study both mechanical ventilation and natural ventilation will be considered for the different type of ro-ro spaces (Olofsson, o.a., 2019).
SOLAS II-2/20 Protection of vehicle, special category and ro-ro spaces specify requirements for ventilation for vehicle spaces, special category spaces and ro-ro spaces, is the regulation that require mechanical ventilation for certain types of spaces. SOLAS II-2/20.1.3 states:

“Vehicle, special category and ro-ro spaces shall be adequately ventilated.”

It is also stated in SOLAS II-2/20.3.1.1 what capacity is meant by "adequately ventilated". For cargo ships, closed ro-ro and closed vehicle spaces which are not special category spaces on vessels with more than 36 passengers, the ventilation system shall have a capacity of 6 air changes per hour (ACPH). For spaces of special category, closed ro-ro spaces and closed vehicle spaces which are not special category spaces on ships with less than 36 passengers, 10 air changes per hour apply. There is thus no requirement for mechanical ventilation for open ro-ro spaces, open vehicle spaces or for weather decks.

The ventilation is primary regulated to prevent flammable and other harmful gases from accumulating in the spaces. The ventilation system should therefore always be running with the above capacity, as long as there are vehicles on board. Exceptions to these rules may be made if the ship has an approved air quality system on board, this is written in SOLAS II-2/20.3.1.2.1:

“In passenger ships, the power ventilation system shall be separate from other ventilation systems. The power ventilation system shall be operated to give at least the number of air changes required in paragraph 3.1.1 at all times when vehicles are in such spaces, except where an air quality control system in accordance with paragraph 3.1.2.4 is provided. Ventilation ducts serving such cargo spaces capable of being effectively sealed shall be separated for each such space. The system shall be capable of being controlled from a position outside such spaces.”

Note that the ventilation system for ro-ro spaces shall be separated from other ventilation systems. This will prevent smoke from a fire to spread through the ventilation system.

For cargo ships, the corresponding regulation is written in SOLAS II-2/20.3.1.2.2:

“In cargo ships, the ventilation fans shall normally be run continuously and give at least the number of air changes required in paragraph 3.1.1 whenever vehicles are on board, except where an air quality control system in accordance with paragraph 3.1.2.4 is provided. Where this is impracticable, they shall be operated for a limited period daily as weather permits and in any case for a reasonable period prior to discharge, after which period the ro-ro or vehicle space shall be proved gas-free. One or more portable combustible gas detecting instruments shall be carried for this purpose. The system shall be entirely separate from other ventilation systems. Ventilation ducts serving ro-ro or vehicle spaces shall be capable of being effectively sealed for each cargo space. The system shall be capable of being controlled from a position outside such spaces.”

In SOLAS (IMO, 1974) regulation 20, reference is made to MSC.1/Circ.1515 (IMO, 2015) for the performance of ventilation systems. MSC.1/Circ.1515 Revised design guidelines and operational recommendations for ventilation systems in ro-ro cargo spaces are divided into two parts. The first part (IMO, 2015) deals with "Design guidelines for ventilation systems in ro-ro cargo spaces", and describes, inter alia, the basic principles for designing ventilation systems on board. MSC.1 / Circ.1515 / 2.1 states:
“Ventilation systems for ro-ro cargo spaces on board ship generally operate according to the principle of dilution ventilation, whereby the supply air flow to the area is sufficient for the exhaust gases to mix thoroughly with the air and be removed.”

The same section defines that both exhaust air systems and supply air systems can be on board:

“There are two main types of dilution ventilation: exhaust air ventilation and supply air ventilation. Briefly, in exhaust air ventilation, fans remove air from a ro-ro cargo space, and this is then replaced by outdoor air entering through open ramps, doors and other openings. Exhaust air ventilation is employed when sub-atmospheric pressure is required in the ro-ro cargo space. The sub-atmospheric pressure prevents the pollution from spreading to adjacent areas.”

In some cases, the systems can be reversible, so the crew can choose how to use the system:

“Ventilation systems on board ship often combine these two principles. The fans can then be reversible, so that they can either supply air into the ro-ro cargo space or exhaust air from it.” (IMO, 2015)

In Part 2 of the circular (IMO, 2015), MSC.1/Circ.1515 Operational recommendations for minimizing air pollution in ro-ro cargo spaces, include recommendations on how to test and run the ventilation system to minimize exposure to air pollution. It is aimed primarily for the crew involved in cargo handling in cargo spaces. Part 2 MSC.1/ Circ.1515 / 3.1 states:

“When optimizing the ventilation of a ro-ro cargo space, all appropriate options should be considered. Such options include different fan speeds, fan configurations and the use of natural ventilation through hull openings. Consideration should also be given to the relative safety and environmental conditions.”

See more of design of ventilation systems in section 2.2 in this report.

2.1.2.1.1 Location and activation of fire dampers

According to SOLAS 2-II/9.4.1.1.9 a fail-safe automatic closing fire damper shall be fitted adjacent to the division “where it is necessary that a ventilation duct passes through a main vertical zone division...” and further “The damper shall also be capable of being manually closed from each side of the division. The operating position shall be readily accessible and be marked in red light-reflecting colour. The duct between the division and the damper shall be of steel or other equivalent material and, if necessary, insulated to comply with the requirements of paragraph 3.1. The damper shall be fitted on at least one side of the division with a visible indicator showing whether the damper is in the open position.”

Automatic fire damper may also be found in the galley ventilation duct on ships constructed on or after 1 January 2016. The following is stated in SOLAS 2-II/9.7.2.1: “The ventilation systems for machinery spaces of category A, vehicle spaces, ro-ro spaces, galleys, special category spaces and cargo spaces shall, in general, be separated from each other and from the ventilation systems serving other spaces. However, the galley ventilation systems on cargo ships of less than 4,000 gross tonnage and in passenger ships carrying not more than 36 passengers need not be completely separated from other
ventilation systems, but may be served by separate ducts from a ventilation unit serving other spaces. In such a case, an automatic fire damper shall be fitted in the galley ventilation duct near the ventilation unit."

According to SOLAS 2-II/9.7.3. "Ducts passing through "A" class divisions shall meet the following requirements:

.3 automatic fire dampers shall be fitted in all ducts with a free cross-sectional area exceeding 0.075 m² that pass through "A" class divisions. Each damper shall be fitted close to the division penetrated and the duct between the damper and the division penetrated shall be constructed of steel in accordance with paragraphs 7.2.4.2.1 and 7.2.4.2.2. The fire damper shall operate automatically, but shall also be capable of being closed manually from both sides of the division. The damper shall be fitted with a visible indicator which shows the operating position of the damper. Fire dampers are not required, however, where ducts pass through spaces surrounded by "A" class divisions, provided those ducts have the same fire integrity as the divisions which they penetrate. A duct of cross-sectional area exceeding 0.075 m² shall not be divided into smaller ducts at the penetration of an "A" class division and then recombined into the original duct once through the division to avoid installing the damper required by this provision."

The above-mentioned requirement may indicate that for ro-ro spaces on new built ships (on ships constructed on or after 1 January 2016) it is possible to share ventilation duct if there are fire dampers when the duct passing the A-class deck. See more of fire integrity in section 2.1.2.4.

2.1.2.1.2 Ventilation and dangerous good
SOLAS II-2/19 Carriage of dangerous goods specifies special requirements for ships that transport dangerous goods. For the ventilation and transport of dangerous goods, the following requirements are set out in SOLAS II-2/19.3.4:

“Adequate power ventilation shall be provided in enclosed cargo spaces. The arrangement shall be such as to provide for at least six air changes per hour in the cargo space based on an empty cargo space and for removal of vapours from the upper or lower parts of the cargo space, as appropriate.”

It can be noted that the air exchanges are based on an empty space. As mentioned before, there may potentially be a high flow above the lorries when the ship is loaded with vehicles that occupy volume. The regulation continues:

“The fans shall be such as to avoid the possibility of ignition of flammable gas air mixtures. Suitable wire mesh guards shall be fitted over inlet and outlet ventilation openings.”

“Natural ventilation shall be provided in enclosed cargo spaces intended for the carriage of solid dangerous goods in bulk, where there is no provision for mechanical ventilation.”

The above-mentioned requirements in regulation 19 apply regardless of whether the vessel could make exemption with air quality systems on board according to regulation 20 which was described earlier in this section. SOLAS II-2/20.3.1.2.4 states:

“For all ships, where an air quality control system is provided based on the guidelines developed by the Organization, * the ventilation system may be operated at a decreased
number of air changes and/or a decreased amount of ventilation. This relaxation does not apply to spaces to which at least ten air changes per hour is required by paragraph 3.2.2 of this regulation and spaces subject to regulations 19.3.4.1 and 20-1.”

* refers to MSC/Circ.1515.

For natural ventilation, permanent openings have requirements in where they are located, SOLAS II-2/20.3.1.5 states the following:

“Permanent openings in the side plating, the ends or deckhead of the space shall be so situated that a fire in the cargo space does not endanger stowage areas and embarkation stations for survival craft and accommodation spaces, service spaces and control stations in superstructures and deckhouses above the cargo spaces.”

Other than above nothing is found about geometrical shape, size or location of openings for permanent natural ventilation.

2.1.2.1.3 Maintenance and inspection

First of all, when the ship is delivered, the ventilation system shall be tested confirming that the design supply air flow is obtained. This is required in the MSC.1/Circ.1515 (IMO, 2015). Since the design is made to an empty deck, also the test shall be done with an empty deck and the result will not show any represented or equivalent result to the conditions present when loading/unloading or at sea. Wind and obstacles in the space will then change the conditions. It is then of importance that the crew gain experience of how to use the ventilation system. In MSC.1/Circ.1515 (IMO, 2015) section 3.1 the following can be read:

“To utilize the ventilation system in the ro-ro cargo spaces on a ship most effectively, knowledge should be acquired of its capacity from experience and through simple tests. It is important that guidelines, rules and routines be established for using the ventilation system in typical loading and unloading conditions. It is also important that experience gained will be documented and passed on, to provide guidance for the ship's crew.”

Maintenance and inspection of a system is very important to keep it working as intended. Onboard maintenance and inspections should be carried out according to the ship's maintenance plan, a plan which is required by SOLAS regulation II-2/14.

According to MSC.1/Circ.1432 (IMO, 2012) "Revised guidelines for the maintenance and inspection of fire protection systems and appliances” section 6.3 all the fire dampers in the ventilation system shall be tested for local operation every quarter of a year. The section states: “Quarterly inspections should be carried out to ensure that the indicated actions are taken for the specified equipment”.

In section 7.6 of the same circular it is also stated that 7.6 all fire dampers shall be tested for remote operation and verified that galley exhaust ducts and filters are free of grease build-up as well as all ventilation controls interconnected with fire-protection systems for proper operation shall be tested.

It is regulated that the inspections shall be made by the crew working onboard. MSC.1/Circ.1432 (IMO, 2012) section 3.3 states the following:

“Inspections should be carried out by the crew to ensure that the indicated weekly, monthly, quarterly, annual, two-year, five-year and ten-year actions are taken for the
specified equipment, if provided. Records of the inspections should be carried on board the ship, or may be computer-based. In cases where the inspections and maintenance are carried out by trained service technicians other than the ship's crew, inspection reports should be provided at the completion of the testing.”

2.1.2.1.4 Documentation of ventilation system

As mentioned in 2.1.2.1.3 records of inspection of the fire dampers shall be stored onboard. If we look back to the design guidelines and operational recommendations for ventilation systems in ro-ro cargo spaces MSC.1/Circ.1515 (IMO, 2015) the following is stated in part 1, section 4.1, about documentation:

“An operation manual should be supplied and should include a plan of the ventilation system, showing fans, supply air and exhaust air openings and doors, ramps, hatches, etc. The location of the control panel for the ro-ro cargo space ventilation system should also be marked.

The plan should show the various options for operation of the ventilation system. It should include details of the design air flow and of the estimated number of different types of vehicles in the different ro-ro cargo spaces under various loading and unloading conditions.

The plan should be periodically revised and/or supplemented on the basis of the experience gained from the normal vehicle loading and unloading conditions. A number of blank drawings should therefore be kept on board.

On the basis of such experience, it should also be possible to draw up guidelines for the maximum number of vehicles that should be allowed to operate simultaneously.

Whenever possible, places which are sheltered from the air flow should be indicated on the plans.

The operation manual should include guidance for the service and maintenance of the systems.”

Continuing reading part 1 of the MSC.1/Circ.1515 (IMO, 2015) it is also stated that “a plan of the ship's ro-ro cargo spaces, showing the location of fans and openings, should be kept at the control panel. Each fan should be given an individual designation.” And that “Indications as to which fans should be used for a given ro-ro cargo space under various loading conditions should also be on display at the control panel.”

Also, the control of the air quality systems should be indicated at the control panel, this is mentioned in section 4.2 in MSC.1/Circ.1515 (IMO, 2015).

So, the ventilation system shall be documented, and plans shall be available onboard. Also, on the General Arrangement plan (GA) the ventilating system including particulars of the fan control positions, the position of dampers and identification numbers of the ventilating fans serving each section shall be shown. This is stated in to SOLAS 2-II/15.2.4.1:

“General arrangement plans shall be permanently exhibited for the guidance of the ship's officers, showing clearly for each deck the control stations, the various fire sections enclosed by "A" class divisions, the sections enclosed by "B" class divisions together with particulars of the fire detection and fire alarm systems, the sprinkler installation, the fire-
extinguishing appliances, means of access to different compartments, decks, etc., and the ventilating system including particulars of the fan control positions, the position of dampers and identification numbers of the ventilating fans serving each section. Alternatively, at the discretion of the Administration, the aforementioned details may be set out in a booklet, a copy of which shall be supplied to each officer, and one copy shall at all times be available on board in an accessible position. Plans and booklets shall be kept up to date; any alterations thereto shall be recorded as soon as practicable. Description in such plans and booklets shall be in the language or languages required by the Administration. If the language is neither English nor French, a translation into one of those languages shall be included.”

So, the plans shall be for the crew to go and look at, preferably in prevention purpose, so if and when something needs to be done, they know where to go and to use the ventilation system and its fans and fire dampers.

2.1.2.1.5 Ventilation and fire development

Since a fire needs oxygen to proceed, the ventilation conditions affect the development of a fire. If there is limited access to oxygen and free access to fuel, the fire is called "ventilation-controlled fire" and its maximum effect is determined by the amount of oxygen that enters the space through openings or mechanical ventilation (Quintere, 1999). In a closed space, where the amount of oxygen is limited, the fire may eventually self-extinguish or continue to burn with low intensity. Another mechanism that may cause the fire to self-extinguish is due to effects of in Retation. This occurs when the hot gas layer (which include high concentrations of inert gases such as CO₂ and H₂O) which eventually will enclose the fire itself. In this case the fire does not communicate with the external openings through transport of oxygen. The maximum effect of a fire in a closed ro-ro space with smaller openings and the time until a fire can self-extinguish in a closed ro-ro space will be investigated in the experimental part of the project (Olofsson, o.a., 2019).

Is there free access to oxygen, like on a weather deck, the fire is called "fuel-controlled" and the fire development is determined by the availability and characteristics of fuel (Quintere, 1999). However, on a weather deck, the speed and direction of the air and smoke can affect the development of the fire and the risk of fire spread is important to take into account.

Airflow from ventilation, whether natural or mechanical, can affect the time of detection and it is mentioned in SOLAS II-2/20.4.1 that the location of detectors shall take into account the effects of ventilation:

“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.”

What is difficult to take into account is the location of detectors in relation to the vehicles loaded on board and the conditions that exist when a fire starts. Many high trucks that occupy a large proportion of the volume can possibly cause the airflow above the trucks where detectors are located to become high and thus delay/prevent detection or cause a detector other than the closest to the fire to detect first. A study of this was done in
Firesafe II (Bureau Veriteas, RISE Research Institutes of Sweden, Stena Rederi AB, 2018).

For ships constructed on January 1, 2016 or later there are structural requirements for the ventilation system. These requirements are included in SOLAS II-2/9.7 and states for example that ventilation ducts should be of steel or equivalent material, with certain exceptions. More of the fire integrity of ventilation system is described in section 2.1.2.4 of this report.

2.1.2.2 Fire detection

The general requirements for detection and alarm is set out in SOLAS II-2 regulation 7 Detection and alarm. The purpose of the regulation is stated in the first paragraph SOLAS II-2/7.1:

“The purpose of this regulation is to detect a fire in the space of origin and to provide for alarm for safe escape and fire-fighting activity. For this purpose, the following functional requirements shall be met:

.1 fixed fire detection and fire alarm system installations shall be suitable for the nature of the space, fire growth potential and potential generation of smoke and gases;

.2 manually operated call points shall be placed effectively to ensure a readily accessible means of notification; and

.3 fire patrols shall provide an effective means of detecting and locating fires and alerting the navigation bridge and fire teams.”

SOLAS II-2/7.6 specify protection of cargo spaces in passenger ships with the following requirement:

“A fixed fire detection and fire alarm system or a sample extraction smoke detection system shall be provided in any cargo space which, in the opinion of the Administration, is not accessible, except where it is shown to the satisfaction of the Administration that the ship is engaged on voyages of such short duration that it would be unreasonable to apply this requirement.”

Specific requirements for vehicle, special category and ro-ro spaces is found in SOLAS II-2/20.4.1. See text from SOLAS below:

”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. 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.”

What is referred to in clause 4.3.1 is that detection and alarm systems can be excluded in special category spaces with continuous fire watch by crew throughout the journey of the ship.
In TSFS 2009:98 (Transportstyrelsen, 2009:98), this requirement applies only to closed ro-ro spaces, vehicle spaces and special category spaces. In TSFS 2009:98 Appendix 1, Rule 20, Section 4.1 it states that:

“all closed ro-ro spaces, vehicle spaces and special category spaces shall have a fixed fire detection and fire alarm system that meets the requirements of the FSS Code, unless otherwise stated in 4.3.1. The system should quickly detect a fire using smoke detectors or a combination of smoke and flame detectors. After installation, the system will be tested under normal ventilation conditions.”

Open ro-ro spaces are thus excluded from detection in the Swedish rule interpretation, but not in the origin of SOLAS.

Except fixed fire detection, it is also a requirement of manual call point. In SOLAS II-2/20.4.3.2 it is regulated with manual call points:

“Manually operated call points shall be spaced so that no part of the space is more than 20 m from a manually operated call point, and one shall be placed close to each exit from such spaces.”

The automatic fire detection systems are in some cases extended with fire patrols. In SOLAS II-2/7.8 it is stated that:

“For ships carrying more than 36 passengers an efficient patrol system shall be maintained so that an outbreak of fire may be promptly detected. Each member of the fire patrol shall be trained to be familiar with the arrangements of the ship as well as the location and operation of any equipment he may be called upon to use.”

2.1.2.3 Fire extinguishing

Regulation 10 in SOLAS (IMO, 1974) chapter II-2 is the general regulation for fire fighting with the following purpose, stated in 10.1.1:

“The purpose of this regulation is to suppress and swiftly extinguish a fire in the space of origin, except for paragraph 1.2. For this purpose, the following functional requirements shall be met:

.1 fixed fire-extinguishing systems shall be installed having due regard to the fire growth potential of the protected spaces; and

.2 fire-extinguishing appliances shall be readily available.

Fire extinguishing systems are required for vehicle spaces, closed ro-ro spaces and special category spaces. The extinguishing system shall be designed according to the FSS Code (IMO, 2007). Different types of extinguishing systems are specified depending on the space to be protected and if the space can be closed tightly. SOLAS II-2/20.6.1.1 state:

“Vehicle spaces and ro-ro spaces, which are not special category spaces and are capable of being sealed from a location outside of the cargo spaces, shall be fitted with one of the following fixed fire-extinguishing systems:

- A fixed gas fire-extinguishing system complying with the provisions of the Fire Safety Systems Code;
- A fixed high-expansion foam fire-extinguishing system complying with the provisions of the Fire Safety Systems Code; or
Further in regulation 20 the following is stated in SOLAS II-2/20.6.1.2:

“Vehicle spaces and ro-ro spaces not capable of being sealed and special category spaces shall be fitted with a fixed water-based fire-fighting system for ro-ro spaces and special category spaces complying with the provisions of the Fire Safety Systems Code which shall protect all parts of any deck and vehicle platform in such spaces.”

So, water-based systems are the general system onboard ro-ro passenger ships and gas, foam or water are more common on pure cargo ships with ro-ro spaces.

In SOLAS II-2/10.7.3 there are requirements for newbuilt ships (constructed on or after 1 January 2016) designed to carry five or more tiers of containers on or above the weather deck. These ships shall carry at least one water mist lance and mobile water monitors*.

* Refer to the Guidelines for the design, performance, testing and approval of mobile water monitors used for the protection of on-deck cargo areas of ships designed and constructed to carry five or more tiers of containers on or above the weather deck (MSC.1/Circ.1472).

This regulation does not apply for weather deck as a ro-ro space since a container is not possible to roll on and off by its own machine, however, it can be interesting to have in mind when developing the concept solutions in this project.

For water-based systems, the MSC.1/Circ.1430 (IMO, 2012) “Revised guidelines for the design and approval of fixed water-based fire-fighting systems for ro-ro spaces and special category spaces” applies.

2.1.2.3.1 Fire extinguishing and dangerous goods
Regulation 19 sets further requirements for fire extinguishing systems for ships carrying dangerous goods. Fire hydrant supply (SOLAS II-2/19.3.1) and portable extinguishing equipment (SOLAS II-2/19.3.7) are examples. A water spray system shall be provided in open ro-ro spaces according to SOLAS II-2/19.3.9:

“Each open ro-ro space having a deck above it and each space deemed to be a closed ro-ro space not capable of being sealed, shall be fitted with an approved fixed pressure water-spraying system for manual operation which shall protect all parts of any deck and vehicle platform in the space, except that the Administration may permit the use of any other fixed fire-extinguishing system that has been shown by full-scale test to be no less effective...”

2.1.2.3.2 Requirements for fire extinguishing systems in accordance to not freeze and its capacity of drainage
Ships are operating in almost all weather. High wind velocity, temperatures below zero or other hard conditions. The fire extinguishing system can possibly be exposed to the same conditions as on the outside.

For the water supply of fire pumps, fire mains, hydrants and hoses shall comply with SOLAS 2-II/10.2.1.1 saying that “...The arrangement of pipes and hydrants shall be such
as to avoid the possibility of freezing. Suitable drainage provisions shall be provided for fire main piping. Isolation valves shall be installed for all open deck fire main branches used for purposes other than fire fighting. In ships where deck cargo may be carried, the positions of the hydrants shall be such that they are always readily accessible, and the pipes shall be arranged as far as practicable to avoid risk of damage by such cargo.”

Separate guidelines for “the drainage of fire fighting water from closed vehicle and ro-ro spaces and special category spaces of passenger and cargo ships” are formed in MSC.1/Circ.1320 (IMO, 2009). It firstly refers to SOLAS regulation 20.

For fixed fire extinguishing systems regulation 20 in SOLAS 2-II have requirement of “A sufficient number of drainage valves to ensure complete drainage of the system” according to section 6.1.2.4.

For ships fitted with a fixed pressure water-spraying system the section 6.1.4 in SOLAS 2-II regulation 20 applies, saying:

“When fixed pressure water-spraying systems are fitted, in view of the serious loss of stability which could arise due to large quantities of water accumulating on the deck or decks during the operation of the fixed pressure water-spraying system, the following arrangements shall be provided:

.1 in passenger ships:

.1.1 in the spaces above the bulkhead deck, scuppers shall be fitted so as to ensure that such water is rapidly discharged directly overboard, taking into account the guidelines developed by the Organization *;

.1.2.1 in ro-ro passenger ships, discharge valves for scuppers, fitted with positive means of closing operable from a position above the bulkhead deck in accordance with the requirements of the International Convention on Load Lines in force, shall be kept open while the ships are at sea;

.1.2.2 any operation of valves referred to in paragraph 6.1.4.1.2.1 shall be recorded in the log-book;

.1.3 in the spaces below the bulkhead deck, the Administration may require pumping and drainage facilities to be provided additional to the requirements of regulation II-1/35-1. In such case, the drainage system shall be sized to remove no less than 125% of the combined capacity of both the water-spraying system pumps and the required number of fire hose nozzles, taking into account the guidelines developed by the Organization *.

.2 in cargo ships, the drainage and pumping arrangements shall be such as to prevent the build-up of free surfaces. In such case, the drainage system shall be sized to remove no less than 125% of the combined capacity of both the water-spraying system pumps and the required number of fire hose nozzles, taking into account the guidelines developed by the Organization *.

Bilge wells shall be of sufficient holding capacity and shall be arranged at the side shell of the ship at a distance from each other of not more than 40 m in each watertight compartment;
side shell of the ship at a distance from each other of not more than 40 m in each watertight compartment. If this is not possible, the adverse effect upon stability of the added weight and free surface of water shall be taken into account to the extent deemed necessary by the Administration in its approval of the stability information **. Such information shall be included in the stability information supplied to the master as required by regulation II-1/5-1.

* Refer to Guidelines for the drainage of fire-fighting water from closed vehicle and ro-ro spaces and special category spaces for passenger and cargo ships (MSC.1/Circ.1320)

According to SOLAS 2-II/20.6.1.5 “On all ships, for closed vehicles and ro-ro spaces and special category spaces, where fixed pressure water-spraying systems are fitted, means shall be provided to prevent the blockage of drainage arrangements, taking into account the guidelines developed by the Organization *. Ships constructed before 1 January 2010 shall comply with the requirements of this paragraph by the first survey after 1 January 2010.”

Back to the guidelines in MSC.1/Circ.1320 (IMO, 2009) it can be read in section 5.1 that:

“An easily removable grating, screen or other means should be installed over each drain opening in the protected spaces to prevent debris from blocking the drain. The total open area ratio of the grating to the attached drain pipe should be at least 6 to 1. The grating should be raised above the deck or installed at an angle to prevent large objects from blocking the drain. No dimension of the individual openings in the grating should be more than 25 mm.” Further on in 5.2:

“No grating or screen is required when a fixed mechanical system is provided to unblock the drainage system, or when other than a gravity drain system is provided with its own filter.” And in 5.3 it is stated that:

“A clearly visible sign or marking should be provided not less than 1,500 mm above each drain opening stating, “Drain opening – do not cover or obstruct”. The marking should be in letters at least 50 mm in height.”

The guidelines in MSC.1/Circ.1320 (IMO, 2009) is also giving equations for how to calculate the minimum required area of scuppers and connected piping above the bulkhead deck and the criteria for bilge pumps under bulkhead deck in passenger ships. For cargo ships “the depth of water (h₁ – h₂) on each deck should be calculated by multiplying the maximum flow rate of the installed fire-extinguishing system water pumps plus the flow from two fire hoses (four if required by SOLAS regulation II-2/19.3.1.2) by an operating time of 30 min. This volume of water should be divided by the area of the affected deck.” This shall be done do ensure that no free water surfaces are built up.

Last, but not least, in the guidelines (IMO, 2009) the testing is mentioned. It is stated that:

“The drainage facilities on ro-ro passenger ships should be functionally tested before the ship enters service to verify that the capacity of the system is adequate. The drainage facilities on all ships should be periodically visually examined for blockage or other damage and should be flushed with fire hoses or similar means to verify that the system is functional, if obstructions are noted.”
According to MSC.1/Circ.1430 which is the “Revised guidelines for the design and approval of fixed water based fire fighting systems for ro-ro spaces and special category spaces.” There are also requirements for the system not to freeze. In accordance with section 3.6 in the circular the following is written:

“Wet pipe systems on board vessels that can operate in areas where temperatures below 0°C can be expected, should be protected from freezing either by having temperature control of the space, heating coils on pipes, antifreeze agents or other equivalent measures.”

2.1.2.3.3 Influence from ventilation on extinguishing media

Already in the circular MSC.1/Circ.1430 (IMO, 2012) it is assumed that the wind can affect the performance of an extinguishing system. In section 1 of the circular (IMO, 2012) the following general guidelines apply for water-based systems:

“Deluge systems can be applied on open ro-ro spaces when the actual wind condition is taken into consideration, for example through the use of high velocity nozzles. Systems using automatic sprinklers or nozzles are only permitted for closed ro-ro and special category spaces or other spaces where wind conditions are not likely to affect system performance.”

The report “Influence of ventilation on road tunnel fires with and without water-based suppression systems” (Li & Ingason, 2016) has the objective to study the effects of ventilation on the conditions in the tunnel both with and without a water spray system. The environment in a tunnel can be assumed to be similar as in a ro-ro space, a long space filled with vehicles and can have a height of approximately 5 m. Therefore, the results from the report can be interesting reading for this project.

According to the report (Li & Ingason, 2016) side spray nozzles with a water density of 10 mm/min was able to suppress a fire development despite a high speed of the ventilation fans and the fire development was limited effected by the ventilation system after the activation of suppression system. From the perspective of CO production and visibility, a higher velocity of ventilation is preferred, a little bit higher than 3 m/s but not higher than 6 m/s. It is worth noting that if the fire suppression system has a lower capacity or effectiveness, the ventilation could affect the fire development in another way. So, it is not directly comparable with a suppression system onboard a ro-ro space. First, it is not praxis with side spray nozzles in a ro-ro space. Second, the ventilation direction cannot be assumed the same as in a tunnel

The influence from ventilation and wind will further be studied in simulations and model scale tests in this research project.

2.1.2.4 Fire integrity

In SOLAS II-2/9 Containment of Fire, fire divisions are mentioned. The purpose with the requirements is to contain a fire where it starts. To meet this, the following functional requirements are mentioned in SOLAS II-2 / 9.1:

“the ship shall be subdivided by thermal and structural boundaries”

“thermal insulation of boundaries shall have due regard to the fire risk of the space and adjacent spaces”
“the fire integrity of the divisions shall be maintained at openings and penetrations”

For passenger ships there is a requirement for vertical division of the ship into main fire zones, also called main vertical zones and shortened MVZ (SOLAS II-2/9.2.2.1). A main fire zone is allowed to be maximum 1600 m² (SOLAS II-2/9.2.2.1.2) and width and length of the MVZ may not exceed 48 meters. The height of such a main fire zone is governed by what spaces are adjacent to each other. A main fire zone must meet the A60 integrity classification. However, exceptions are made in SOLAS II-2/9.2.2.1.5.1 which states that:

“In ships designed for special purposes, such as automobile or railroad car ferries, where the provision of main vertical zone bulkheads would defeat the purpose for which the ship is intended, equivalent means for controlling and limiting a fire shall be substituted and specifically approved by the Administration.”

Ships with ro-ro spaces can thus, instead of vertical main fire zones, meet the requirement in another way. The bulkheads shall be replaced by equivalent devices for control and limitation of fires. For special category spaces, SOLAS regulation 20 applies to what classification the division shall comply with, SOLAS II-2 / 9.2.2.1.5.2 states the following:

“However, in a ship with special category spaces, such spaces shall comply with the applicable provisions of regulation 20 and where such compliance would be inconsistent with other requirements for passenger ships specified in this chapter, the requirements of regulation 20 shall prevail.”

SOLAS II-2 / 20.2.2.1 describes that the division into vertical fire zones is not adapted to vehicle spaces on passenger ships and therefore equivalent protection must be achieved through a horizontal division and by providing a fixed fire extinguishing system. Such a horizontal classification may include special category spaces in more than one deck, provided that the total height of vehicles in each zone does not exceed 10 meters. In the words of SOLAS II-2 / 20.2.2.1:

“The basic principle underlying the provisions of this regulation is that the main vertical zoning required by regulation 9.2 may not be practicable in vehicle spaces of passenger ships and, therefore, equivalent protection must be obtained in such spaces on the basis of a horizontal zone concept and by the provision of an efficient fixed fire-extinguishing system. Based on this concept, a horizontal zone for the purpose of this regulation may include special category spaces on more than one deck provided that the total overall clear height for vehicles does not exceed 10 m.”

In practice, it means that two deck with ro-ro spaces can be included in the same horizontal fire zone and that no insulation is required between the decks. The principle applies to ro-ro spaces on passenger ships. For cargo ships there is no requirement for division into vertical fire zones, and SOLAS II-2 / 20.2.2.1 therefore does not apply to cargo ships. Certain methods shall be used for protection of accommodation areas but for ro-ro spaces on cargo ships, SOLAS II-2 / 9.2.3.3 Fire integrity of bulkheads and decks applies, and spaces applies. Different spaces are categorized and is the base for fire integrity. Category 11 includes ro-ro spaces and vehicle spaces. Depending on the spaces adjacent to each other, the requirements for fire integrity are different.

Class A30 applies to bulkheads and decks between ro-ro spaces (SOLAS II-2 / 9.2.3.3.2 Tables 9.5 and 9.6) on ships constructed after July 1, 2014. It is thus a relatively new rule.
and existing ships have no fire insulation between ro-ro spaces on cargo ships. Exception is if SOLAS II-2/9.2.2 is not achieved, the following is stated in SOLAS II-2/20.5:

“Notwithstanding the provisions of regulation 9.2.2, in passenger ships carrying more than 36 passengers, the boundary bulkheads and decks of special category spaces and ro-ro spaces shall be insulated to "A-60" class standard. However, where a category (5), (9) and (10) space, as defined in regulation 9.2.2.3, is on one side of the division the standard may be reduced to "A-0". Where fuel oil tanks are below a special category space or a ro-ro space, the integrity of the deck between such spaces, may be reduced to "A-0" standard.”

From SOLAS II-2 / 9.2.3.2 Table 9.6 it declares what fire integrity the deck boundary shall comply with depending on what is on the other side of the deck of the ro-ro or vehicle space:

- Control stations (1) and machinery spaces of category A (6) must meet the A60-class,
- Corridors (2), Accommodation spaces (3), stairways (4), service spaces (high risk) (9) must meet the A30-class,
- Service spaces (low risk) (5), other machinery spaces (7), cargo spaces (8), open decks (10) must meet the A0-class.

The corresponding table exists for passenger ships that do not take more than 36 passengers, SOLAS II-2 / 9.2.2.4.2 Table 9.4 shows that a ro-ro space or special category space that has decks adjacent to

- Control stations (1) must meet the A60-class,
- Corridors (2), accommodation spaces (3), stairways (4), machinery of category A (6), service spaces (high risk) (9) must meet the A30-class,
- accommodation spaces (3), service spaces (low risk) (5), other machinery spaces (7), cargo spaces (8), open decks (10) must meet the A0-class.

Based on Regulation 9 and Regulation 20, a fire zone for a ro-ro space on a passenger ship, open or closed, may have an area of nearly 4000 m², which is considerably larger than the 1600 m² maximum permitted for vertical main fire zones in other parts of the ship. The height of such a fire zone, which extends over two double decks, may be 12-13 meters. A fire zone with ro-ro space can thus comprise a volume of about 48000 m³ which can be fully loaded with cars and trucks, with own fuel in their tanks but also with varied goods in load. Such a large space is difficult to control if a fire occurs, which have been seen from the accident investigations studied, see section 2.3 of this report. The size of a fire zone in the national building code in Sweden can have the maximum size of 2500 m² if an automatic fire detection system is installed and the size is unlimited if an automatic fire extinguishing system is installed (Boverket, 2016).

2.1.2.4.1 Fire integrity and ventilation
The ventilation system for ro-ro spaces shall be separated from other ventilation systems, this is stated in SOLAS II-2/7.2.1:

“The ventilation systems for machinery spaces of category A, vehicle spaces, ro-ro spaces, galleys, special category spaces and cargo spaces shall, in general, be separated from each other and from the ventilation systems serving other spaces. However, the galley ventilation systems on cargo ships of less than 4,000 gross tonnage and in passenger ships carrying not more than 36 passengers need not be completely separated from other
ventilation systems, but may be served by separate ducts from a ventilation unit serving other spaces. In such a case, an automatic fire damper shall be fitted in the galley ventilation duct near the ventilation unit.”

Further on, it is required that the ducts from ro-ro spaces not pass through certain spaces and that ducts from other spaces not pass through a ro-ro space. In SOLAS II-2/7.2.2 it is stated:

“Ducts provided for the ventilation of machinery spaces of category A, galleys, vehicle spaces, ro-ro spaces or special category spaces shall not pass through accommodation spaces, service spaces, or control stations unless they comply with paragraph 7.2.4.”

The other way around is noted in SOLAS II-2/7.2.3:

“Ducts provided for the ventilation of accommodation spaces, service spaces or control stations shall not pass through machinery spaces of category A, galleys, vehicle spaces, ro-ro spaces or special category spaces unless they comply with paragraph 7.2.4.”

Paragraph 7.2.4 is a list of how the ducts shall be to be able to pass through the spaces:

1. “constructed of steel having a thickness of at least 3 mm for ducts with a free cross-sectional area of less than 0.075 m², at least 4 mm for ducts with a free cross-sectional area of between 0.075 m² and 0.45 m², and at least 5 mm for ducts with a free cross-sectional area of over 0.45 m²;
2. suitably supported and stiffened;
3. fitted with automatic fire dampers close to the boundaries penetrated; and
4. insulated to "A-60" class standard from the boundaries of the spaces they serve to a point at least 5 m beyond each fire damper;”

Instead of complying with 1-4, the ducts can be constructed of steel in accordance with 1 and 2 in the list above and insulated to A-60 class standard throughout the spaces they pass through, except for ducts that pass-through spaces of category (9), sanitary and similar spaces, or (10) tanks, voids and auxiliary machinery spaces having little or no fire risk.

The ducts shall generally be in steel or equivalent material, stated in SOLAS II-2/9.7.1.1

“Ventilation ducts, including single and double wall ducts, shall be of steel or equivalent material except flexible bellows of short length not exceeding 600 mm used for connecting fans to the ducting in air-conditioning rooms. Unless expressly provided otherwise in paragraph 7.1.6, any other material used in the construction of ducts, including insulation, shall also be non-combustible. However, short ducts, not generally exceeding 2 m in length and with a free cross-sectional area * not exceeding 0.02 m², need not be of steel or equivalent material, subject to the following conditions:

.1 the ducts shall be made of non-combustible material, which may be faced internally and externally with membranes having low flame-spread characteristics and, in each case, a calorific value ** not exceeding 45 MJ/m² of their surface area for the thickness used;

** Refer to the recommendations published by the International Organization for Standardization, in particular publication ISO 1716:2002, Reaction to the fire tests for building products – Determination of the heat of combustion.
the ducts are only used at the end of the ventilation device; and

the ducts are not situated less than 600 mm, measured along the duct, from an opening in an "A" or "B" class division, including continuous "B" class ceiling.”

2.1.2.4.2 Fire integrity and dangerous goods

Regarding the division of ro-ro spaces on ships carrying dangerous goods, the following requirements are set out in SOLAS II-2 / 19.3.10:

“In ships having ro-ro spaces, a separation shall be provided between a closed ro-ro space and an adjacent open ro-ro space. The separation shall be such as to minimize the passage of dangerous vapours and liquids between such spaces. Alternatively, such separation need not be provided if the ro-ro space is considered to be a closed cargo space over its entire length and shall fully comply with the relevant special requirements of this regulation.”

“In ships having ro-ro spaces, a separation shall be provided between a closed ro-ro space and the adjacent weather deck. The separation shall be such as to minimize the passage of dangerous vapours and liquids between such spaces. Alternatively, a separation need not be provided if the arrangements of the closed ro-ro spaces are in accordance with those required for dangerous goods carried on adjacent weather deck.”

The same paragraph in TSFS 2009:98 (Transportstyrelsen, 2009:98) Annex 1, Regulation 19, Section 3.10.1 indicates that such separation, for example, is a portal. The regulation is translated below:

"If a closed ro-ro space has an opening to another ro-ro space, this opening should be provided with a separation (such as a portal) that prevents the dispersion of hazardous liquids or gas between spaces. If also the adjacent ro-ro space can be considered a closed ro-ro space, meeting the same requirements, such separation must not exist."

Drainage and ventilation have also been mentioned by the Swedish Transport Agency as a possibility of separation. This separation does not need a fire classification but should prevent gases and liquids from spreading between different ro-ro spaces/weather decks. No examples of separation are mentioned in SOLAS.

2.1.3 Compilation of regulations

It is apparent from the regulations that there is an intention to structurally divide passenger ships so that a fire cannot spread, and that fire extinguishing system or horizontal divisions should exist to control a fire, while the principle of large ro-ro spaces is an important part of the shipping industry. Some of the accident investigations reveal that the large spaces such as open ro-ro spaces make it difficult to meet the functional requirements of the regulations and that they may be prohibited. IMO has discussed forbidden open ro-ro spaces and the results from this project, RO5, will be announced to IMO so that they can continue with the "Fire Safety of Ro-ro Passenger Ship" agenda (MSC 97/19/3) (Maritime Safety Committee, 2016).

A summary of the requirements for different ro-ro spaces is shown in Table 2.
Table 2. Summary of requirements for different types of ro-ro spaces. X marks it is required in that space and – marks it is not required.

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Regulation</th>
<th>Open ro-ro space</th>
<th>Closed ro-ro space</th>
<th>Weather deck</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical ventilation</td>
<td>SOLAS</td>
<td>-</td>
<td>6/10 ACPH</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>TSFS</td>
<td>-</td>
<td>6/10 ACPH</td>
<td>-</td>
</tr>
<tr>
<td>Fire detection</td>
<td>SOLAS</td>
<td>X</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>TSFS</td>
<td>-</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td>Fire alarm</td>
<td>SOLAS</td>
<td>X</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>TSFS</td>
<td>X</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td>Fire extinguishing</td>
<td>SOLAS</td>
<td>X</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>TSFS</td>
<td>X</td>
<td>X</td>
<td>-</td>
</tr>
</tbody>
</table>

Weather deck has no requirements of fire protection, if not carrying dangerous goods or for new construction carrying more than 5 tiers of containers, while closed ro-ro spaces must have all safety measures. Open ro-ro spaces are excluded from mechanical ventilation but need the other fire protection systems.

2.2 Ventilation inventory

The purpose of this ventilation inventory was to collect information of how the mechanical ventilation system can work and be designed in ro-ro spaces onboard a ship. The information has been collected from ventilation drawings, literature, interviews and a study visit onboard Stena Scandinavica.

According to SOLAS II-2/20.3.1.1 “There shall be provided an effective power ventilation system sufficient to give at least the following air changes:

1. Passenger ships

   Special category spaces 10 air changes per hour

   Closed ro-ro and vehicle spaces other than special category spaces for ships carrying more than 36 passengers 10 air changes per hour

   Closed ro-ro and vehicle spaces other than special category spaces for ships carrying not more than 36 passengers 6 air changes per hour

2. Cargo ships

   6 air changes per hour

The Transport Administration may require an increased number of air changes when vehicles are being loaded and unloaded.”

This means that there is no requirement to have mechanical ventilation in open ro-ro spaces and these spaces will therefore not be further investigated in the inventory. The regulation also states that the number of air changes might be higher when loading and
unloading the ship, which is the case for the investigated ships. Nowhere in the regulation could it be found where 10 respectively 6 ACPH actually comes from. As mentioned above the regulation states that the number of ACPH has to be able to keep the concentration of pollutants under the maximum limit. Searching has been done in books and on the internet to try to find out where the numbers comes from, but no such information has been found.

If the ship is equipped what a gas monitoring system, the number of ACPH can be reduced (SOLAS 2-II/20.3.1.2.4). If the ventilation system can be run at a lower speed, there can be positive effects of this. First of all, the ventilation system will not consume the same amount of energy. Secondly, the temperature will not be as low in the ro-ro spaces as when the fans are running full speed. This can have a good effect on the fixed extinguishing system in terms of freezing, if the temperature is higher it is easier to keep the system pipes and valves from freezing. It will also have a positive effect for the staff working in these spaces since it will not be such a cold work environment for them. But again, the main purpose with the ventilation is to avoid stagnation of harmful gases, so this needs also to be investigated if the ventilation rate shall be changed.

Other possible effects of a reduced ventilation rate are that a potential fire might be easier to detect. The smoke will not spread as much when the ventilation system runs at a lower speed and the density of the smoke will be higher at the origin of the fire which makes the smoke detectors detect the smoke faster.

In this inventory each ships ro-ro space configuration, placement of supply and exhaust air and how the ventilation system is used in different situations will be presented. At the end a summary from the study visit onboard Stena Scandinavica will be done.

The following ro-ro passenger ships have been a part of the inventory:

- Stena Superfast
- Stena Germanica
- Stena Scandinavica

### 2.2.1 General design of ventilation system

As mentioned earlier in the report, the circular MSC.1/Circ.1515 (IMO, 2015) section 2.2.1 “Ventilation systems for ro-ro cargo spaces on board ship generally operate according to the principle of dilution ventilation, whereby the supply air flow to the area is sufficient for the exhaust gases to mix thoroughly with the air and be removed.”

The ventilation system in ro-ro spaces is unique for each ship. Different volumes and designs of the ships determine what types and capacity of fans and ducts that is needed in the particular space. However, there are three common ways to supply and exhaust air from the ro-ro space according to the book “Luftbehandling ombord” (Lembratt, 2010). The first one, called longitudinal ventilation, is that supply air is placed in the fore and aft, and exhaust air is placed in the middle of the vessel, see Figure 3.
Figure 3. Sketch of longitudinal ventilation

The second type of ventilation configuration, called transverse ventilation, is when the air flow goes across the ship. In this case all supply air fans are situated at one side of the boat and the exhaust air fans are situated on the other side, see Figure 4.

Figure 4. Sketch of transverse ventilation

The last type is a combination of the first two and is called long-transverse ventilation. Here the supply air fans are situated at the fore and aft and the exhaust air fans are situated on each side of the boat, see Figure 5.

Figure 5. Sketch of long-transverse ventilation

According to Sebastian Norén (Norén, 2019), project engineer at Fläkt Marine, it is very difficult to relate to any standard design when designing ro-ro ventilation since each project is unique. The regulations and standards that he use are MSC.1/Circ.1515 (IMO, 2015) as well as the minimum number of air changes specified in regulation 19.3.4 and 20.3 of the 1974 SOLAS Convention (IMO, 1974). The project engineer also follows the applicable classification society's rules for the current vessel.
Sebastian continuous “When designing the ventilation system for ro-ro spaces, we work according to the dilution principle, where the supply air must be mixed with the exhaust gases sufficiently well and then be removed from the space so that those who work and are in the space are not exposed to any health risks. Here are two types of procedures you can use depending on how the space looks, however, a combination of these is usually designed with the use of reversible fans:

1. exhaust ventilation
2. supply air

Option 1 means that we remove air from the cargo space with extract air fans where outdoor air to the ro-ro space flows in through openings in the vessel. This option provides a vacuum in the cargo space and prevents contamination from spreading to other tires.

Option 2 means the reverse where the supply air dilutes exhaust gases in the ro-ro space and an overpressure causes the air to spread to other decks, which may mean odours and dangerous gases to these decks.

The goal of the ro-ro ventilation is that the distribution of the air flow should reach all spots in the space, but since all projects are unique, there is no solution that we can apply to all vessels without an individual calculation where we as an aid use tables and values specified in SOLAS and MSC standards for obtaining the required air volumes to dilute contaminants in the ro-ro space.

It should also be taken into account that vehicles and other objects can block the air flow to certain spaces in the calculations and certain zones can therefore be marked out in the space as zones where one should not stay too long. As a rule of thumb, we also say that the throw length should be at least the height of the current tire in order to get a sufficient spread on the air.” (Norén, 2019)

2.2.2 Stena Superfast

Stena Superfast is a ro-ro passenger ship that has a length of 203.9 meters and a capacity of loading 661 cars (Asklander, 2018). To find information about the design of the ventilation system onboard ventilation drawings, with drawing number 357-3101-0001-000 (Diagr. of Car Deck Ventilation upper Decks Deck 3-6, 2001), has been studied. Since no other documentation has been available, the design of the ventilation system presented here is only from studying the drawings.

On Superfast, see Figure 6, there are six decks which has ro-ro spaces. Deck 5 and 6 are one closed ro-ro space and has an opening in the aft. Deck 3 and 4 are one ro-ro space which is a closed ro-ro space. At deck 3 there is one ramp in the fore and one ramp in the aft from which loading, and unloading is done. When at sea, the ramps at deck 3 are closed. Deck 1 and 2 are separate ro-ro spaces and are both defined as closed ro-ro spaces.
On Superfast all air inlets and outlets have fire dampers and are fitted with grilles or steel nets inside the ship. They are also equipped with sufficient drainage. The fans can be operated remotely from cargo office at deck 3 and from the bridge at deck 10 and locally. If a fire is detected by a fire alarm the fans will be stopped, and dampers will be closed automatically by the fire alarm, and if a damper for some other reason is closed the corresponding fan will not start.

2.2.2.1 Loading

When loading the vessel from either the fore or the aft, the number of air changes and flow are different for each deck. In Table 3 the volume, air change per hour (ACPH) and flow for the different decks are presented.

<table>
<thead>
<tr>
<th>Deck</th>
<th>Volume (m³)</th>
<th>ACPH</th>
<th>Flow (m³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deck 5-7</td>
<td>14 700</td>
<td>21,6</td>
<td>88</td>
</tr>
<tr>
<td>Deck 3-4</td>
<td>20 500</td>
<td>20,0</td>
<td>114</td>
</tr>
<tr>
<td>Deck 2</td>
<td>2700</td>
<td>20,1</td>
<td>15,1</td>
</tr>
<tr>
<td>Deck 1</td>
<td>1650</td>
<td>21,8</td>
<td>10</td>
</tr>
</tbody>
</table>

Figure 7 below shows a screenshot from the ventilation drawing “Diagram of Car Deck Ventilation Upper Decks Deck 3-6, 2001,” showing the ventilation fans that are running when loading from the aft. From this picture it can be seen that one ventilation fan, that has its air inlet on deck 7, supplies deck 1 with air and one exhaust air and has its outlet to the atmosphere at deck 5. For deck 2 there are one supply air fan at the back of the deck which has its inlet at deck 7 and one exhaust fan in the fore of the deck which has its outlet on deck 5. Both of these decks have ventilation type that are most similar to the longitudinal type of ventilation configuration, except that on this vessel the exhaust air and supply air are in each end of the ship.

At deck 3 and 4 the aft is open during loading and in the fore there are four exhaust fans located at the sides and two exhaust fans located in the middle of the vessel at the centerline. These exhaust fans all have ducts leading up to deck 5 were their outlets are located. Since the aft is open during loading the ventilation system is not used in a way that is similar to one of the three types mentioned in section 2.2.1. Deck 5 and 6 have an opening in the aft and there are two exhaust fans running during loading. These fans are located at the sides in the fore and the ducts lead up to deck 7 where the outlets are. The
way the ventilation is running at deck 5 and deck 6 is most similar to the longitudinal type of ventilation configuration, except that in these vessels the exhaust air and supply air are in each end of the ship.

Figure 7. Screenshot of fans running when loading from the aft (Diagr. of Car Deck Ventilation upper Decks Deck 3-6 , 2001)

As can be seen in Figure 8 below, when loading from the fore it is the same arrangement with the exhaust and supply fans as when loading from the aft at deck 1 and 2. At deck 3 and 4 there are two exhaust fans located at the sides in the aft with ducts leading directly out to the atmosphere. In the middle of the vessel, at the centreline, there are two exhaust fans with ducts leading up to deck 5 where they have their outlets to the atmosphere. On deck 5 and 6 there are two exhaust fans located at the sides in the fore with ducts leading to deck 7 where the outlets are.

Figure 8. Screenshot of fans running when loading from the fore (Diagr. of Car Deck Ventilation upper Decks Deck 3-6 , 2001)

2.2.2.2 At sea

When the vessel is at sea the ventilation system is operated in a different way compared to when loading at harbour. In Table 4 the volume, ACPH and flow for each deck at sea is presented.
Table 4. Volume, air change per hour and flow at different decks when at sea (Diagr. of Car Deck Ventilation upper Decks Deck 3-6, 2001)

<table>
<thead>
<tr>
<th>Deck</th>
<th>Volume (m³)</th>
<th>ACPH</th>
<th>Flow (m³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deck 5-7</td>
<td>14 700</td>
<td>15,7</td>
<td>64</td>
</tr>
<tr>
<td>Deck 3-4</td>
<td>20 500</td>
<td>10,0</td>
<td>57</td>
</tr>
<tr>
<td>Deck 2</td>
<td>2700</td>
<td>13,3</td>
<td>10</td>
</tr>
<tr>
<td>Deck 1</td>
<td>1650</td>
<td>14,4</td>
<td>6,6</td>
</tr>
</tbody>
</table>

In Figure 9 it is shown that at sea the same ventilation fans are running at deck 1 and 2 as during loading. At deck 3 and 4 there are two exhaust fans located at the sides in the aft which exhausts air directly to the atmosphere. In the middle of the vessel at the centerline there are two fans that are working reversed at sea and supply air with the air intake at deck 3 and deck 4. The four fans situated in the fore of deck 4 are also reversible and supplies air when at sea, the air intakes are situated at deck 5. At deck 5 and 6 the fans are operated in the same way as when loading with two exhaust fans situated in the aft.

2.2.2.3 Comparison loading and at sea

When comparing how the ventilation system is used when at harbour and driving at sea one thing that can be seen is that at all ro-ro spaces, except deck 3 and 4, the same ventilation fans are used at harbour and at sea. The difference is that at harbour there are more air changes per hour then at sea for all decks. At deck 3 and 4 there are both supply and exhaust fans running at sea whilst at harbour loading or unloading there are only exhaust fans running. As mentioned in the beginning of this chapter, the Administration may require a higher number of air change during loading and unloading than at sea, which is the case for Stena Superfast. The reason for having a higher number of air changes is to be able to ventilate the polluted gases from the vehicles embarking or disembarking. When at sea the vehicles are standing still, and no engines are running and producing exhaust gases.
2.2.3 Stena Germanica

Stena Germanica is a ro-ro passenger ship that has a length of 240 meters and a capacity of loading 300 cars (Stena Line, 2018). To find information about the design of the ventilation system onboard ventilation drawings (Stena Line, unknown) (Novenco Hi-Pres, 1996) has been studied. Since no other documentation has been available, the design of the ventilation system presented here is only interpretations from the drawings.

On Stena Germanica there are seven decks which has ro-ro spaces, see Figure 10. One of them, deck 7, is partly a weather deck and partly an open deck. This deck will not be further investigated due to lack of mechanical ventilation in this space. Deck 5 and 6 are a closed ro-ro space with a permanent opening in the aft. Deck 3 and 4 are one closed ro-ro space with an opening in the aft where the loading and unloading is done. A ramp is situated in the aft at deck 3 which is for loading and unloading. When at sea, the ramp at deck 3 is closed and the opening at deck 3 and deck 4 is closed. Deck 1 and 2 are two separate closed ro-ro spaces without any openings.

![Figure 10. Sideview of Stena Germanica (Stena Line, unknown)](image)

2.2.3.1 Loading

When loading the vessel, the number of air changes and flow are different for each deck. In Table 5 the volume, air change per hour and flow for the different decks are presented.

Table 5. Volume, air change per hour and flow for different decks when loading (Novenco Hi-Pres, 1996)

<table>
<thead>
<tr>
<th>Deck</th>
<th>Volume (m³)</th>
<th>ACPH</th>
<th>Flow (m³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deck 5-6</td>
<td>10 950</td>
<td>30</td>
<td>91.5</td>
</tr>
<tr>
<td>Deck 3-4</td>
<td>21 750</td>
<td>30</td>
<td>197.8</td>
</tr>
<tr>
<td>Deck 1-2</td>
<td>6200</td>
<td>30</td>
<td>52</td>
</tr>
</tbody>
</table>

When loading and unloading there are four ventilation fans that supplies air to deck 1 and 2. Two of them are situated in the fore and the other two are situated in the middle of the vessel at the sides and are reversible. On deck 3 and 4 there are a total of eleven fans. Four of them are situated near the fore and supplies air. In the middle of the vessel on the sides, three exhaust fans are placed. Near the aft the remaining four fans are situated, which are all reversible, two on each side of the vessel. Out of these are the two nearest the aft stopped during loading and unloading and the other two supplies air. This ventilation configuration is the same as the longitudinal one mentioned in section 2.2.1. Deck 5 and 6 are closed ro-ro spaces. Near the fore there are four fans that supplies the decks with air and through the opening in the aft the air is naturally ventilated.
2.2.3.2 At sea

When at sea the ventilation system is operated in a different way than at harbour. In Table 6 the volume, air change per hour and flow for each deck at sea is presented.

Table 6. Volume, air change per hour and flow at different decks when at sea (Novenco Hi-Pres, 1996)

<table>
<thead>
<tr>
<th>Deck</th>
<th>Volume (m$^3$)</th>
<th>ACPH</th>
<th>Flow (m$^3$/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deck 5-6</td>
<td>10 950</td>
<td>20</td>
<td>61</td>
</tr>
<tr>
<td>Deck 3-4</td>
<td>21 750</td>
<td>10</td>
<td>60.6</td>
</tr>
<tr>
<td>Deck 1-2</td>
<td>6200</td>
<td>12.8</td>
<td>22</td>
</tr>
</tbody>
</table>

When at sea the two fans located in the fore of deck 1 and 2 are supplying air and the ones in the middle of the vessel are now reversed and exhaust air. On deck 3 and 4 of the fans are stopped and three supplies air. The three fans in the middle of the vessel are stopped when at sea and the four fans near the aft are reversed and exhausts air. On deck 5 and 6 the four fans situated in the fore supplies air and the air is exhausted through natural ventilation through the opening in the aft.

2.2.3.3 Comparison loading and at sea

When comparing how the ventilation is used during loading at harbour and going at sea the air changes per hour at sea are less then at harbour. As mention before the Administration can require that more air changes are needed when loading the ship, which is the case for Stena Germanica. On deck 5 and 6, which has an open end, there is only supply air at both sea and harbour. On the other decks there are in general more exhaust fans running at sea then at harbour loading. The fans that are reversed to exhaust fans at sea are situated in the middle of the vessel at deck 1 and deck 2 and at deck 3 and deck 4 the reversed fans are situated in the aft.

2.2.4 Stena Scandinavica

Stena Scandinavica is a ro-ro passenger ship that has a length of 240 meters and a capacity of loading 300 cars (Stena Line, 2018). A study visit to the ship was conducted the 11 of July 2018 in Gothenburg to see the ship ventilation system in reality. With on the visit was Elin Ranudd from RISE and Senior Master Jan Sjöström from Stena. General arrangement drawings and ventilation drawings of the boat was received. The information about the ventilation system presented here comes from studying the received drawings and from the onboard study visit.

On Stena Scandinavica there are seven decks which has ro-ro spaces, see Figure 11. Deck 7 is a deck that is partly a weather deck and partly an open deck and it has no mechanical ventilation. Deck 5 and 6 are closed ro-ro spaces with an opening in the aft. At deck 3 and 4 the loading and unloading from land is done. Here is a stern ramp which is open during loading and unloading and closed at sea which makes these closed ro-ro spaces. Deck 1 and 2 are both closed ro-ro spaces but they are not separated from the other decks because a fixed ramp leads from deck 1 up to deck 3 without any possibility to separate the decks from each other.
Stena Scandinavica have an air quality control system installed which is unusual in Sweden, according to the Senior Master onboard. The system enables constant measure of the concentration of carbon monoxide (CO), nitrogen oxide (NO₂) and the Lower Explosion Limit (LEL). According to SOLAS II-2/20.3.1.2.4 “For all ships, where an air quality control system is provided based on the guidelines developed by the Organization, the ventilation system may be operated at a decreased number of air changes and/or a decreased amount of ventilation.”

Since the ship is equipped with an air quality control system there is no need for the ventilation to be running when at sea.

According to MSC.1/Circ.1515 (IMO, 2015):

“Ventilators should be controlled by the air quality control system in order to provide the appropriate number of air changes to restore the normal values of CO, NO₂ and LEL as soon as those levels are exceeded during 5 minutes. The ventilation regime should be continuously regulated in relation to the increase of gas concentration and to restore normal levels of CO or NO₂ as soon as possible.”

And

“Alarm should be given when the level exceeds 40 mg/m³ CO or 4 mg/m³ NO₂ long-term exposure according to the standard ISO 9785:2002 or when a relative concentration of the atmosphere to the LEL is higher than 10%.”

If the concentration rises over the levels mentioned above the speed of the fans increases and then reduces when the concentration is below the value lowered again.

On all the closed decks the ventilation fans are situated along the bulkheads and they supply air to the vessel during loading and unloading. This design of ventilation is similar to transverse ventilation mention in section 2.2.1. The difference is that onboard Stena Scandinavica they only have supply air, but some of the fans are reversible and can exhaust air if needed.

In case of fire the ventilation system can be closed remotely from three different control stations. These are situated at deck 2, deck 3 and at the bridge. When the fans are stopped, the fire dampers close automatically. The dampers then must be opened again before the ventilation fans can be started.

2.2.4.1 Interview with Senior Master

During the study visit 11th of July 2018 an interview was done with the Senior Master Jan Sjöström (Sjöström, 2018). One question asked was about maintenance and practising
with the ventilation system, and according to Jan they have routines onboard where maintenance of the ventilation system is included. Once a week they also have a fire drill where they shut down the ventilation system and close the fire dampers.

If the fire alarm detects a fire onboard the signal goes to the bridge first, as a silent alarm. They then send a person down to the place of detection and if there is a fire, they shut down the ventilation system and start the fire extinguishing system immediately. The rest of the crew are then informed and start to act according to the muster plan.

A concern the Senior Master had was if a fire would occur at deck 7 which is partly open and partly a weather deck. At the moment they do not have any detection system here, which according to the regulations is not required on weather decks, and the free access of oxygen can make a fire grow fast before it is detected. If the wind is hard the fire can spread rapidly, and the get out of control. The Senior Masters concern is strengthened by the reviewed accident investigation analysis made in section 2.3 in this report. The analysis shows that in the accidents where the fire occurred on an open deck the fire and smoke spread to several decks and got out of control in three out of four accidents. This indicates that it is hard to manage a fire if it starts at an open deck or a weather deck.

### 2.2.5 Discussion of fire scenarios with different type of ventilation design

If a fire occurs inside a ro-ro space the placement of the fire origin can have a great impact on the fire and smoke spread. If for example a fire occurs in a ro-ro space with a longitudinal type of ventilation system and the fire is placed near the exhaust fan in the middle, the smoke might not be so dense in that particular ro-ro spaces since it will be extracted, if the exhaust fans are still running. On the other hand, the smoke might spread to other decks, depending on where the ducts lead. The fire may not spread to the surrounding cars because of the airflow leading towards the exhaust fans. What might happen is that the fire spreads through the ventilation duct to another deck, if it does not lead directly out to the atmosphere.

If a fire occurs in a ro-ro space with a transverse type of ventilation the worst placement of the fire would probably be near the side with the supply fans. The air flow will be strong near the supply fans and this can make the spread of the fire to other vehicles faster since there is a “wind” that blows the fire plume towards other vehicles. The smoke will also spread fast in that particular ro-ro space where the fire started. If the fire is placed near the side with exhaust fans it might not spread as easily to other cars since the fire plume is directed towards the fans that will extract the smoke. The smoke will probably be extracted through the exhaust fans and depending on where it leads it will either go out to the atmosphere or spread to another deck.

In a ro-ro space that has a long-transverse type of ventilation system it is harder to imagine where the worst placement of a fire is. Throughout the whole space it will probably be a good air flow but near the supply fans the flow will be highest. If a fire is placed at the centreline close to anyone of the supply fans the fire can spread in all directions and the exhaust fans will “draw” the fire plume out towards the sides and a fire can spread fast.
Another factor that can affect the fire and smoke spread is the number of air changes in the ro-ro space. During loading and unloading the number of air changes are more than when going at sea. This also makes the air flow higher during loading and unloading. If a fire would occur during this time the fire and the smoke will probably spread faster at harbour, then at sea due to the higher air flow. Many ships have a ramp for loading and unloading which leaving an opening in either the fore or the aft when at harbour. This gives the fire free access of oxygen at the spaces where the opening is situated. At sea this ramp is closed and there is no free access of oxygen and the wind cannot affect the fire in the closed spaces.

The ACPH will also result in a different velocity in different spaces and even if it is a requirement that the air should be distributed all over the space it was earlier mentioned by the project engineer (Norén, 2019) that it can be spots in a space where the fans are not able to meet the correct air change.

### 2.3 Accident investigation analysis

The purpose of this accident investigation analysis was to investigate how the ventilation system and natural ventilation (openings) has affected the fire development in historic accidents and how the ventilation system is used during a fire on board. It will also be investigated how the fire extinguishing system, the manual intervention and the detection system are affected by what type of ro-ro space is involved in the fire.

A total of 14 accident reports has been investigated. The accidents occurred between 2003 and 2016 and all include fire on a ro-ro space onboard a ro-ro passenger ship. In 10 out of the 14 accident investigation reports studied, the fire started in a closed ro-ro space. At the end of each report, conclusions and recommendations are made by the investigator. The ones of most interest for the analysed parts in this study are presented in the end of this chapter, see section 2.3.5. Where the time was noted in the reviewed accident report the fire was detected between 19:09 in the evening and 07:40 in the morning.

In Table 7 the name of the ship, year of accident, reason why the fire started, what type of ro-ro space the fire started in and what type of accident investigation report that was reviewed is presented. All the reviewed reports are open to the public and can be downloaded from internet.

<table>
<thead>
<tr>
<th>Ship name</th>
<th>Year of accident</th>
<th>Reason why fire started</th>
<th>Type of ro-ro space where fire started</th>
<th>Type of report reviewed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joseph and Clara Smallwood</td>
<td>2003</td>
<td>Unclear, believed to be in one truck/car</td>
<td>Closed deck</td>
<td>Marine accident report</td>
</tr>
<tr>
<td>Amorella</td>
<td>2005</td>
<td>Failure in an electrical device in car engine</td>
<td>Closed deck</td>
<td>Marine accident report</td>
</tr>
<tr>
<td>Al Salam Boccaccio</td>
<td>2006</td>
<td>N/A</td>
<td>Closed deck</td>
<td>Marine accident report</td>
</tr>
<tr>
<td>Ship name</td>
<td>Year of accident</td>
<td>Reason why fire started</td>
<td>Type of ro-ro space where fire started</td>
<td>Type of report reviewed</td>
</tr>
<tr>
<td>---------------------------</td>
<td>------------------</td>
<td>--------------------------------------------------------------------------------------</td>
<td>---------------------------------------</td>
<td>-----------------------------------</td>
</tr>
<tr>
<td>Und Adriyatik</td>
<td>2008</td>
<td>N/A</td>
<td>Open deck</td>
<td>Marine accident report</td>
</tr>
<tr>
<td>Commodore Clipper</td>
<td>2010</td>
<td>Cable plugs incorrectly assembled, wire stripped</td>
<td>Closed deck</td>
<td>Marine accident report</td>
</tr>
<tr>
<td>Pearl of Scandinavia</td>
<td>2010</td>
<td>Electrical car being charged</td>
<td>Closed deck</td>
<td>Marine accident report</td>
</tr>
<tr>
<td>Mecklenburg Vorpommern</td>
<td>2010</td>
<td>Likely due to a technical defect in a car battery. The car was stowed on the load space of a trailer</td>
<td>Closed deck</td>
<td>Marine accident report</td>
</tr>
<tr>
<td>Lisco Gloria</td>
<td>2010</td>
<td>Power supply to trailers</td>
<td>Weather/open deck</td>
<td>Marine accident report</td>
</tr>
<tr>
<td>Kriti II</td>
<td>2012</td>
<td>Potentially short circuit and electric arc in a refrigerator truck.</td>
<td>Closed deck</td>
<td>Safety recommendation</td>
</tr>
<tr>
<td>Victoria Seaways</td>
<td>2013</td>
<td>Short circuit in the electrical system in one of the second-hand cars caused sparks that fell on a dirty surface and fire started</td>
<td>Closed deck</td>
<td>Marine accident report</td>
</tr>
<tr>
<td>Stena URD</td>
<td>2014</td>
<td>Fluorescent light fixture on the main car deck</td>
<td>Closed deck</td>
<td>Marine accident report</td>
</tr>
<tr>
<td>Norman Atlantic</td>
<td>2014</td>
<td>Reefer</td>
<td>Open deck</td>
<td>LMIU</td>
</tr>
<tr>
<td>Sorrento</td>
<td>2015</td>
<td>N/A</td>
<td>Open deck</td>
<td>LMIU</td>
</tr>
<tr>
<td>Stena Spirit</td>
<td>2017</td>
<td>Technical defect in a refrigerator unit on a truck</td>
<td>Closed deck</td>
<td>Marine accident report</td>
</tr>
</tbody>
</table>

In the Bachelor thesis carried out in the project by Andreas Lilja and Martin Lindgren (Lilja & Lindgren, 2019) a more detailed fire and ventilation analysis of some of the accidents in Table 7 was done. The work by (Lilja & Lindgren, 2019) is given in Table 8.
Table 8. Summary of some relevant fire and ventilation information from previous fires on ro-ro ships (Lilja & Lindgren, 2019).

<table>
<thead>
<tr>
<th>Name of the ship</th>
<th>Ventilation</th>
<th>Spread of fire</th>
<th>Size of damage</th>
<th>Important observations</th>
<th>Casualties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joseph and Clara Smallwood</td>
<td>Mechanical: turned off immediately. Natural: Fire doors not closed and stern door opened after some time.</td>
<td>None, but smoke spread to deck 5.</td>
<td>40 m² deck plating and insulation, one truck completely destroyed, smoke and water damage.</td>
<td>Dense black smoke and close space of vehicles. People trapped on the deck.</td>
<td>Minor injuries: 4 persons.</td>
</tr>
<tr>
<td>Und Adriyatik</td>
<td>An open ro-ro space type according to DNV GL (2016). Smoke spread to engine room through ventilation.</td>
<td>Over several decks. Smoke also spread to engine room via ventilation.</td>
<td>Total loss.</td>
<td>Amount of oxygen described as enough for the fire to grow freely.</td>
<td>Master and Chief Officer broke their ankles and several persons had various degrees of burns.</td>
</tr>
<tr>
<td>Lisco Gloria</td>
<td>Natural: Weather deck and garage area with five large windows on each side (probably open ro-ro space).</td>
<td>The fire spread and grew rapidly.</td>
<td>Total loss.</td>
<td>Drencher system failure. Difficulties to reach the fire due to heavy smoke. Close space between vehicles enhanced the spread.</td>
<td>Minor injuries: 28 persons.</td>
</tr>
<tr>
<td>Pearl of Scandinavia</td>
<td>Mechanical: None during whole voyage. Natural: Three doors opened ajar.</td>
<td>Fire spread over sections on the same deck. Smoke spread to accommodation s.</td>
<td>Two cars and three trailers. Smoke damage.</td>
<td>Gap over flooding control door enabling spread over sections.</td>
<td>No persons injured.</td>
</tr>
<tr>
<td>Mecklenburg - Vorpommern</td>
<td>Mechanical: Turned on. Natural: Fore side door opened when mechanical</td>
<td>Spread to another trailer. Heavy smoke spread.</td>
<td>One vehicle destroyed, two trailers and</td>
<td>The small distance between vehicles.</td>
<td>No persons injured.</td>
</tr>
<tr>
<td>Name of the ship</td>
<td>Ventilation</td>
<td>Spread of fire</td>
<td>Size of damage</td>
<td>Important observations</td>
<td>Casualties</td>
</tr>
<tr>
<td>------------------</td>
<td>-------------</td>
<td>----------------</td>
<td>----------------</td>
<td>------------------------</td>
<td>------------</td>
</tr>
<tr>
<td>Norman Atlantic</td>
<td>Described as open ro-ro space type.</td>
<td>Deck 4 and deck 3 was heavily affected, but also deck 5, 6, 7.</td>
<td>Total loss.</td>
<td>Heavy wind affecting the fire development. Among other things, rescue boats on starboard side unusable due to fire. Drencher system activated at wrong deck.</td>
<td>At least 11 persons died, 12 persons was missing and 31 were injured.</td>
</tr>
<tr>
<td>Sorrento</td>
<td>Described as open ro-ro space type.</td>
<td>Fire spread, extinguished within days.</td>
<td>Total loss.</td>
<td>Drencher system did not extinguish fire.</td>
<td>Minor injuries: 14 persons.</td>
</tr>
<tr>
<td>Stena Spirit</td>
<td>Mechanical: Alternately use of ventilation system to evacuate smoke. Smoke spreading through open ventilation outlets.</td>
<td>Fire spread from refrigerator to the truck.</td>
<td>Two trucks damaged. On ship: Among other things, hydraulic pipelines as well as part of the floor above the fire on deck 5 were damaged.</td>
<td>People located on deck above during the fire. Close space between vehicles. Passengers forced to evacuate to open deck due to very thick smoke.</td>
<td>No persons injured.</td>
</tr>
</tbody>
</table>
2.3.1 Mechanical ventilation

According to SOLAS II-2/20.3.1.4.1 “Arrangements shall be provided to permit a rapid shutdown and effective closure of ventilation system from outside of the space in case of fire, taking into account the weather and sea conditions." The most common way to operate the ventilation system onboard appeared to be to shut down the ventilation when the fire was detected. This was done manually by the crew in the accident investigation reports read.

2.3.1.1 Closed ro-ro spaces

Out of the 14 investigation reports read, 10 of them had the fire started in a closed ro-ro space. In four of them the smoke spread to other decks and in one both fire and smoke spread to several decks. In three of the accidents were smoke spread, the ventilation system was turned off quickly after the fire was detected. In the fourth one the ventilation was turned off 20 minutes after the fire was detected.

There were three accidents where the fire and smoke did not spread at all and for these three the ventilation system was turned off quickly after the fire was detected. In two of them they had exhaust fans, usually used to extract air during loading and unloading, which they turned on after 10 minutes to evacuate the smoke from the fire.

On the Stena Spirit there were no spread of the fire, but smoke spread to another car-deck and to the reception area. The ventilation system was running for 20 minutes after the fire was detected which may have been a contributing factor for the smoke spread.

Another vessel, Urd, was equipped with a ventilation system on the main deck and the lower car deck, designed for evacuating exhaust gases during loading and unloading of ro-ro cargo. The ventilation system was intended for use only when the stern ramp was open to allow a free flow of air from the outside atmosphere. During the fire the system was used for evacuation of smoke on the main car deck with the stern ramp closed. To prevent creation of a vacuum effect created by the running fans, they were run in alternating supply and exhaust directions.

2.3.1.2 Open ro-ro spaces

In SOLAS (IMO, 1974) there is only power ventilation requirements for closed ro-ro spaces, special category spaces and cargo ships. This means that there is no requirement to have mechanical ventilation in an open ro-ro space or on weather decks. The accident reports studied shows that on vessels where the fire started in an open ro-ro space the fire spread to several decks in three out of four accidents, the fourth did not have any information about the fire spread.

One example of fire spread is on the Lisco Gloria where the fire started at a deck which was a semi-deck, partly open and partly weather deck, the fire spread both vertical and horizontal on the vessel. Another example of fire spread in an open ro-ro space is on the Norman Atlantic were the fire and smoke spread over several decks. According to the accident investigation report the wind was hard, and it influenced the course of the fire plume and contributed to the fire and smoke spread.
2.3.2 Fire extinguishing system

According to SOLAS II-2/20.6.1.1 “Vehicle spaces and ro-ro spaces, which are not special category spaces and are capable of being sealed from a location outside of the cargo spaces, shall be fitted with one of the following fixed fire-extinguishing systems:

.1 a fixed gas fire-extinguishing system complying with the provisions of the Fire Safety Systems Code;

.2 a fixed high-expansion foam fire-extinguishing system complying with the provisions of the Fire Safety Systems Code; or

.3 a fixed water-based firefighting system for ro-ro spaces and special category spaces complying with the provisions of the Fire Safety Systems Code and paragraphs 6.1.2.1 to 6.1.2.4.”

According to SOLAS II-2/20.6.1.2 “Vehicle spaces and ro-ro spaces not capable of being sealed and special category spaces shall be fitted with a fixed water-based fire-fighting system for ro-ro spaces and special category spaces complying with the provisions of the Fire Safety Systems Code which shall protect all parts of any deck and vehicle platform in such spaces. Such a water-based fire-fighting system shall have:

.1 a pressure gauge on the valve manifold;

.2 clear marking on each manifold valve indicating the spaces served;

.3 instructions for maintenance and operation located in the valve room; and

.4 a sufficient number of drainage valves to ensure complete drainage of the system.”

This means that all ro-ro spaces in the investigated accident reports need to have a fixed fire-extinguishing system. The extinguishing systems used in the ro-ro spaces of the investigated reports are so called drencher systems. A drencher system is a fixed water system that can be compared with a deluge system. It needs to be manually activated and to prevent the pipes from freezing they are dry; water runs through the pipes upon activation.

2.3.2.1 Closed ro-ro spaces

In 9 out of the 10 accidents where the fire started in a ro-ro space that was closed, the fire could be suppressed or extinguished by the drencher system. These fires did not spread and did not get out of control. For one of the vessels, Al Salam Boccaccio, the drencher system and the fire fighters was not able to suppress the fire and it spread to several decks. Due to smoke the crew could not identify the origin of the fire and the drencher system was activated in several sections. Both manual firefighting and the drencher system was used during a long time and a lot of water was used. Since there was also a problem with the drainage of the water the ship got problems with the stability and eventually it sank. The accident investigation report states:

“According to the interviews, it was clear that the scuppers were blocked due to garbage generated during the fire-fighting operation and the movement of water containing these residuals.”
2.3.2.2 Open ro-ro spaces

In four of the accident reports investigated the fire started in an open ro-ro space. For all of them the fire could not be suppressed or extinguished by the drencher system and the fire fighters onboard. For one of the vessels, Und Adriyatik, the ship had to be evacuated and it was burning for several days. The fire was eventually put out by fire fighting planes.

2.3.3 Manual intervention

According to SOLAS II-2/7.8.1 “For ships carrying more than 36 passengers an efficient patrol system shall be maintained so that an outbreak of fire may be promptly detected. Each member of the fire patrol shall be trained to be familiar with the arrangements of the ship as well as the location and operation of any equipment he may be called upon to use.”

All vessels in the accident investigation reports read had the capacity of carrying more than 36 passengers and therefore needed a firefighting team onboard. In several cases, in both closed and open ro-ro spaces, the firefighting team has experienced difficulties approaching the fire due to densely stowed cars and trailers.

2.3.3.1 Closed ro-ro spaces

When the fire started in closed ro-ro spaces the fire could be extinguished or suppressed by manual fire fighting and the drencher system in all accidents except one (Al Salam Boccaccio). Densely stowed cars, which made it hard for the fire fighters to approach the fire, was mentioned as a problem in seven out of the ten accident reports with closed ro-ro spaces.

One example is the accident on the Kriti II were the stowage of the trucks did not allow direct access and approach of the fire. It was first when unloading the vehicles from the smoke-filled space that the firefighting team was able to approach the fire and was able to extinguish it.

Another accident where the stowage of vehicles turned out to be a problem was at the Urd. It was necessary to load as many vehicles as possible and they were therefore stowed close together. This made it hard for the firefighters to obtain a good overview of the situation. It was also difficult for the firefighters to effectively use the fire hose from their position, just as the stowage of the vehicles made it difficult to approach the fire effectively. The accident report states:

“The chief officer had to climb on to the trailer situated next to the one on fire to undertake the final extinction.”

According to the investigation report there was no vehicle stowage plan onboard Urd and therefore the vehicles had been stowed randomly during the loading. This is a common loading procedure on board ro-ro passenger ships according to the report.

2.3.3.2 Open ro-ro spaces

In all accidents where the fire started in an open ro-ro space the fire could not be suppressed or extinguished by the firefighting team. Three out of four accident reports with open ro-ro spaces claims that densely stowed cars were a problem. The fire fighters
had a hard time to reach the seat of the fire which made it possible for the fire to grow and spread.

2.3.4 Fire detection system

The accident reports read in this literature study do not contain a lot of information about the detection of the fires. What has emerged is that in some incidents the fire alarm has detected the fire early and action could be taken in an early stage. In other cases, the fire alarm has detected the fire up to 20 minutes after the fire started, hence the action from crew was delayed. The type of fire detection system in the investigated vessels is either heat detectors or combined heat and smoke detectors. According to SOLAS II-2/7 a fixed fire detection and fire alarm system shall be provided on board and it shall comply with the FSS code (IMO, 2007) but it is not specified what detector types that is required in ro-ro spaces.

2.3.4.1 Closed ro-ro spaces

In 9 out of 10 accidents where the fire occurred in closed ro-ro spaces the fire was detected fast, in the tenth one, *Al Salam Boccaccio*, there was a delay in the detection which may have contributed to the growth of the fire.

2.3.4.2 Open ro-ro spaces

In two out of the four accidents where the fire occurred in an open ro-ro space there were no problems with the detection of the fire. In one accident report there was no information about the detection. At one of the vessels, *Norman Atlantic*, the fire detection was delayed due to wind. The accident report states:

“In this specific case, the weather conditions, in particular wind, as well as the speed of the ship, were considerable and cannot be ignored. Such parameters have certainly played a relevant role both for the smoke detectors and in the first phases of the fire and in its propagation.”

2.3.5 Recommendations and conclusions

In the end of the analysed accident reports there are recommendations given and conclusions made by the investigator. The ones which are of most interest for the different factors investigated in this analysis (ventilation, extinguishing system, manual intervention and detection) are presented in the following sections.

2.3.5.1 Ventilation closed ro-ro spaces

In three of the accidents where the fire started in a closed ro-ro space the smoke spread to other decks, that was not ro-ro spaces, even though the ventilation was shut down quickly after the fire was detected. The reason for this is hard to tell just by reading the accident reports due to the lack of information about the design of the ventilation system in the reports. According to SOLAS ro-ro spaces should have separate ventilation systems so the smoke which spread to decks that was not ro-ro spaces might have spread through unsealed penetrations, open doors or similar leakages.

In one of the accidents they used the ventilation system to exhaust the smoke from the space. This vessel did not get any smoke spread and the visibility in the fire room got
better. The ventilation system is not generally designed to evacuate hot gases with, and it could be interesting to further investigate if the ventilation system can be used for this purpose on existing ships.

2.3.5.2  Ventilation open ro-ro spaces

Ro-ro spaces which are open can be problematic when it comes to the fire and smoke spread. In all the accident with open ro-ro spaces, that had information about the fire spread, the fire and smoke spread to several decks. The free access to oxygen and the blowing wind makes it difficult to control and suppress a fire. One of the recommendations from one of the investigation reports was that “open ro-ro spaces on passenger ships (new construction) should not be permitted”.

2.3.5.3  Extinguishing system closed ro-ro spaces

The fire could be suppressed or extinguished in all accidents except one in the closed ro-ro spaces. In the accident with *Al Salam Boccaccio* there were a series of events that went wrong which made the ship sink. One of the recommendations made in the accident investigation report is “It is of great importance to conduct a review, as a matter of urgency, of the type and performance of fixed fire extinguishing systems, in particular, the water type systems installed in the car-decks of Ro-Ro passenger ships, in order to avoid the effects caused by the excessive use of water during a firefighting operation.”

In general, a fire seems easier to control if it is in a closed ro-ro space than in an open if the extinguishing system is used the correct way. This is conclusion made from reading the accident reports.

2.3.5.4  Extinguishing system open ro-ro spaces

In the accidents were the fire started in an open ro-ro space the fire could not be suppressed or extinguished by the drencher system. The free access of oxygen and the wind make the fire grow fast and can get out of control fast.

2.3.5.5  Manual intervention closed ro-ro spaces

Densely stowed cars are an issue which hinders the firefighting team from approaching the fire. In several of the fires the firefighters were not able to reach the fire and they got to crawl under and climb over cars and trailers. One of the recommendations given was “A standardized distance between cars while stowed in the car-decks of RORO passenger ships should be established in order to allow easy movement of crew members within the car-deck during emergency situations.” Today there are not this type of regulations and the crew can stow the cars and trailers however they want to.

2.3.5.6  Manual intervention open ro-ro spaces

Since the fires at the open ro-ro spaces grew fast and got out of control the firefighting team was not able to suppress it or extinguish it. As for the accidents that happened in closed ro-ro spaces, densely stowed cars were a problem that also emerged in the open ro-ro spaces. This seems to be an issue on most of the ships and need to be further addressed.
In TSFS 2009:98 (Transportstyrelsen, 2009:98) appendix 1 regulation 13.5.1 the Swedish Authority has clarified the distances on open ro-ro spaces and special category spaces on passenger ship, regarding possibility for evacuation. The paragraph states that in these spaces there shall be special walkways to the escape routes with a width of at least 600 mm. The vehicles must be parked in such a way that the walkways are always kept free. Equivalent safety level in ro-ro spaces is achieved by not blocking the doors of the vehicle. In order to avoid blocking, there must be a free passage with a width of at least 600 mm on one side of the vehicle. Approximately every 24 m, there should be a free passage with a width of at least 600 mm to reach the emergency exits from all vehicles. The exits from the ro-ro space shall be located in such a way that there is at least one exit on each side of the deck in direct connection to each main vertical zone of the above deck.

This requirement, valid for Swedish flagged ships, is interpreted as there shall always be a free pathway of 600 mm width through the stowed vehicles. How this is used in practise is hard to tell. Almost the same writing is found in SOLAS II-2 regulation 13.5 Means of escape on passenger ships from special category and open ro-ro spaces to which any passengers carried can have access where the following requirements apply:

“In special category and open ro-ro spaces to which any passengers carried can have access, the number and locations of the means of escape both below and above the bulkhead deck shall be to the satisfaction of the Administration and, in general, the safety of access to the embarkation deck shall be at least equivalent to that provided for under paragraphs 3.2.1.1, 3.2.2, 3.2.4.1 and 3.2.4.2. Such spaces shall be provided with designated walkways to the means of escape with a breadth of at least 600 mm. The parking arrangements for the vehicles shall maintain the walkways clear at all times.”

The text in SOLAS does not require a free width every 24 m which can affect the possibility to reach between the cars from one side of the deck to another.

2.3.5.7 Detection closed ro-ro spaces

Information about the detection of the fire couldn’t be found in any larger extent in the investigation reports. The one issue that occurred was that in one case the fire was detected very late. Recommendations given for getting a quicker detection in the investigation report of Al Salam Boccaccio was “The requirements established in SOLAS 74, Chapter II-2, as well as the FSS Code, with regard to fire detection systems within the car-decks of RORO passenger ships, should be reviewed, in order to include smoke detectors. Despite the fact that heat detectors are devices used for fire detection, it has been noted that, in this case, a smoke detector may have been able to detect the fire at an earlier stage than a heat detector, especially when dealing with car-decks.” The reason that the smoke detector might be better is because of the large volumes inside the ro-ro space. It takes time to heat up the surrounding air and therefore a smoke detector is better.

2.3.5.8 Detection open ro-ro spaces

At the Norman Atlantic the detection was delayed due to the wind which can occur at all open ro-ro spaces. This delay gives the fire time to grow and when the fire fighters are alerted of the fire it might be too late to suppress or extinguish the fire.
3 Workshop – Hazard identification

On May 23, 2018 a workshop for the RO5 research project was performed. The workshop was a so-called hazard identification (HazId) workshop where the hazards for fires in ro-ro spaces and for managing fires in ro-ro spaces were discussed. Participants from Stena, Destination Gotland, Transportstyrelsen (Swedish Transport Agency’s), MacGregor, Johnson Control International and researchers from RISE were represented during the day. The A-G scenarios shown in Figure 12 were studied during the workshop with the aim of identifying hazards and safety measures taking into account the different ventilation conditions of each scenario. Results from the workshop are presented in a table in Appendix A.

Figure 12. The scenarios discussed during the hazard identification workshop
3.1 Risk control measures

From the resulting table, see Appendix A, that was filled in during the HazId workshop all the potential safety measures was listed in a separate table as risk control measures (RCMs). The RCMs was later categorized into where in the fire scenario the RCM affect. Prevention, if it was a preventive safety measure, detection if it was in the early stage to detect a fire and fire development if it was the fire development. Since this project focus on fire development only the RCMs that was in the category fire development was further studied.

The chosen RCMs was then categorized into three categories depending on what the RCM addresses; a system, the crew or the construction. Crew if the crew is involved, for example safety gear or instructions. System if it involved a system, for example system for fire ventilation. Construction if it was something that should be built in or is part of construction of the ship. More examples of RCMs are air lock to other spaces, better location of dampers on the outside of the ship, installation of reversible fans, subdivision of the ro-ro space, water monitors with remote control and better design of the ventilation system. The full table can, as mentioned before, be seen in Appendix A.

The RCMs was also marked with which type of ro-ro space it was intended for. Open, closed or weather deck. Some of them was covering all types and some only one of them. Finally, the RCMs was sorted to be study further with computer simulation (Lilja & Lindgren, 2019), test or with more literature research. In the Test and Simulation report of RO5 (Olofsson, o.a., 2019) the RCMs that are further studied described and evaluated.
4 Two zone simulations

In the first half of the project two zone modelling was used to get a wider understanding of the ventilation onboard and the fire behaviour with different constellations of fans and openings. This modelling was mainly done by two students from the Luleå University of Technology writing their Bachelor thesis at RISE. The students performed both comparison simulations with previous fire tests and parametric study of different constellations of natural and mechanical ventilation. The full result of the student work can be seen in “Influence of ventilation on ro-ro space fire development - A study using two-zone fire models in order to explore tendencies of how different ventilation parameters affects the fire development in a ro-ro space (Lilja & Lindgren, 2019). A summary of the report with results and conclusions are made in this chapter.

The purpose of the two zone modelling study is to “increase the knowledge of how the natural and mechanical ventilation, with different parameters, affects the fire development within a ro-ro space” and to “identify ventilation related problems in previous fire incidents within ro-ro spaces”. The students had also the long-term goal to “reduce the consequences, the severity and the number of fires within ro-ro spaces through better understanding of the effects of ventilation on fire development”. (Lilja & Lindgren, 2019).

Besides the literature study with analysing fire accident reports, which is mentioned in Table 8, three steps were conducted for this study:

- Comparison of simulations and model scale fires tests (Model 1:8)
- Upscaling of simulation model (Model 1:1)
- Parameter study using two-zones fire model simulation (Model 1:1)

Two models were used and compared, the first one is called Model 1:8 and the second one is called Model 1:1, they are further presented in Table 9 below.

<table>
<thead>
<tr>
<th>Model</th>
<th>Explanation</th>
<th>Length x width x height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1:8</td>
<td>Model used by Larsson et al. (Larsson, Ingason, &amp; Arvidson, 2002)</td>
<td>11.425 x 2.786 x 0.625</td>
</tr>
<tr>
<td>Model 1:1</td>
<td>Upscaled model of Larsson et al. (Larsson, Ingason, &amp; Arvidson, 2002)</td>
<td>91.4 x 22.3 x 5</td>
</tr>
</tbody>
</table>

4.1 Questions to be answered

The students wrote down questions and worked to find answers for them with a lot of simulation work. For the part with natural ventilation, these are the questions: In the aspect of fire development;

1. what impact does the following parameters have?
   a. Quantity of openings
   b. Position of openings
   c. Size of openings
d. Sill height of openings
   e. Geometry of openings
2. is any kind of opening preferable considering the parameters in 1)?
3. is the limit defined by SOLAS realistic when determining if a ro-ro space is closed or open?

For the part with mechanical ventilation, these are the questions: In the aspect of fire development;

4. what impact does the following parameters of mechanical ventilation have?
   a. Quantity of fans
   b. Position of fans
   c. Capacity of fans, air changes per hour (ACPH)
5. is any setup preferable considering the parameters in 4.?
6. can the mechanical ventilation remain on without any significant impact on the fire or should it be shut off in the event of fire?

### 4.2 Method

The first step of the two zone modelling is comparison between simulations and model scale fire tests. This was done in order to determine the reliability and uncertainties in two different two-zones model software: B-RISK and CFAST and select the one that will be used for the rest of the study. Four tests were compared in terms of smoke layer height, temperature and heat release rate. It appeared that CFAST showed similar results as experimental tests on three of four tests, CFAST was chosen for further simulations in the 1:1 model parameter study.

The second step is upscaling the model from Model 1:8 to Model 1:1 and use it in simulations in CFAST. The scaling laws used all along the RO5 study are based on the Froude modelling as done in previous study by (Larsson, Ingason, & Arvidson, 2002) and is further described in student report (Lilja & Lindgren, 2019) and in RO5 test report (Olofsson, o.a., 2019). The design fire used is a design fire developed based on a test of a free burning wood crib done by (Larsson, Ingason, & Arvidson, 2002). The heat release rate result from that test was upscaled and used as input fire in the parameter study using Model 1:1. This upscaled fire is shown on Figure 13.

![Heat release rate - Upscaled Test 19 - Design fire](image_url)

**Figure 13.** Upscaled heat release curve from Larsson et al. (Larsson, Ingason, & Arvidson, 2002).
The third step is a parameter study of fires in ro-ro space, with CFAST and Model 1:1. As explained, two cases were studied: naturally ventilated enclosure and mechanically ventilated enclosure. The studied parameters are shown in Figure 14 and Figure 15.

**Figure 14.** Overview of performed simulations regarding naturally ventilated enclosure.

**Figure 15.** Overview of performed simulations regarding mechanically ventilated enclosure.
4.3 Results from two zone simulations

The comparison using CFAST between simulations at scale 1:1 and 1:8 showed similar behavior of the heat release rate in case of a particular test, even if a difference should be noted when a window is open during the test, implying a higher heat release rate in case of the model 1:1.

4.3.1 Natural ventilation

Regarding the quantity of openings, CFAST does not take into account the number of openings, when the total area of openings, sill and soffit height was remained the same.

Regarding the opening size, the percentage used here represents the total area of openings divided by the total area of the hull sides, as also mentioned in the comment to definition of open ro-ro space in Table 1. One of the most important result of this part is that the fire was found fuel-controlled with an opening of at least 4%.

The results of simulations for the sill height as parameter showed that a lower sill results in a slightly lower heat release rate.

The last parameter is the geometry of the openings. Two sub parameters are involved in this step; openings are situated at roof level and situated at floor level. Regarding the case where the openings are situated at roof level, simulations showed tendencies that a more oblong opening resulted in lower heat release rate and temperature. In the same way, when the openings are situated at floor level, a more oblong opening resulted in lower heat release rate and temperature. A simple comparison between situation at roof level and floor level for openings indicated that when openings are at roof level, a slightly higher heat release rate and temperature is observed.

4.3.2 Mechanical ventilation

The first parameter on the influence of fire developing is the number of fans available on the closed ro-ro space. Unfortunately, CFAST does not take into account the number of fans and their related positions. This was also confirmed by the simulations made with different quantity and position of fans.

The second parameter is the air change per hour, from no ventilation up to 10 ACPH. Simulations showed a very similar behavior in terms of heat release rate and upper layer smoke temperature for the cases with no ventilation, 1 ACPH and 3 ACPH. For those cases, the fire seemed to extinguish by itself, contrary to the cases with 6 ACPH and 10 ACPH where the fire burnt to the end of the simulation time.

The third parameter is alternating ventilation. In some cases, the ventilation is switched down after some minutes, or turned on. Results of simulations of this parameter showed that turning off ventilation leads to a self-extinguishment of the fire, and in other hand turning on the ventilation leads to a fully developed fire, and both not depending of the original condition of the ventilation.

The last parameter is the study of combination between mechanical and natural ventilation on a closed ro-ro space. The mechanical ventilation consisted on 10 ACPH and natural ventilation consisted on varying the size of openings between 0.1% to 3%.
The outcomes of the simulations showed that for the cases 0.1%, 1% and 2% of openings, the fire became rapidly limited in term of heat release rate and temperature of the upper layer of the smoke. In the case of 3% of openings with 10 ACPH of mechanical ventilation, the quantity of oxygen is enough to reach a fully developed fire.

4.4 Conclusions from the study

Since the conclusions are based on results from the CFAST simulations, taking in account limitations of the model and its uncertainties, results should be seen as indicatives and require further investigations under the form of more precise simulations and experimental tests. Conclusions are also based on their literature review of accident investigations.

The students made the following conclusions from their study regarding the aspect of fire development (Lilja & Lindgren, 2019):

- open ro-ro spaces are recommended to be avoided, since natural ventilation results in large fire development;
- the large opening sizes required for open ro-ro space (i.e. at least one end open and more than 10% open in sideplating) make the geometrical shape and the sill height of the openings insignificant;
- if natural ventilation is nevertheless required, the simulations indicate that, for a given opening area, openings constructed as wide as possible and with as low sill height and soffit height as possible are preferable;
- open ro-ro spaces are supplied with enough oxygen, to support a large and long-lasting fire;
- the definition of a closed ro-ro space is considered too broad regarding the size of the openings. In the aspect of fire development, there is a difference in having a closed ro-ro space with one end open plus 9% openings compared with a closed ro-ro space without openings. Hence the regulations and definitions concerning closed ro-ro space are suggested to be reviewed;
- larger openings results in a larger fire development;
- depending on the size of a completely closed compartment, without openings and no mechanical ventilation, there is an amount of oxygen available to sustain a fire development during a certain time before it starts to decay. Due to the oxygen available in a ro-ro space (because of its large size) a fire may grow enough to cause severe damage even with small permanent openings and no mechanical ventilation;
- increased air changes per hour results in larger fire development; and
- switching off the mechanical ventilation will result in a smaller fire development and turning on the mechanical ventilation will result in a larger fire development.
5 Conclusion

Ro-ro spaces are an important component in Swedish and international shipping. A significant number of fire incidents on ro-ro ships and lacking signs of diminishing numbers indicate that fire protection must be improved.

There are differences in the fire protection between the different categories of ro-ro spaces. Open ro-ro spaces have no requirement for mechanical ventilation but has a lot of natural ventilation and in the Swedish ratification of SOLAS there is no requirement for fire detection system in an open ro-ro space. Closed ro-ro spaces need fire detection and alarm system, fire extinguishing system and mechanical ventilation with 6 or 10 ACPH and can have a significant area of natural openings. Weather deck has no requirement for fire protection systems and have free access to fresh air by its definition.

The ventilation is primary to prevent flammable and other harmful gases from accumulating in the spaces. It is a must for the crew to gain knowledge about the system and its capacity from tests and experiences. It is important that guidelines, rules and routines are established for using the ventilation system in typical conditions (loading/unloading etc.) and that it is documented and passed on to provide guidance for the ship’s crew.

Designing the ventilation system is unique for each ro-ro space so each system has its own way to most effectively work in different scenarios. There are three concepts to supply and exhaust air from the ro-ro space: longitudinal ventilation, transverse ventilation and the long-transverse ventilation. All of them having a combination of fans for supply and exhaust air. Reversible fans are a good way of making the ventilation system more flexible and easier to optimize depending on the scenario. It is interesting to further investigate if/how the ventilation system can be designed and used for evacuating hot gases from a fire.

Different interpretations of the regulations can be made between countries and it is proposed that “ro-ro spaces” in SOLAS should be defined as “ro-ro cargo spaces”, the definition should state that “ro-ro spaces are cargo spaces not normally subdivided...”; that “Vehicle spaces” in SOLAS should be defined as “Vehicle spaces are cargo ro-ro spaces intended for carriage of motor vehicles with fuel in their tanks for their own propulsion”; that a definition of “side” or a “space side” should be added in SOLAS and that the definition shall include what is a side, and how high a side needs to be, to be a side. It is also proposed to give a guidance of how to calculate the openness of an open ro-ro space, are ends and decks included in the calculation, or only hull sides?

The basic principle of dividing the ship into vertical fire zones are usually not practical in ro-ro spaces and fire integrity must be achieved in another way. Based on Regulation 9 and Regulation 20, both in SOLAS, a fire zone for a ro-ro space, open or closed, on a passenger ship may have an area of nearly 4000 m², which is considerably larger than the 1600 m² maximum permitted for vertical main fire zones in other parts of the ship. It is understandable that a fire within such a large space is hard to handle by the fire fighters onboard. This is also noticed from the accident investigation that was reviewed in the project. Densely stowed cars and problems with reaching the fire source is another problem that seems to be an issue on most of the accident reports and need to be further addressed.
6 References


Bureau Veriteas, RISE Research Institutes of Sweden, Stena Rederi AB. (2018). FIRESAFE II detection and decision. EMSA.


IMO. (2015, June 8). Part 1 DESIGN GUIDELINES FOR VENTILATION SYSTEMS IN RO-RO CARGO SPACES. MSC.1/Circ.1515 DESIGN GUIDELINES FOR
VENTILATION SYSTEMS IN RO-RO CARGO SPACES. London: International Maritime Organization.


Lilja, A., & Lindgren, M. (2019). Influence of ventilation on ro-ro space fire development - A study using two-zone fire models in order to explore tendencies of how different ventilation parameters affects the fire development in ro-ro space. X7007B: Luleå University of Technology.


# Appendix A: Hazard Identification workshop

## Hazard identification: Fire development, fire management

<table>
<thead>
<tr>
<th>Case</th>
<th>Type of ro-ro space</th>
<th>Desired functions</th>
<th>Safety systems</th>
<th>Hazards</th>
<th>Effect</th>
<th>Potential safety measures</th>
<th>General comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Close d ro-ro space, no ventilation</td>
<td>Early and precise detection</td>
<td>Detection system</td>
<td>No ventilation and thus the possibility of accumulation of gases</td>
<td>Unhealthy work environment, explosion risk, fuel supply</td>
<td>Gas detection, ventilation, protective equipment for personnel / respirator, sniffer / small gas detector on clothes, ex-classified equipment</td>
<td>This case (case A) does not exist in theory because ventilation systems must always / continuously be activated in closed ro-ro spaces (both on passenger ships and cargo vessels) as there are vehicles in the space.</td>
</tr>
<tr>
<td></td>
<td>Impeded fire development</td>
<td>Enclosed, tight, space</td>
<td>Extinguishing system</td>
<td>Greater likelihood of flashover, incomplete combustion, build-up of overpressure (which can lead to the spread of smoke)</td>
<td>Smoke and heat ventilation system, air locks to other spaces (mainly stairwells), pressure difference between ro-ro spaces and other spaces to prevent fire gas spread, ensuring (fire) gas tightness for doors</td>
<td>Sliding doors from ro-ro space to the living area often have gaps that can spread smoke / fire.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fire suppression</td>
<td>Open fire dampers in case of fire due to non-maintained damper, operating error, not knowing where damper / actuator is located, active selection to open damper (vent out).</td>
<td>A-class divisions</td>
<td>Smoke spread to adjoining spaces via the outside (e.g. LSA, escape routes), fire gas spread via adjoining spaces that have supply air from the space that is burning.</td>
<td>Remote control of dampers, clear / simple documentation of what controls what, training for crew, better positioning of dampers in relation to the spread of smoke on the outside of the ship, installation of reversible fans, improved maintenance.</td>
<td>It can be difficult to put as many dampers / exhaust air openings as are required when they are to be spread out and there is only a certain area that is possible for placement</td>
<td></td>
</tr>
<tr>
<td>Fire containment</td>
<td>Portable extinguishing equipment and fire hoses</td>
<td>Risk of explosion, explosion hazards</td>
<td>Structural damage can lead to fire and smoke spread to the rest of the ship</td>
<td>Pressure relief, ex-classified equipment</td>
<td>Ordinary vehicle / cargo on board is not and cannot be checked for ex-classification.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------------</td>
<td>------------------------------------------------</td>
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<td>--------------------------------------------------------------------------</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Smoke containment</td>
<td>Collection of heat in hull / deck structures</td>
<td>Faster fire development, fire spread to decks above (if fire insulation is missing), structural damage, fire spread, hot spots, adjacent spaces often fuel tanks that can cause a worse scenario for the fire.</td>
<td>Thermal insulation (fire insulation) in bulkheads and decks, manual cooling of the deck with water from boundary cooling, ventilation systems.</td>
<td>Class A-30 applies in decks and bulkheads between ro-ro spaces / vehicle spaces / special category spaces for cargo ships and passenger ships with fewer than 36 passengers built after July 1, 2014. Why not on passenger ships with more than 36 passengers?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Possibility for manual intervention</td>
<td>No ventilation in case of fire</td>
<td>Smoke are not vented away, more difficult intervention (due to poor visibility)</td>
<td>Smoke and heat ventilation system, use of portable systems / fans, routines for using existing ventilation system in case of fire</td>
<td>To quay, shore power is connected, should it be the ship's current instead? The vessel has greater capacity, which reduces the risk of interruptions, e.g. when activating the drencher pump or other energy-intensive activities at a fire.</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Opened door, e.g. during manual operation</td>
<td>Backdraft, the fire starts up again when oxygen is supplied, smoke damage of unprotected personnel behind the penetration path (only parts of the staff have smoke diver equipment with respiratory protection / BA), spread of smoke to other parts of the ship.</td>
<td>Ventilate before penetration/intervention, gas monitoring to identify gas levels, air lock to the stairwell, better scenario-based plan for where you can have safe penetration paths seen to both the risk of injury and the risk of smoke spread.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Case</td>
<td>Ro-ro space</td>
<td>Desired functions</td>
<td>Safety systems</td>
<td>Hazards</td>
<td>Effect</td>
<td>Potential safety measures</td>
<td>Comments</td>
</tr>
<tr>
<td>------</td>
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<td>----------</td>
</tr>
<tr>
<td>B</td>
<td>Close ro-ro space, mech ventilation</td>
<td>Early and precise detection</td>
<td>Detection system</td>
<td>Ventilation &quot;spread out&quot; the smoke</td>
<td>Delayed detection, &quot;fault&quot; location detection, delayed intervention, activation of the wrong extinguishing system section.</td>
<td>Reduced flow for the ventilation system possibly in combination with gas monitoring (see MSC/Circ.1515), sampling detection system.</td>
<td>MSC/Circ.1515 specifies guiding design and recommendations on the use of ventilation systems in ro-ro spaces.</td>
</tr>
</tbody>
</table>

Lack of insulation between decks.
Spread of heat, spread of fire
Thermal insulation (fire insulation) between decks, manual cooling of the deck with water from boundary cooling

Class A-30 applies in decks and bulkheads between ro-ro spaces / vehicle spaces / special category spaces for cargo ships and passenger ships with fewer than 36 passengers built after July 1, 2014. Why not on passenger ships with more than 36 passengers?

Large volume with potential leaks
Long time to oxygen-controlled fire (if possible, to reach oxygen-controlled fire)
division of the space, identification and maintenance of leaks

Ca  se  Ro-ro spac e  Desired functions  Safety systems  Hazards  Effect  Potential safety measures  Comments
B   Close ro-ro space, mech ventilation  Early and precise detection  Detection system  Ventilation "spread out" the smoke  Delayed detection, "fault" location detection, delayed intervention, activation of the wrong extinguishing system section.  Reduced flow for the ventilation system possibly in combination with gas monitoring (see MSC/Circ.1515), sampling detection system.  MSC/Circ.1515 specifies guiding design and recommendations on the use of ventilation systems in ro-ro spaces.  

Impeded fire development
Unfavourable environment in case of high air circulation and cold climate outdoors (cold).
Worse capability of personnel, poorer manual detection capability (manual rounds), frozen systems, self-closing doors will stop working, weakening in fire water system, scuppers freeze by ice, Do not have ventilation systems activated (at certain weather / temperatures), warm clothes for personnel, heating system in the space, drainage of extinguishing systems (stationary water in pipes), heat-seeking systems (heat tracing), heating of relevant systems.  Is there a requirement for drainage of extinguishing systems / deluge systems? What does the FSS code say?
<p>| Fire suppression | A-class divisions | Extinguishing system with small droplet size in combination with high flow in ventilation. | Activation of extinguishing system in the wrong place, free liquid surfaces, delayed activation, &quot;drifting&quot; movement of water | Lower ventilation flow, better adapted ventilation system and extinguishing system | The ventilation systems on board are not designed or adapted to be activated in the event of a fire. |
| Fire containment | Portable extinguishing equipment and fire hoses | Fire spread within the space due to ventilation. | Faster fire development, greater risk of fire spread, more difficult to predict the development of the fire. | Lower ventilation flow, better adapted ventilation system and extinguishing system | The design and activation of the ventilation system (the number of air changes) is made for an empty space, according to the regulations, but in reality, the space is relatively full of goods. |
| Smoke containment | Ventilation (6/10 ACPH) | Fire and smoke spread via extract air and supply air openings. | Fire and smoke spread via ventilation systems to other spaces, life-saving appliances (LSA) and escape routes. | Fire and smoke dampers between each space, automatic closing of dampers, clearer requirements at distances from exhaust air and supply air openings to LSA, escape routes, fresh air intake etc. | Where are the requirements for fire and fire gas dampers according to the rules? Why is it not automatic closing of dampers? OVK (obligatory ventilation control), which is done in buildings for the purpose of checking the ventilation system and to show that the indoor climate is good, is not done on ships. How is this checked today, who is responsible? |
| Possibility for manual intervention | Operates the ventilation system incorrectly. | Pressure differences between spaces, potential fire / fire gas spread. | Increased knowledge of ventilation systems, increased knowledge of using ventilation systems in the event of fire, ventilation systems adapted to be on fire during fire. | Increased knowledge of ventilation systems, increased knowledge of using ventilation systems in the event of fire, ventilation systems adapted to be on fire during fire. | What are the advantages / disadvantages of stopping ventilation systems in the event of a fire? |</p>
<table>
<thead>
<tr>
<th>Unknowledge about the ventilation system (capacity, location of the damper / damper etc.)</th>
<th>Handling error, wrong flow capacity at the wrong time, not knowing where the damper / actuators are located.</th>
<th>Increased knowledge of ventilation systems, increased knowledge of running the ventilation systems both in normal cases and in the event of fire.</th>
<th>Training in &quot;tactical / practical ventilation&quot; with existing equipment / systems is requested by Stena.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stagnant air at waterproof barriers.</td>
<td>Smoke are not vented away, more difficult intervention.</td>
<td>Smoke and heat ventilation system, portable systems / fans, routines and knowledge for use of existing ventilation system.</td>
<td>How long does it take to evacuate fire gases, i.e. to create an environment to make manual efforts in?</td>
</tr>
<tr>
<td>Stagnant air at waterproof barriers.</td>
<td>Accumulation of gases, unhealthy working environment, risk of explosion.</td>
<td>Improved ventilation at waterproof barriers so that the air does not become stationary, gas detection system, protective equipment for personnel.</td>
<td>How shall / should dangerous goods be placed with regard to ventilation / supply air / extract air?</td>
</tr>
<tr>
<td>Lack of fire insulation between decks</td>
<td>Spread of heat, spread of fire.</td>
<td>Thermal insulation (fire insulation) between decks, manual cooling with water (boundary cooling)</td>
<td>Class A-30 applies in decks and bulkheads between ro-ro spaces / vehicle spaces / special category spaces for cargo ships and passenger ships with fewer than 36 passengers built after July 1, 2014. Why not on passenger ships with more than 36 passengers?</td>
</tr>
<tr>
<td>Open fire dampers in case of fire due to harsh dampers, non-maintained dampers, handling error, not knowing where the dampers / actuators are located, active selection to open dampers (ventilate).</td>
<td>Smoke spread to adjacent spaces (e.g. LSA, escape routes), via adjacent spaces that have supply air from the space with fire.</td>
<td>Remote control of dampers, clear / simple documentation of what controls what, exercise for crew, better positioning of dampers in relation to the spread of smoke on the outside of the ship, installation of reversible fans, improved maintenance.</td>
<td>It can be difficult to place as many dampers / exhaust air openings as are required when they are to be spread out and there is only a certain area that is possible for placement.</td>
</tr>
<tr>
<td>Case</td>
<td>Desired functions</td>
<td>Safety systems</td>
<td>Hazards</td>
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<tr>
<td>C</td>
<td>Close d ro-ro space, mech ventil, one end open</td>
<td>Early and precise detection</td>
<td>Detection system</td>
</tr>
<tr>
<td></td>
<td>Impeded fire development</td>
<td>Free access to oxygen.</td>
<td>Extinguishing system</td>
</tr>
<tr>
<td></td>
<td>Fire suppression</td>
<td>No possibility of closing / closing the extract air (from the free).</td>
<td>A-class divisions</td>
</tr>
<tr>
<td></td>
<td>Fire containment</td>
<td>Lack of fire insulation between decks</td>
<td>Portable extinguishing equipment and fire hoses</td>
</tr>
<tr>
<td>Smoke containment</td>
<td>Ventilation (6/10 ACPH)</td>
<td>Possibility for manual intervention</td>
<td>Observation</td>
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<tr>
<td>Open fire dampers in case of fire due to jamming dampers, non-maintained dampers, handling error, not knowing where the dampers / actuators are located, active selection of open dampers (ventilate).</td>
<td>Some spread to adjacent spaces (e.g. LSA, escape routes), smoke spread via adjacent spaces that have supply air from the space with fire.</td>
<td>Remote control of dampers, clear / simple documentation of what controls what, training for staff, automation of dampers, placing dampers on &quot;better&quot; place, possibility of reversible fans, maintenance.</td>
<td>Ships with more than 36 passengers?</td>
</tr>
<tr>
<td>Unfavourable environment in case of high air circulation and cold climate outdoors (cold)</td>
<td>Worse intervention capacity of the personnel, poorer manual detection capability (manual rounds), frozen systems, self-closing doors will stop working, weakening in fire water systems, scuppers freeze by ice, extinguishing systems get ice in low points, hard-operated valves.</td>
<td>Do not have ventilation systems activated (at certain weather / temperatures), warm clothing for personnel, heating system in the space, drainage of extinguishing systems (stationary water in pipes), heat tracing for relevant systems, barrier to openings to the open to keep the heat.</td>
<td>Difficult to put many dampers, there may not be so many placements to choose from.</td>
</tr>
<tr>
<td>Back layering, that is, hot fire gases spread towards the direction of ventilation flow.</td>
<td>Fire and smoke spread within the space</td>
<td>Knowledge of ventilation system, shutdown of ventilation system in case of fire.</td>
<td>Destination Gotland has carried out tests on board where they compared fans with having open at one end. The vessel was loaded with vehicles. The result was that it was difficult to ventilate the air all the way through the vessel's length.</td>
</tr>
<tr>
<td>Back layering is an effect you see in tunnels. A fire gives rise to hot gases which have such force that they move towards the flow direction of the ventilation.</td>
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</tbody>
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<table>
<thead>
<tr>
<th>Case</th>
<th>Open ro-ro space, one end open and 10% open in sides</th>
<th>Desired functions</th>
<th>Safety systems</th>
<th>Hazards</th>
<th>Effect</th>
<th>Potential safety measures</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>Early and precise detection</td>
<td>Detection system</td>
<td>Fire spread possible from many openings in sides and ends.</td>
<td>Higher fire spread potential.</td>
<td>Permanent closing of openings, closing on alarms, sprinkler nozzles on the outside above openings (freezing resistant), design requirements in parts above the opening to prevent spreading, shielding / protection against weather decks.</td>
<td>What are the positive effects of openings? What will be the effects of closing the openings?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Impeded fire development</td>
<td></td>
<td>Smoke spread from more openings</td>
<td>Greater damage because more areas are exposed to smoke.</td>
<td>Permanent closing of openings, closing on alarms, sprinkler nozzles on the outside above openings (freezing resistant), design requirements in parts above the opening to prevent spreading, shielding / protection against weather decks.</td>
<td>Difficult to manoeuvre the vessel in a favourable direction to reduce smoke spread.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Extinguishing system</td>
<td></td>
<td>Limited possibility of choosing how to control the smoke.</td>
<td>Uncontrolled spread of smoke.</td>
<td>Fire gas ventilation system, use of portable fans.</td>
<td>Wind power (transverse) vs fan / ventilation (longitudinal), what is the difference in the possibility of detection and impact on extinguishing systems?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A-class divisions</td>
<td></td>
<td>Lack of fire insulation between decks.</td>
<td>Heat spread, fire spread to adjacent decks and spaces.</td>
<td>Thermal insulation (fire insulation) between decks, manual cooling with water (boundary cooling).</td>
<td>Class A-30 applies in decks and bulkheads between ro-ro spaces / vehicle spaces / special category spaces for cargo ships and passenger ships with fewer than 36 passengers built after July 1, 2014. Why not on passenger ships?</td>
<td></td>
</tr>
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<tr>
<td>E</td>
<td>Open ro-ro space, two ends open</td>
<td>Early and precise detection</td>
<td>Detection system</td>
<td>Worse detection, detection in &quot;wrong&quot; place, due to airflow that &quot;spreads out&quot; fire gases.</td>
<td>Delayed detection, delayed intervention, activating the wrong section on extinguishing system</td>
<td>Reduced flow for the ventilation system possibly in combination with gas monitoring (see MSC / Circ.1515), sampling detection system</td>
<td>The detection on double-ended vessels is often fast, as there are &quot;many eyes&quot; on the deck.</td>
</tr>
<tr>
<td>Impeded fire development</td>
<td>Stationary air in the middle of the ship.</td>
<td>Accumulation of gases, difficult to vent out smoke.</td>
<td>Ventilation openings or mechanical ventilation in the middle of the ship.</td>
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</tr>
<tr>
<td>Fire suppression A-class divisions</td>
<td>No possibility to control the ventilation and create under / over pressure.</td>
<td>Uncontrollable fire, difficult to make manual intervention.</td>
<td>Operate the ship so that the smoke is vented away.</td>
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</tr>
<tr>
<td>Fire containment Portable extinguishing equipment and fire hoses</td>
<td>Free access to oxygen.</td>
<td>The fire can continue as long as there is fuel.</td>
<td>Fire separation, gates, fire protection curtain for openings to the fresh air.</td>
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</tr>
<tr>
<td>Smoke containment</td>
<td>No opportunity to close the exhaust air</td>
<td>Fire / smoke spread to adjacent spaces.</td>
<td>Fire separation, gates, fire protection curtain for openings to the fresh air.</td>
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<tr>
<td>Possibility for manual intervention</td>
<td>No insulation between decks.</td>
<td>Spread of heat, spread of fire.</td>
<td>Thermal insulation (fire insulation) between decks, manual cooling with water (boundary cooling).</td>
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</tbody>
</table>

Ventilation / air flow stagnates in the middle of the vessel / space regardless of fan or opening, according to experiments done by Destination Gotland.

Double-ended vessels often have a short route and thus close to port.

As case C but without mechanical ventilation.

Possibly a case that we do not proceed with as it is not so commonplace in reality.

Class A-30 applies in decks and bulkheads between ro-ro spaces / vehicle spaces / special category spaces for cargo ships and passenger ships with fewer than 36 passengers built after July 1, 2014. Why not on passenger ships with more than 36 passengers?
<table>
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<tr>
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<th>Comments</th>
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<td></td>
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<td>Open fire dampers in the event of fire due to harsh dampers, non-maintained dampers, handling error, not knowing where the dampers / actuators are located, active selection of open dampers (ventilate).</td>
<td>Smoke spread to adjacent spaces (e.g. LSA, escape routes), smoke spread via spaces that have supply air from the with fire.</td>
<td>Remote control of dampers, clear / simple documentation of what controls what, training for staff, automation of dampers, placing dampers on &quot;better&quot; place, possibility of reversible fans, maintenance.</td>
<td>Unfavourable environment in case of high air circulation and cold climate outdoors (cold)</td>
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<td></td>
<td>Worse capacity of the personnel, poorer manual detection capability (manual rounds), frozen systems, self-closing doors will stop working, weakening function in fire water systems, scuppers freeze by ice, extinguishing systems get ice in low points, hard-operated valves.</td>
<td>Do not have ventilation systems activated (at certain weather / temperatures), warm clothes for personnel, heating system in the space, drainage of extinguishing systems (stationary water in pipes), heat tracing for relevant systems, barrier against openings to the open to keep the heat.</td>
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<td></td>
<td></td>
<td>Accumulation of heavy gases.</td>
<td>Unhealthy work environment, explosion, fuel supply.</td>
<td>Gas detection, ventilation, protective equipment for personnel / breathing mask, sniffer, ex-classified equipment, openings in the hull sides at the bottom.</td>
<td></td>
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</tbody>
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<table>
<thead>
<tr>
<th><strong>Weather deck, open from above and in two ends, high sides</strong></th>
<th><strong>Early and precise detection</strong></th>
<th><strong>Portable extinguishing equipment and fire hoses</strong></th>
<th><strong>Accumulation of heavy gases.</strong></th>
<th><strong>Unhealthy work environment, explosion, fuel supply.</strong></th>
<th><strong>Gas detection, ventilation, protective equipment for personnel / breathing mask, sniffer, ex-classified equipment, openings in the hull sides at the bottom.</strong></th>
<th><strong>Effect of e.g. explosion is smaller than in an &quot;under room&quot; (case A), there are small sniffers / gas meters (in size as a pen) on the market today (which staff can bring along on rounds).</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Impeded fire development</strong></td>
<td><strong>A-class divisions</strong></td>
<td><strong>No possibility to extinguish the fire with a fixed extinguishing system.</strong></td>
<td><strong>Uncontrolled fire, difficult to make manual intervention.</strong></td>
<td><strong>Fixed installed extinguishing system (e.g. CAFS, water / foam monitor, water-based system with nozzles attached to the sides), water monitor with remote control.</strong></td>
<td><strong>CAFS = compressed air foam system</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Fire suppression</strong></td>
<td></td>
<td><strong>Late detection due to lack of detection system (no requirement).</strong></td>
<td><strong>Late intervention, no automatic specification of the fire position.</strong></td>
<td><strong>Fixed installed detection system (e.g. fibre optic cable or flame detectors), extra patrols.</strong></td>
<td><strong>Easier to attach detectors on high sides than without sides (compare weather decks that do not have high sides).</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Fire containment</strong></td>
<td></td>
<td><strong>Heat radiation from sides back to the fire, compared with conventional weather deck that has no high sides.</strong></td>
<td><strong>Faster fire development.</strong></td>
<td><strong>Fixed installed detection system (e.g. fibre optic cable or flame detectors), extra patrols.</strong></td>
<td><strong>A weather deck with high sides is more protected from wind impact, which can reduce the fire's development, fire spread and fire gas spread. On the other hand, the sides can reflect heat radiation back to a fire and possibly affect the fire's development.</strong></td>
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<td>G</td>
<td>Weather deck, open from above and in two ends</td>
<td>Early and precise detection</td>
<td>Portable extinguishing equipment and fire hoses</td>
<td>No possibility to extinguish the fire with fixed extinguishing system and difficult to make manual intervention.</td>
<td>Hard / uncontrollable fire.</td>
<td>Fixed installed extinguishing system (e.g. CAFS, water / foam monitor, water-based system with nozzles attached to the sides), water monitor with remote control.</td>
</tr>
</tbody>
</table>

- **Smoke containment**
  - Lack of insulation between decks.
  - Heat spread, fire spread to adjacent decks and space, heated steel gives poorer bearing capacity.
  - Thermal insulation (fire insulation) between tires, manual tire cooling with water from boundary cooling.

- **Possibility for manual intervention**
  - Class A-30 applies in decks and bulkheads between ro-ro spaces / vehicle spaces / special category spaces for cargo ships and passenger ships with fewer than 36 passengers built after July 1, 2014. Why not on passenger ships with more than 36 passengers?
<table>
<thead>
<tr>
<th>Fire development</th>
<th>A-class divisions</th>
<th>Fire suppression</th>
<th>Fire containment</th>
<th>Possibility for manual intervention</th>
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<td>Impeded fire</td>
<td>Late detection because no detection system</td>
<td>Late effort, no specification of the fire position.</td>
<td>Fixed installed detection system (e.g. fibre optic cable or flame detectors), extra patrols.</td>
<td>Easier to attach detectors on high sides than without sides (compare weather decks that do not have high sides).</td>
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