A study on how to improve mass evacuation at sea with the use of survival crafts

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Abstract
The development of maritime safety is often triggered by accidents. The purpose of this study is to learn how mass evacuation with survival crafts can be improved at sea, by reviewing the publicly available information from some of the most recent accidents. Information has been collected and analyzed from official investigation reports, passenger statements and the reporting of media. In addition, interviews have been conducted with experts in the maritime field in order to reach conclusions.

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Summary

The development of maritime safety is often triggered by accidents. The Titanic tragedy, in 1912, generated the first international convention regarding safety of ships, which later led to the foundation of IMO *(International Maritime Organization).* The tragedy of M/S Estonia, in 1994, led to additional improvements and was the cause to the founding of "Guidelines on Evacuation Analyses for ro-ro passenger ships". Due to recent accidents, the topic of maritime safety has become relevant again. In 2012, M/S Costa Concordia ran aground causing 32 persons to drown. In 2014, M/S Norman Atlantic caught fire in the Adriatic Sea, which resulted in 18 casualties. What lessons can be learned from the newest accidents?

In comparison with building evacuation, ship evacuation differs in several aspects. One of the characteristic differences being the use of survival crafts *(lifeboats and liferafts)*, which enable passengers and crew to abandon the ship. As the capacity and size of passenger ships and cruise ships are increasing, higher demands are put on the performance of survival crafts.

The purpose of this study is to learn how evacuation at sea using survival crafts can be improved. To achieve this, a literature study has been carried out to get familiarized with the topic in question. A review has been conducted of relevant evacuation theories, ship evacuation procedures, regulations and technical specifications of survival crafts. With the use of official investigation reports, passenger statements and reporting of media, past ship incidents have been studied, in order to reach the conclusions of how evacuation of ships with survival crafts can be improved. In addition, interviews have been conducted with experts in the maritime field for the purpose of this study. A number of issues have been identified to affect the evacuation at sea negatively. The following conclusions are drawn:

- **The prescriptive evacuation times might not be always met** and may be followed only in ideal conditions. The issue can be linked to technical malfunctions and crew procedural problems. Therefore, these are the main areas in need of improvements.
- **Delays in initiation of evacuation procedures** contribute to a narrow time frame for the embarking and launching phase. A solution to this problem can be more thorough inspections so that technical systems reliability is increased and by training and educating master and officers more in the "decision support system for masters" provided by SOLAS regulation *(SOLAS, Chp. III, regulation 29)*
- **The embarkation of survival crafts can be impeded by fire** and smoke coming out from ro-ro ferries' garage openings. To improve this problem, SOLAS regulations regarding passive fire protection of garage openings or survival crafts should take this issue into account.
- **Lifeboats and rescue boats may fall down during launching** due to corrosion on wires. To prevent the problem, the maintenance of wires should be improved, the exchange period of the wires shortened and the reliability of wires increased by higher

demands on corrosion resistance. This can be achieved by regulatory enforcements in SOLAS regulations and LSA code.

- **The capacity of lifeboat may not be filled during launching**, consequently limiting the evacuation possibilities for the remaining persons on board. The problem can be improved by regulatory measures in STCW and SOLAS regulations so that the amount of training and awareness regarding the issue is increased.
- **MES chute system may not perform well in high wind speeds**. To improve the problem, the regulation *(LSA code, 6.2.2.1.7)* should be enhanced so that MES (marine evacuation systems) are required to perform above a wind force of 7 on the Beaufort scale.
- **Crews may not be prepared** sufficiently by training**.** Consequently**,** the evacuation procedures can be affected negatively. To improve the problem, enhancement can be done to STCW and SOLAS regulations so that the amount of training is increased and so that the training corresponds to more realistic settings.
- **Communication issues due to language barrier may occur** when a crew consists of several companies. This affects evacuation procedures negatively. To improve the problem, the occurrence of crews consisting of companies lacking a shared communication language should be avoided or regulated. Also, the predicted language spoken by the passengers should also be taken into account.
- **Crew evacuation procedures may have difficulties to function when put under stress.** To improve the problem, enhancement can be done to STCW and SOLAS regulations so that the amount of training is increased and so that the training corresponds to more realistic settings, so that the crew evacuation procedures become more resilient during emergencies.
- **Hypothermia affecting passengers** may be a problem during evacuation. To improve this, regulations should be included so that anti-exposure suits available for passengers. In addition, more emphasis can be put, during training of crews, on hypothermia preventing measures, e.g. bringing blankets.
- **The transferring system from survival crafts to rescue units is problematic,** especially during high seas. To improve this, systems need to be developed and implemented in survival crafts and rescue units, which ease the debarkation process. This can be achieved with regulatory measures.

Sammanfattning

Utvecklingen av sjösäkerheten utlöses ofta av marina olyckor. Titanic tradegin år 1912, framkallade utvecklingen av den första internationella konventionen angående säkerhet för fartyg som senare ledde till skapandet av IMO *(International Maritime Organization)*. M/S Estonia tragedin år 1994, ledde till ytterliggare förbättringar och var orsaken till skapandet av "Guidelines on Evacuation Analyses for ro-ro passenger ships". På grund av den senaste tidens olyckor, har ämnet sjösäkerhet blivit aktuellt igen. År 2012 gick M/S Costa Concordia på grund, vilket kostade 32 personer livet. År 2014 tog M/S Norman Atlantic eld, vilket resulterade i 18 dödsfall. Vilka lärdommar kan dras från de senaste tidens olyckor?

I jämförelse med utrymning av byggnader skiljer sig utrymning av fartyg i flera avseenden. En av de karakteristiska skillnaderna är användningen av livbåtar och flottar, vilka ger passagerarna och besättningsmedlemmarna möjlighet att överge skeppet. Eftersom kapaciteten och storleken på passagerarfaryg och kryssningsfartyg ökar, ökar även kraven på livbåtarnas och flottarnas duglighet.

Syftet med denna studie är att utreda hur evakuering till sjöss med livbåtar samt flottar kan förbättras. För att åstadkomma detta har en litteraturstudie genomförts för att bekanta sig med ämnet i fråga. En genomgång har genomförts av relevanta evakuationsteorier, utrymningsprocedurer, regelverk och tekniska specifikationer av livbåtar samt flottar. Med hjälp av officiella utredningsrapporter, passageraruttalanden och medias rapportering har tidigare fartygsincidenter studerats, för att nå slutsatser om hur evakuering av fartyg med livbåtar samt flottar kan förbättras. Utöver detta har intervjuer genomförts med experter inom sjösektorn för att uppnå studiens ändamål. Som resultat har ett antal faktorer identifierats att påverka evakueringen till sjöss negativt. Följande slutsatser har dragits:

- **De föreskrivna utrymningstiderna verkar inte alltid uppfyllas** och följs endast i ideala förhållanden. Problemet kan knytas an till tekniska fel och utrymningsprocedurer. Därför behövs förbättringar huvudsakligen inom dessa områden.
- **Fördröjningar i påbörjandet av utrymning** bidrar till en kort tidsram för påstignings- och sjösättningsfasen av livbåtar samt flottar. En lösning till detta problem kan vara att tillämpa noggrannare inspektioner för att öka tillförligheten på tekniska system och att utbilda fartygsbefäl mer i "decision supportsystem for masters" som finnes i SOLAS-föreskifterna *(SOLAS, Kapitel III, regel 29).*
- **Påstigningsprocessen av livbåtar och flottar kan förhindras under brand** av plym, som kommer ut från ro-ro färjors garageöppningar. För att åtgärda detta bör SOLAS föreskifterna ta hänsyn till detta problem, genom att förbättra föreskrifterna gällande passivt brandskydd av garageöppningar, livbåtar och flottar.

- **Livbåtar och räddningsbåtar kan möjligen slita sig loss under sjösättning och falla**, pga. korrision av vajrarna. För att förbättra problemet bör underhållet av vajerna förbättras, tjänlighetsperioden av vajrar kortas och tillförlitligheten ökas genom högre krav på vajernas korrisions resistans. Detta kan åstadkommas genom förbättringar i SOLAS och LSA code föreskrifterna.
- **Livbåtarnas kapacitet utnyttjas möjligen inte under sjösättning**, vilket begränsar utrymningsmöjligheterna för de återstående personerna ombord. En lösning till detta kan åstadkommas genom förbättringar av STCW och SOLAS föreskrifterna så att mängden utbildning samt medvetenhetsgraden gällande problemet ökas.
- **MES chute systemen fungerar möjligtvis inte vid höga vindstyrkor.** För att åtgärda problemet, bör föreskrifterna *(LSA code, 6.2.2.1.7)* förbättras så att krav finns på att MES (marine evacuation systems) ska upprätthålla sin funktion vid en vindstyrka på 7 eller mer på Beaufort skalan.
- **Besättningsmedlemmarna är möjligtvis inte förberedda tillräckligt** genom utbildning, vilket kan påverka utrymningsprocedurerna negativt. För att förbättra problemet kan STCW och SOLAS föreskrifterna förbättras så att mängden utbildning ökas för besättningsmedlemmar samt genom att utbildningen återspeglar mer realistiska förhållanden.
- **Kommunikationsproblem kan förekomma p.g.a. språkhinder** då besättningen består av anställda från flera olika företag. Detta påverkar utrymningsprocedurerna negativt. För att förbättra problemet bör förekomsten av besättningsmedlemmar från flera företag som saknar ett gemensamt språk undvikas eller regleras i föreskrifterna. Dessutom bör passagerarnas språkkunskaper tas i beaktning i frågan.
- **Utrymningsprocedurerna kanske inte vidhåller sin funktion under påfrestning.** För att åtgärda problemet kan förbättringar göras i STCW och SOLAS föreskrifterna, så att mängden utbildning av besättningen ökar samt så att den återspeglar mer realistiska förhållanden för att utrymningsprocedurerna ska bli mer resillienta (motståndskraftiga) under nödsituationer.
- **Passagerare kan påverkas av hypotermi** under evakuering. För att förbättra detta problem kan föreskrifterna ändras så att krav sätts på att anti-exponeringsklädsel ska vara tillgänglig för passagerare. Dessutom, kan större vikt läggas under utbildning av besättning på förebyggande åtgärder så som t.ex. att hämta filtar.
- **Överföringen av personer från livbåtar och flottar till räddningsenheter är problematisk**, framförallt under hårt väder. För att förbättra detta kan system utvecklas vilka underlättar avstigningsprocessen och implementeras i livbåtarna, flottarna samt räddningsenheterna. Detta kan åstadkommas genom ändringar i föreskrifterna.

Terminology

ASET = Available Safe Egress Time
Bow = The front part of a ship
Δt_{aband} = Abandonment time
Δt_{det} = Detection time
Δt_{embark} = Embarkation time
Δt_{evac} = Evacuation time
Δt_{launch} **=** Launching time
Δt_{pre} = Pre-evacuation time
Δt_{rec} = Recognition time
Δt_{resp} = Response time
Δt_{trav} = Travel time
Δt_{warn} = Alarm time
Flag state = the country under which laws the ship is registered
IMO = International Maritime Organization
ISM code = International Safety Management code
JRCC = Joint Rescue Coordination Centre
LSA code = International Life-Saving Appliances Code
Merchant ship = Cargo and passenger ships
MES = Marine Evacuation System
Muster list = A document with emergency instructions for crewmembers
Portside = Left side of the ship when facing the bow
RINA = The Royal Institution of Naval Architects
Ro-ro = Roll on/Roll off (ship)
Ro-pax = Roll/Roll off (passenger ship)
RSET = Required Safe Egress Time
SAR = Search And Rescue
SAR Convention = International Convention on Maritime Search and Rescue
SOLAS Convention = International Convention for the Safety of Life at Sea
Starboard = Right side of a ship when facing the bow
STCW Convention = International Convention on Standards of Training, Certification and Watchkeeping for Seafarers
Stern = The rear of the ship
Survival Craft = Lifeboats or liferafts

Contents

1. INTRODUCTION

This chapter presents the background, questions at issue, purpose and aim, methodology and limitations of the thesis.

1.1 Background

Having a surface consisting of more than 70% of water, it is no wonder that our planet is referred to as "the Blue Planet" (Perlman, 2016). This body of water is constantly being traversed by ships back and forth. Fires, collisions, rough sea and other elements, which can compromise the safety on board, pose a threat for the passengers and crew. Proper safety and evacuation design is therefore a necessity for ships.

The development of maritime safety is often triggered by accidents. The Titanic tragedy, in 1912, generated the first international convention regarding safety of ships, which later led to the foundation of IMO *(International Maritime Organization).* The tragedy of M/S Estonia, in 1994, ferry led to additional improvements and was the cause to the founding of "Guidelines on Evacuation Analyses for ro-ro passenger ships" (Klüpfel, 2008; History.com Staff, 2009). Due to recent accidents, the topic of maritime safety has become relevant again. In 2012, M/S Costa Concordia ran aground causing 32 persons to drown (Gillman, 2015). In 2014, M/S Norman Atlantic caught fire in the Adriatic Sea, which resulted in 18 casualties (Maritime Executive, 2015). What lessons can be learned from the newest accidents?

In comparison with building evacuation, ship evacuation differs in several aspects. One of the characteristic differences being the use of survival crafts *(lifeboats and liferafts)*, which enable passengers and crew to abandon the ship. As the capacity and size of passenger ships and cruise ships are increasing, higher demands are put on the performance of survival crafts.

The Swedish Maritime Administration (SMA) is engaged to improve the ship safety and encouraged the graduates at Lund's Institution of Technology to look upon this field. This thesis is a part of the Fire Safety Engineering program and it is the final work required to obtain the academic degree.

1.2 Questions at issue

To evacuate from a building, the occupants generally need to step out through one of the exit doors to be safe, while on a ship there is an additional need to launch and board a survival craft to be taken to safety. This thesis will more closely examine the use of survival crafts and have as a purpose to enlighten the issues concerning ship evacuation at sea, in which the survival craft launching phase plays a key role in the success of the procedure. The following research questions are investigated:

- What are currently the common practices and regulatory procedures concerning ship evacuation at sea?

- What are the main differences between ship and building evacuation, and what needs especially to be taken into consideration in ships?
- What can we learn from previous ship incidents?
- How can the ship evacuation process at sea be more efficient?

1.3 Purpose and aim

The purpose and aim of this thesis is to:

- Review the information of ship evacuation at sea using survival crafts.
- Review existing evacuation procedures, technical specifications of survival crafts and regulatory information about times needed to access survival crafts in case of evacuation.
- Investigate two ferry incidents at sea involving the use of survival crafts.
- Discuss improvements in ship evacuation using survival crafts.

1.4 Methodology

The method starts by acquiring and presenting relevant information regarding evacuation theory and common marine terminology to get a basic understanding for the topic in question, (see section 2.1). Secondly, a review is made on which evacuation crafts exist for the use of evacuation of ships, such as lifeboats, liferafts and rescue boats. Technical specifications of them are collected and presented (see section 2.2). Thirdly, information on common evacuation procedures during passenger ship evacuation is reviewed, (see section 2.3). Fourthly, common marine regulations concerning passenger safety at sea are reviewed and described (see section 2.4).

With the information collected, a couple of ship incident cases are studied to identify plausible issues during ship evacuation (see chapter 3). The information in the case studies is collected through official investigation reports and media reporting.

Thereafter, the information gathered in chapter 3 is used to assemble a list of issues, which may affect evacuation of ships. The list of issues is then used to form a questionnaire (see Appendix A) to be used to interview a set of experts in the maritime field. The questionnaire is semi-structured, to allow the list of issues to be addressed and to give the interviewees the opportunity to discuss additional issues.

Finally, the information from the case studies and the interviews is used to draw conclusions.

1.5 Limitations

The thesis has the following limitations:

- The focus of the thesis is on the use of survival crafts on passenger ships.
- The number of interviews is limited, therefore the thesis should be considered as exploratory rather than exhaustive.
- Observations made in the case studies are difficult to generalize because of the variability occurring in each case and because of the limited number of observations.
- Variability of design of survival crafts makes it difficult to generalize some concepts.
- The information from media's reporting and passenger statements can be influenced by subjective values and therefore limit the reliability of the collected information.
- Reports in different languages than English and Swedish cannot be taken into consideration due to limitations in the author's language knowledge.

2. EVACUATION WITH SURVIVAL CRAFTS

In this chapter, information regarding evacuation theory, technical specifications of survival crafts and rescue boats, evacuation procedures and regulations is reviewed and presented.

2.1 Theory

This section describes evacuation theory and nautical terminology.

2.1.1 Evacuation theory

An important objective of fire safety engineering is to ensure that safe evacuation is possible. There are two main methods used to determine this, the prescriptive and performance-based method. The prescriptive method is based on pre-accepted solutions, which have predefined standards and rules that are to be followed to ensure that the fire safety level is adequate. The nature of the prescriptive method enables a relatively fast and easy solution to be made. However, it has limitations when it comes to uncommon building designs in terms of appliance. The performance-based method in the other hand is based upon whether the available evacuation time exceeds the escape time. This enables the design of any building, as long as the fire safety level is sufficient. The demand for and acceptance of the performance-based approach has increased during the last decades, since more and more untypical designs are being made. An additional approach, is the hybrid method that is a combination of the performance based and the prescriptive method, where one of them can be used to validate the other (Ronchi & Nilsson, 2016; CFPA Europe, 2009).

When determining the safety of evacuation using the performance based method, often an ASET/RSET analysis is conducted. The analysis relies on the comparison between ASET *(Available Safe Egress Time)* and RSET *(Required Safe Egress Time)*. For a safe evacuation to be possible, ASET needs to exceed RSET. Therefore, the following formula is used as a condition for safe evacuation (Klüpfel, 2008).

$$RSET \leq ASET$$

ASET *(Available Safe Egress Time)* is the time from the beginning of ignition or emergency until the point of time when a safe evacuation is no longer possible. It is no longer possible to conduct a safe evacuation when conditions, which arise, are hazardous to the point that they prevent the occupants to save themselves. This can be when e.g. the structure gets smoke filled or, in the case of ships, the ship list to such degree that the use of survival crafts is no longer possible. ASET can be determined by calculations of the hazards, simulations of fire and smoke spread and risk analysis. Parameters that are of importance when assessing ASET are the visibility, thermal radiation, temperature and toxicity. Another approach to establish ASET is by having the fire resistance (e.g. A60 walls) of the structure as a benchmark (Klüpfel, 2008).

RSET *(Required Safe Egress Time)* is the required time for escape. It can be divided into consecutive steps. Each step is describing the type of phase during the evacuation process and the human behavior at the point of time. The sum of these steps represents the total time for evacuation, RSET. The evacuation process can be divided into four steps and therefore following equation is presented:

$$RSET = \Delta t_{det} + \Delta t_{warn} + \Delta t_{pre} + \Delta t_{trav}$$

This type model is referred to as the time-line model and is a simplification of the reality, since the consecutive step can in reality start before the previous ones has ended. However, the use of it enables quantitative analysis to be applied to the evacuation process. The different phases involved are the following:

- Δt_{det} **Detection time:** This is the time from the beginning of the ignition or emergency until detection. The duration of this time is correlated to which detection system is used.
- Δt_{warn} **Alarm time:** This is the time from detection until occupants have been warned. The occupants can be notified for example by the general alarm, staff or smell of smoke. This time depends on which type of warning system is used.
- Δt_{pre} **Pre-evacuation time:** This is the time from when the occupants hear the alarm until they start moving. For the purpose of understanding, it can be divided into two subparts, recognition time (Δt_{rec}) and response time (Δt_{resp}). Both of which are affected by the state of awareness of the occupant, e.g. if the person is at sleep or have consumed alcohol.
    - Δt_{rec} **Recognition time:** is the time from when the occupants have been warned until they perceive that something abnormal has occurred. It is, in addition, affected by which type of warning system is used.
    - Δt_{resp} **Response time:** is the time from when the occupants have perceived that something abnormal has occurred to the time when the occupants start moving. With other words, it is the time it takes for the occupant to decide what to do. This time can be shortened by informing the occupants of what is happening and instructing in what action should be taken.
- Δt_{trav} **Travel time:** This is the time it taken for the occupants to move to safety. In case of ships, it is the time taken to move to the mustering stations/embarkation areas. The travel time is affected by variables such as:
    - Number of occupants – the more occupants the longer the travel time.
    - Distribution/density – the higher density, the longer travel time
    - Distance that needs to be traveled – the longer distance, the longer travel time
    - Walking/travel speed – slower speed relates to increased travel time
    - Dimensions of the structure – large structures, with many doors, stairs tend to increase travel time.
    - Familiarity with structure – knowledge of the structure's escape routes decreases travel time.
    - Hazard progression – hazardous conditions can make occupants to choose different escape routes leading to prolonged travel time.

(Ronchi & Nilsson, 2016; Rasbash, Ramachandran, Kandola, Watts, & Law, 2004)

In case of ship, additional variables affect the travel time, such as:

- The trim and list of the ship
- The motion of the ship

(RINA, 2016c).

Evacuation from ships at sea differs from building evacuation in several ways. On one hand, when evacuating from a building, once the safe place is reached the evacuation can be considered as completed. The evacuation process at sea, on the other hand, presents additional layers of complication. Firstly, there is the need to acquire lifejackets, which depends on type of ship and procedure can be either in the cabins or in the mustering stations. Secondly, the passengers need to orient themselves through the different layer of decks, which may require them to move up or down, or move to the different side of the boat (starboard or port side). Thirdly, the evacuation process may be more complicated and more hazardous due to the motion of the ship, the trim or list and due to the weather conditions. Finally, the passengers need to most likely evacuate through unfamiliar means by embarking lifeboats or liferafts, which are then launched into the sea (RINA, 2016c). Therefore, additional phases are required for the description of the ship evacuation. There is one significant distinguishing feature between building and ship evacuation. It is the abandonment of the ship. This leads to an additional phase, the abandonment phase.

- **Δt_{aband} Abandonment time:** This time represents the total time needed for the abandonment of the ship, from the point of time when assembly has taken place. It consists of two subparts, embarkation time and launching time.
    - **Δt_{embark} Embarkation time:** is the time from when the passengers have assembled at the muster points to the point of time when the survival crafts are boarded.
    - **Δt_{launch} Launching time:** is the time it takes for the survival crafts to be launched.

Consequently, the process of abandonment of ships can be described with five phases. The sum represents the total time for evacuation RSET. Following equation is presented:

$$RSET = \Delta t_{det} + \Delta t_{warn} + \Delta t_{pre} + \Delta t_{trav} + \Delta t_{aband}$$

In conclusion, for an evacuation to be successful, RSET need to be lower than ASET. Figure 1 shows the chain of events during an evacuation, traditionally used in buildings. It displays the correlation between ASET and RSET and the different components involved. The time between RSET and ASET is the safety margin. The sum of pre-evacuation and travel time is called evacuation time (Δt_{evac}) (Ronchi & Nilsson, 2016).

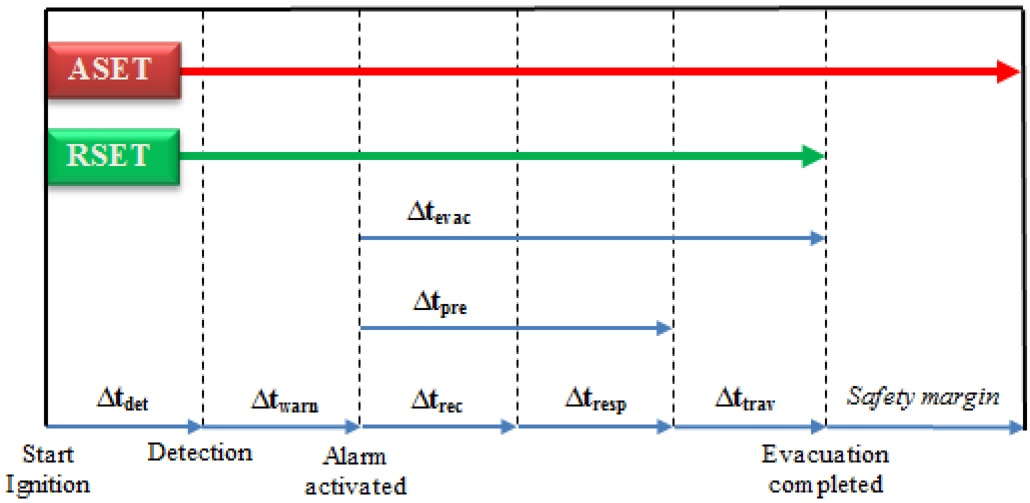

Figure 1 show an egress time-line model based on theory from: (Ronchi & Nilsson, 2016)

In ship abandonment, an additional phase (Δt_{aband}) is required in comparison with building evacuation. Figure 2 illustrates the chain of events during a ship evacuation. It shows the correlation between ASET and RSET and the different components involved in the ship abandonment process. The evacuation time (Δt_{evac}) in ships is prolonged due to the abandonment phase (Δt_{aband}).

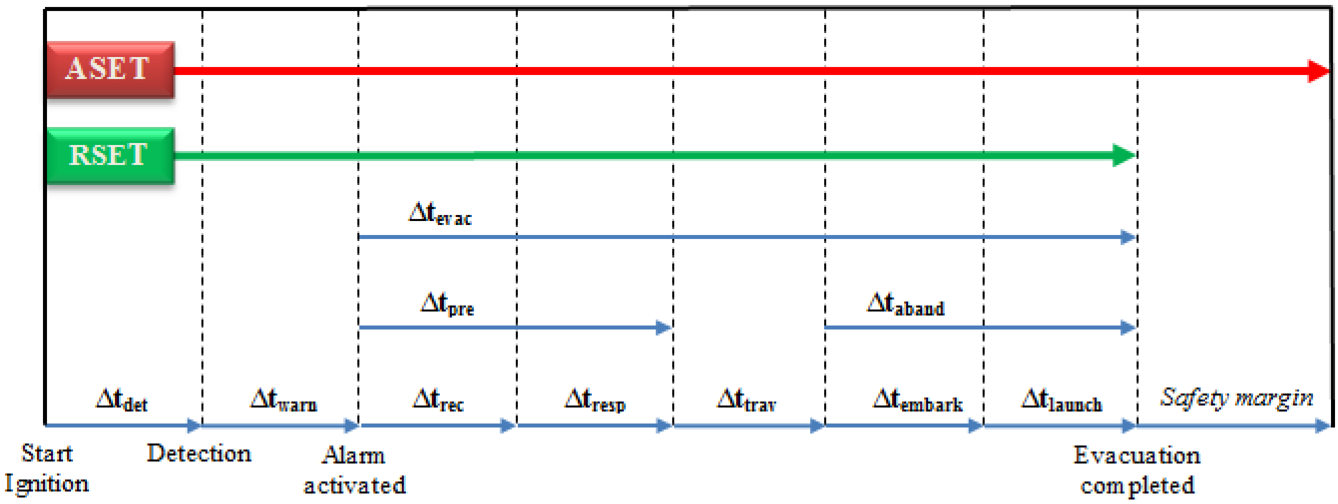

Figure 2 shows an egress time-line model for the abandonment of ships.

Figure 2 shows the phases during ship abandonment. However, in order for the evacuees to be completely safe, they need to debark or be rescued from the survival crafts, succeeding the abandonment.

2.1.2 Nautical terminology

According to IMO, passenger ships are defined as ships that carry more than 12 passengers. (IMO, 2016c). The two main types of passenger ships are cruise ships and ferries. Both have as a main task to carry passengers. Cruise ships are typically used for recreational trips. Ferries in the other hand, are used to transit passengers with or without a load of vehicles from one destination to another.

Ro-ro ships (acronym for roll on roll off) are all ships with the capability of carrying vehicles, which can be loaded in a convenient way by simply driving in. Ferries carrying both passengers and vehicles, typically car ferries, are named ro-pax ferries. (Kaushik, 2016)

When describing differenet parts of a ship the following terminology is commonly used. Bow is the front part and stern is the rear part of the ship. Starboard side is reffered to as the right side when facing the bow. Port side is the left side when facing the bow, in other words opposite to starboard. Figure 3 illustrates this in a simple way. (Msc.com, 2016)

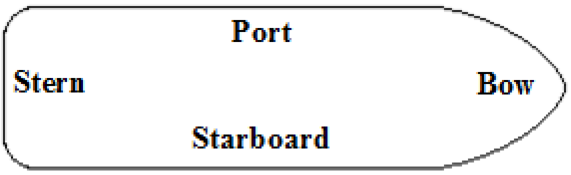

Figure 3 illustrates the marine terminology describing ship parts.

Ship motion can influence the evacuation process of ships. Figure 4 shows some of the most common types of ship motions. List, heel and trim can be described as static tilting conditions. The terminology is of list and heel is very similar. Although there is a significant difference, list is caused by internal unbalance such as flooding. Heel is caused by external force, such as wind or the turning of the ship. Rolling and pitching in the other hand, are dynamic motions causing the ship rocking back and forth, mostly as a result by the wave motion (Worldwideflood, 2016).

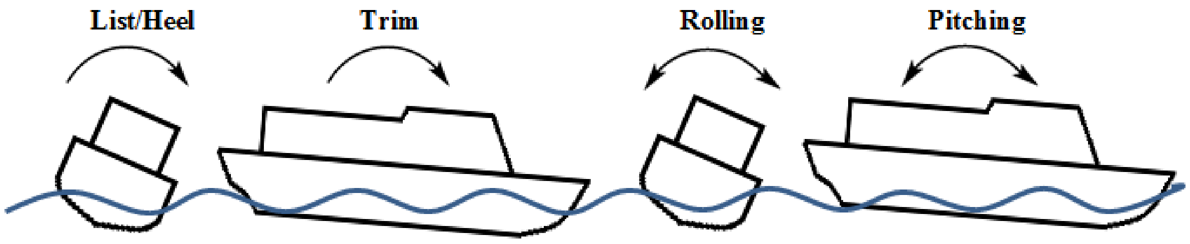

Figure 4 illustrates and explains nautical terms describing the motion of ships.

2.2 Lifeboats, liferafts & rescue boats

This chapter aims to give a description of the types of evacuation vessels used on ships and their way of launching. The evacuation vessels can be divided into three groups, lifeboats, liferafts and rescue boats. There is a vast amount of regulations covering all aspects of the crafts and they should comply with the SOLAS requirements and LSA code (IMO, 2014). The term survival craft is a generic term, which is used for lifeboats or liferafts, not rescue boats (Cornwell Univeristy Law School, 2016).

2.2.1 Lifeboats

Lifeboats are survival crafts designed in rigid material and have their own propulsion. Due to amendments in SOLAS regulations in 1983, passenger ships are required to carry lifeboats with motorized propulsion, which are partially or totally enclosed *(SOLAS, Chp. III, regulation 21.1).* Thus, replacing the traditional open lifeboats propelled by oars (RINA, 2016d). According to regulations, all lifeboats on a ship should be launched and tested by the crew at least once every three months *(SOLAS, Chp. 3, regulation 19.3.3.3)* and inspected monthly by the ship's crew, to ensure that all lifeboat equipment is accounted for and functional *(SOLAS, Chp. 3, regulation 20.7)* (IMO, 2014).

2.2.1.1 Enclosed Lifeboats

Enclosed lifeboats are the most common-used lifeboats and are, due to its enclosure, very resistant against the influence of surroundings. The lifeboats are equipped with survival equipment such as first aid, compass, food and water. During launching, they are operated by crewmembers that lower them with wires to the surface of water with the help of davit systems (crane structures). The davit systems on passenger ships are powered by gravity. There are two types of enclosed lifeboats, partially enclosed and totally enclosed.

Figure 5 shows a lifeboat with its gravity launched davit system. Picture is taken from: (Nautic Expo, 2016a)

(SHM, 2016; Freefalllifeboat.com, 2016; HY-Precision Technology, 2016; Wankhede, 2016b)

Partially Enclosed lifeboats

Partially enclosed lifeboats are the most common type of lifeboats used on passenger ships due to their capacity and accessibility. The maximum capacity on lifeboats is 150 persons, according to regulations *(LSA code, 4.4.2.1)*. Therefore, most often the lifeboats on passenger ships have the capacity of 150. Table 1 shows an example of the range of technical specifications of a partially enclosed lifeboat.

Figure 6 shows a partially enclosed lifeboat. Picture taken from: (EO Lifesaving, 2016)

Table 1 shows technical data of partially enclosed lifeboats. (EO Lifesaving, 2016a)

Technical Specifications of Partially Enclosed Lifeboats	
Length (m)	7.00-9.60
Height (m)	3.10-3.45
Width (m)	2.7-4.60
Davit load (kg)	6367-17000
Hook distance (m)	6.6–9.2 m
Capacity (persons)	45-150
Maximum speed (knots)	6
Propulsion	Inboard diesel engine and propeller
Hull	Fire retardant glass fiber reinforced polyester (GRP)

(IMO, 2010; Wankhede, 2016b; Freefalllifeboat.com, 2016; HY-Precision Technology, 2016; SHM, 2016)

A new type of partially enclosed lifeboats has recently been developed named the mega lifeboat (Modell name: CRV55) to counter the demand of the growing cruise ships. Normally, lifeboats are not permitted to have more than 150 passengers according to regulations. However, alternative designs can be made, if proven to have equivalent level of safety. The mega lifeboats have a capacity of 370 persons and are launched with davits. They have a length of 16.7m, width of 5.6m and a top speed of 6 knots. (RINA, 2016a; Royal Caribbean Cruises, 2015)

Figure 7 shows a mega lifeboat on a cruise ship. Picture taken from: (Flickr, 2016)

Totally Enclosed Lifeboats

Totally enclosed lifeboats are better protected against the surroundings than partially enclosed lifeboats, due to their enclosure, but their accessibility is lower. Thus, their area of use is often other than passenger ships, e.g. cargo or tanker ships. Many models have enhanced passive and active fire protection systems, e.g. external water spray system and internal air supply system. Table 2 shows an example of the range of technical specifications of a totally enclosed lifeboat.

Figure 8 shows a totally enclosed lifeboat. Picture taken from: (EO Lifesaving, 2016)

Table 2 shows technical data of totally enclosed lifeboats. (EO Lifesaving, 2016b)

Technical Specifications of Totally Enclosed Lifeboats	
Length (m)	5.00-12.50
Height (m)	2.85-4.00
Width (m)	2.20-4.20
Weight (kg)	4365-22395
Hook distance (m)	4.6-12.1
Capacity (persons)	22-150
Maximum speed (knots)	6
Propulsion	Inboard diesel engine and propeller
Hull	Fire retardant glass fiber reinforced polyester (GRP)

(Wankhede, 2016b; Freefalllifeboat.com, 2016; SHM, 2016; HY-Precision Technology, 2016)

Free-fall Lifeboats

A free-falling lifeboat is a totally enclosed lifeboat but has a different way of launching. It is launched through a davit mechanism and slides from a ramp down into the water below. Due to the height of drop, it is designed in an aerodynamic shape so that the force of impact is reduced when penetrating the surface of water. The advantage of free-fall lifeboats is its fast launching ability. Due to this, they are primary used on tankers and oilrigs, where there is a higher risk for rapid-fire development. The free-fall lifeboats are normally located on the stern of the ship to maximize the clear area distance from the vessel when launched. Since free-fall lifeboats are often designed for different purposes than evacuating passenger ships, their capacity varies and tends to be lower than other types of lifeboats. Table 3 shows example on the range of technical specifications from free-fall lifeboats.

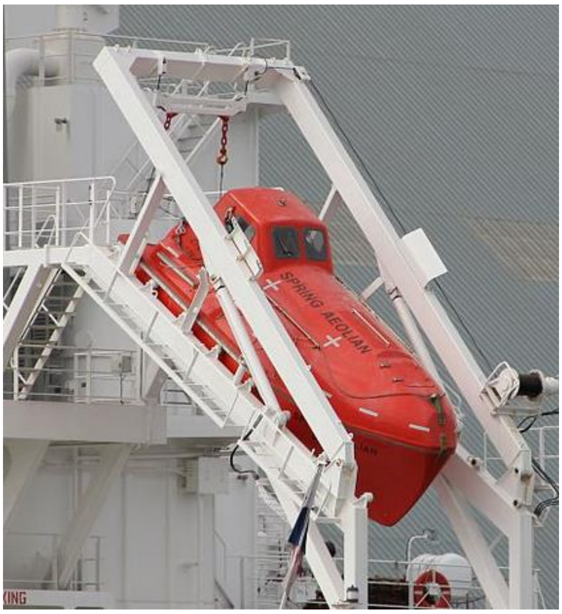

Figure 9 shows a free-fall lifeboat. Picture taken from: (Wikipedia, u.d.)

Table 3 shows technical data of free-fall lifeboats. (EO Lifesaving, 2016)

Technical Specifications of Free-fall Lifeboats	
Length (m)	4.9-16.5
Height (m)	3.10-3.55
Width (m)	2.25-3.74
Davit Load (kg)	4040-25500
Capacity (persons)	16-100
Certified drop height (m)	16-42
Length of ramp (m)	5.90-19.80
Maximum speed (knots)	6
Propulsion	Inboard diesel engine and propeller
Hull	Fire retardant glass fiber reinforced polyester (GRP)

(Wankhede, 2016b) (Wankhede, 2016a; Wankhede, 2016b; Survitec, 2016)

2.2.2 Liferafts

Liferafts are survival crafts, which are collapsible. They are stored in their collapsible state in sealed fiberglass containers on the deck of ship. Unlike lifeboats, SOLAS regulations require them to be removed and inspected periodically by a certified agency and never by the ship's crewmembers themselves. The liferafts contain basic survival equipment. When launched they are inflated by high-pressure gas. There are two methods of launching. The first is by inflating them on board the ship and then lower them with the use of davits. This enables the persons to enter the liferaft before launching. The second method is by throwing/releasing the canister overboard. Due to its effectiveness, this method is far more popular. On passenger ships the liferafts are boarded through chutes or slides. This system is referred to as the marine evacuation system.

Figure 10 shows a liferaft stored in a canister. Picture taken from: (Jansoone, 2006)

2.2.2.1 Marine Evacuation System

The marine evacuation system *(MES)* enables mass evacuation through chutes or slides, which transfer people from the ship to inflatable liferafts. MES consists of five components.

- Controls – which are used to launch MES.
- Storage box – that contains the chute/slide and used to embark the system when used.
- Chute/slide – it is the passage that is used to transfer people from the main ship to liferafts.
- Liferafts – that are stored in pairs of 1-4 depending on system.
- Bowsing winch – it is used to keep the raft in place by the side of the ship, while embarkation takes place.

Figure 11 shows a storage box for MES. Picture taken from: (Hering, 2013)

In comparison to lifeboats, MES takes less space on deck and has a greater loading capability. In addition, the system only need one person to be launched according to LSA code regulation. When launched the inflate time is around 2 minutes depending on type of system. MES can be divided into two main type categories:

Chute systems

In a chute system, the evacuees are evacuated from the ship to the liferafts by a vertical chute passage, which allows people to slide down, vertically. Examples on the range of technical specifications from chute systems are shown in Table 4.

Table 4 shows an example on technical data for a MES chute system. (Viking, 2016)

Technical Specifications of Chute Systems	
Stowage height (m)	5-20
Number of chutes	1-2
Number of liferafts	1-3
Liferaft capacity (persons)	50-150
Total capacity (persons)	100 - 300
Loading speed (persons)	565-908 persons/30min
Material	Kevlar
Launching	Activated by one handle. Does not need an external power supply

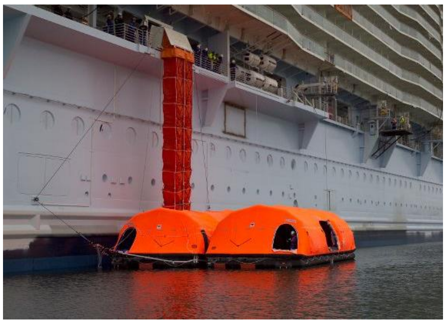

Figure 12 shows chute system with multiple rafts. Picture taken from: (Viking, 2016)

Slide systems

In a slide system, the evacuees are transferred from the ship to the liferafts with the help of slides. Example of technical data is showed in Table 6.

Table 5 shows an example on technical data for a MES slide system (Viking, 2016)

Technical Specifications of Slide Systems	
Stowage height (m)	1.5-15
Number of slides	1-2
Slide length (m)	7-20
Number of liferafts	1-4
Liferaft capacity (persons)	25-150
Total capacity (persons)	25 – 400
Loading speed (persons)	300-657 persons/30min
Material	Nylon webbing covered with natural rubber
Launching	Activated by one handle. Does not need an external power supply

Figure 13 shows a MES slide system. Picture taken from (Viking, Slide Systems, 2016a)

(Freefalllifeboat.com, 2016; MI News Network, 2016; LSA MES, 2016; Motorship, 2011; Wankhede, 2016; www.uscg.mil)

2.2.3 Rescue Boats

In addition to lifeboats and liferafts, rescue boats, also called fast rescue boats (FBR), are used during evacuation. However, they have a different purpose than the survival crafts. The rescue boats are primarily used in man over board operations and for co-ordination during evacuation, e.g. towing the liferafts away from shipwreck. The rescue boats have lower capacity than lifeboats and are faster. The launching takes place with a davit, powered by gravity. Table 6 shows examples of technical specifications from rescue boats.

Figure 14 shows a rescue boat with its davit system. Picture taken from: (NauticExpo, 2016)

(NauticExpo, 2016; HY-Precision Technology, 2016a; Norsafe, 2016)

Table 6 shows an example on technical data for a rescue boat. (Harding, 2016)

Technical Specifications of Rescue Boats	
Length (m)	6.10-7.82
Height (m)	2,20-2.72
Width (m)	2.20-2.87
Davit load (kg)	1631- 3644
Capacity (persons)	8-15
Maximum speed (knots)	22-30
Propulsion	Inboard diesel engine and water jet
Hull	Fire retardant glass fiber reinforced polyester (GRP)

2.3 Ship Evacuation Procedures

This section addresses the procedures during the evacuation of passenger ships. There are several regulatory requirements. As, for example, all passenger ships need to have a muster list, which gives instructions on which actions the crew should take when the alarm is sounded *(SOLAS Chp. III, Reg. 37)*. In addition, a decision support system for emergency management should be available on the navigational bridge on all passenger ships. *(SOLAS, Chp. III. regulation 29)* (IMO, 2014). The evacuation process with survival crafts can be divided into four main phases, illustrated in Figure 14.

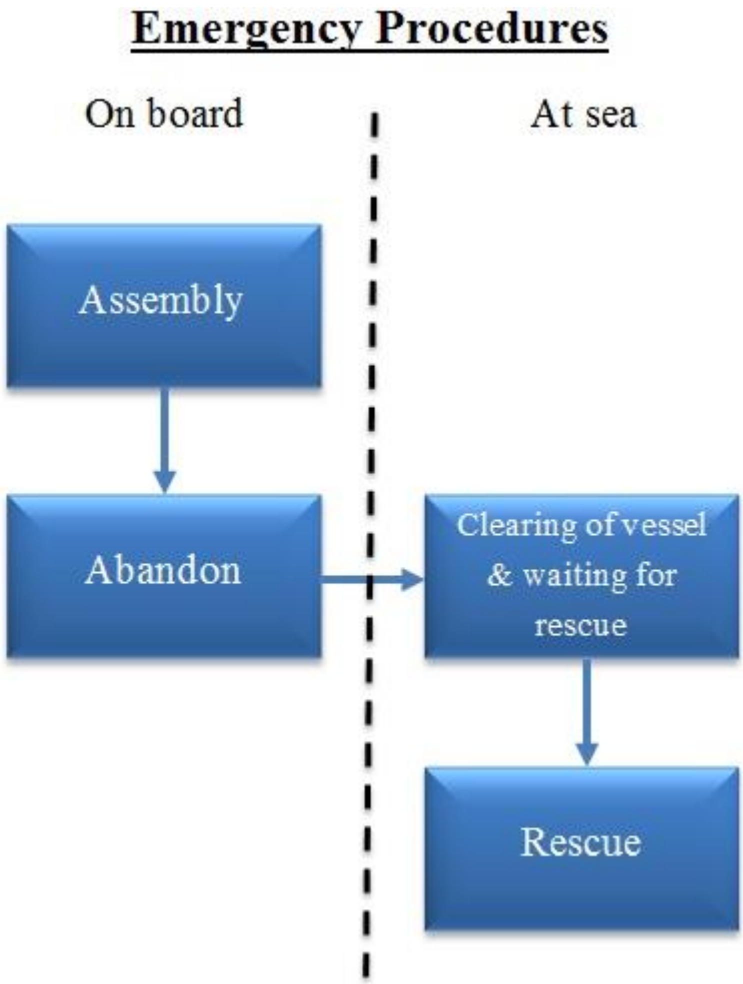

Figure 15 shows the emergency procedures during evacuation of ship.

2.3.1 Assembly phase

The assembly phase starts with the sounding of the general alarm. Passengers are then instructed to go to the mustering stations. Depending on type of ship and procedures, the passengers need to done lifejackets, which can be collected from their cabins or at the muster stations. The crew assignments are to warn the passengers, distribute lifejackets and help passengers donning them correctly, controlling the movement of passengers to the mustering stations and ensuring that blankets are taken to the survival crafts. (RINA, 2016c; IMO, 2014)

2.3.2 Abandonment phase:

The abandonment phase starts when the master gives the order of abandoning ship. In the abandonment phase, the passengers need to be transferred from the mustering stations to the embarkation decks (if that is not already the same area) and then embark into survival crafts, which are launched in to the sea (RINA, 2016c). In contrary to the common believes, no regulations exist that women and children have priority over men during embarkation of survival crafts. The safety design of ships is such that there are enough survival craft accommodations for more than every person aboard. Therefore, selective embarkation, which would in fact prolong the embarkation process, is not needed. However, injured people might be granted priority during embarkation. According to SOLAS regulations, it should take maximum 30 min for all persons aboard to abandon the ship from the point of time when the abandon ship signal has been given *(SOLAS, Chp. III, regulation 21.1.3)*. (IMO, 2014)

2.3.3 Clearing of vessel & waiting for rescue

When the survival crafts have been launched to sea, they need to disengage from the launching appliances and steer away from the ship, since a threat can be posed to the survival crafts e.g. fire and collisions. Liferafts are towed and gathered by the vessel's rescue boats. When the clearing of vessel is accomplished, the survival crafts need to await rescue. (Falck Safety Services, 2014; Corrignan, Breuillard, & Maurier, 2011)

2.3.4 Rescue phase

The rescue phase is the transferring of evacuees from the survival crafts to the rescue units. There are no standardized procedures for this. The evacuees are commonly rescued by three means:

- Re-routed ships (e.g. other passenger ships, cargo ships etc.)
- Maritime rescue boats
- Helicopters

(Corrignan, Breuillard, & Maurier, 2011)

2.4 Regulations

This chapter will describe regulations, which are considered to be relevant for the evacuation of passenger ships using survival crafts.

2.4.1 IMO

IMO *(International Maritime Organization)* is the main agency in United Nations responsible for maritime regulations. As expressed by IMO themselves, they are responsible for *"the safety and security of shipping and the prevention of maritime pollution by ships"* (IMO, 2016a). Mandatory regulations, which are founded by IMO, are binding for the United Nations' members. Guidelines and other treaties, which are not mandatory, can be determined by every individual state as to what extent these recommended treaties should be applied (IMO, 2013). All merchant ships (cargo and passenger ships) are obliged to follow the IMO's regulations and standards at international waters (IMO, 2016c).

IMO was founded 1948 and has since then worked continuously to improve the safety of ships. Their first assignment was updating the old SOLAS regulations *(International Convention for the Safety of Life at Sea)*. They established an updated version, which came into force 1965 replacing the older one and addressing regulations of fire protection, life-saving appliances, safety of navigation and the transportation of dangerous goods. Furthermore, 1972 they adapted the COLREG convention *(International Regulations for Preventing Collisions at Sea)*, which led to a reduced number of collisions. 1979 they released an additional convention called SAR Convention *(International Convention on Maritime Search and Rescue)*, which regulations has led to additional safety of evacuees. Another achievement by IMO was the introduction of the STCW convention (*International Convention on Standards of Training, Certification and Watchkeeping for Seafarers)*, which addresses the training of crewmembers and personnel (IMO, 2013).

2.4.2 SOLAS Convention

SOLAS convention *(International Convention for the Safety of Life at Sea)* is a treaty, which according to IMO, "is generally regarded as the most important of all international treaties concerning the safety of merchant ships." (IMO, 2016). It was adopted 1914, as a response to the tragic sinking of Titanic, and has ever since been continuously improved (IMO, 2016g). The current version of SOLAS was adopted in 1974 and brought into force 1980 (IMO, 2014). The SOLAS regulations addresses the following:

- "General Provisions"
- "Subdivision and stability, machinery and electrical installations"
- "Fire protection, fire detection and fire extinction"
- "Life-saving appliances and arrangements"
- "Radiocommunications"
- "Safety of navigation"
- "Carriage of Cargoes"

- “Carriage of dangerous goods”
- “Nuclear ships”
- “Management for the Safe Operation of Ships”
- “Safety measures for high-speed craft”
- “Special measures to enhance maritime safety”
- “Special measures to enhance maritime security”
- “Additional safety measures for bulk carriers”
- “Verification of compliance”
- “Safety measures for ships operating in polar waters”

(IMO, 2014)

SOLAS is mandatory for all merchant ships traveling on international voyages. However, ships operating on inland or on domestic routes are not covered under the SOLAS regulations. The last decade IMO has recognized this issue and is currently working on improving the regulations for unconventional ferries (IMO, 2016b). The SOLAS regulations specify the location of survival crafts on passenger ships. It states that survival crafts should be stowed as near the water surface as safe and practically possible. In addition, the lifeboats should be stowed as far away from the ships propeller as practicable. (IMO, 2014, s. 240)Furthermore, the following regulations regarding evacuation times can be found in the SOLAS regulations:

Stowage of survival craft

It should take no more than 5 min to prepare a survival craft for embarkation and launching by two crewmembers. *(SOLAS, Chp. III, regulation 13.1.3)*

Survival crafts

It should take at most 30 min to launch all the survival crafts required, with its full complement of people and equipment, to evacuate the total number of persons on board. That period of time starts when the passengers are gathered at the assembly points with the lifejackets donned and ends when the total number of persons has abandoned the ship. *(SOLAS, Chp. III, regulation 21.1.3)* (IMO, 2014)

2.4.3 LSA code

LSA code *(International Life-Saving Appliances Code)* specifies the international requirements for the lifesaving appliances, which are required by chapter 3 in the SOLAS. It was brought into force 1998 and is a mandatory treaty. Since the LSA code regulates the means of evacuation, it is very relevant for the evacuation of passenger ships. The LSA code, describes the following appliances:

- personal life-saving appliances like lifebouys, lifejackets, immersion suits, anti-exposure suits and thermal protective aids
- visual aids, such as parachute flares, hand flares and buoyant smoke signals;

- survival crafts
- rescue boats
- launching and embarkation appliances, marine evacuation systems and line throwing appliances
- general alarm and public address systems
  (IMO, 2010)

Furthermore, recommended tests of the life-saving appliances have been developed by IMO, to ensure that the appliances meet the required standards of the LSA code. As from first of July 2010, all life-saving appliances which are installed on board ships, should have undergone these recommended testing or equivalent ones (IMO, 2010). The LSA code specifies requirements so that survival crafts and rescue boats can be launched even during unfavorable conditions of trim up to 10 degree and list of up to 20 degree (IMO, 2010, s. 60) Research conducted in the Research Institute of Marine Engineering show that the tilting and motion of ships can have a negative influence on the walking speed (Yoshida, Masaki, & Tsuneo , 2001) Furthermore, the LSA code gives the following regulations on evacuation times:

Lifejackets

"An adult lifejacket shall be so constructed that: at least 75% of persons who are completely unfamiliar with the lifejacket can correctly don it within a period of 1 min without assistance, guidance or prior demonstration. *(LSA code, 2.2.1.5.1)*

Inflatable liferafts

"Inflation shall be completed within a period of 1 min at an ambient temperature of between 18°C to 20°C". *(LSA code, 4.2.2.3)*

General requirements for lifeboats

"Every passenger ship lifeboat shall be so arranged that it can be boarded by its full complement of persons in not more than 10 minutes from the time the instruction to board is given. Rapid disembarkation should also be possible". *(LSA code, 4.4.3.1)* (IMO, 2010a)

(IMO, 2010)

2.4.4 ISM Code

In the late 1980's several serious accidents occurred as a result of human and management errors. This was noted by IMO and as a countermeasure a resolution was adopted in 1989 named "Guidelines on management for the Safe Operation of Ships and for Pollution Prevention", A.647(16) (IMO, 2016e). This was the predecessor to the ISM code *(International Safety Management code)* (IMO, 2016f). In 1998, the code became mandatory and in cooperated in the SOLAS regulations as a new chapter IX "Management for the Safe Operation of Ships". The objective of the ISM code is to:

- *"ensure safety at sea"*
- *"prevent human injury or loss of life"*
- to avoid damage to the environment and ship
  (IMO, 2016e)

This is to be achieved by influencing the policy of how ships are managed and operated. As written by IMO, *"The ISM Code establishes an international standard for the safe management and operation of ships and for the implementation of a safety management system (SMS)."* (IMO, 2016f)

2.4.5 STCW Convention

STCW (*International Convention on Standards of Training, Certification and Watchkeeping for Seafarers)* is a treaty brought into force 1984. It has the purpose of enhancing the safety by establishing minimum standards of training, certification and watchkeeping of the seafarer personnel (IMO, 2016d). It is applied to all passenger ships on domestic and international voyages (International Transport Workers' Federation, 2016).

STCW regulates which type of training the seafarer personnel should acquire, how the training should be conducted and the minimum requirements of the seafarer personnel. This has led to an increased competence by the seafarer personnel (IMO, 2016d). A relevant aspect of the STCW convention, bearing in mind passenger ferries, is that that personnel operating on passenger vessels should have training in crowd, crisis management and human behavior (IMO, 2016h).

Furthermore, the convention regulates the labor capability of the personnel and lists acceptable criteria for work and rest hours. It also gives instructions for maximum alcohol and drug limits in blood and breath by the seafarer personnel (IMO, 2016h).

IMO has reported that many fraudulent certificates may exist within the shipping industry. The personnel carrying such certificate has not undergone the required training and, can as a result, expose danger to themselves and the environment. The convention has instated verification regulations of certifications, which has led to a reduced number of such fraudulent certificates and activities (IMO, 2016b).

2.4.6 SAR Convention

The SAR convention *(International Convention on Maritime Search and Rescu*e) was established to enhance the safety for people being in distress at sea. Historically, traditions have existed long time among seafarers to help other vessels in distress. However, it was not until later on when treaties were implemented such as SOLAS 1974 that it became obligatory to help. Nevertheless, there was no international system, at that time, addressing SAR *(Search and Rescue)* operations. The possibility of launching SAR missions varied within the different states and in some states, it was non-existing. As a countermeasure, the convention was established, with the main purpose that conducting SAR missions should be possible independently of location. This issue was addressed with regulations, which divided the world's oceans into different zones where each state got assigned areas of responsibility. In addition, the convention states that all of the states, surrounded by coastal waters, should have rescue co-ordination centers, which enables SAR services 24-hours a day with qualified English speaking workers. The convention describes which procedures should be used and who is responsible for what during a SAR operation. In addition, the regulations states that ships should have ship-reporting system which tracks their position. The use of it has reduced the delay during the assistance of persons being in distress. The convention has in general contributed to an overall increase in efficiency of rescue operations. It is mandatory and its regulation applies to all member states of IMO (IMO, 2016i).

2.4.7 IMO Guidelines

To simplify the analysis of evacuation on passenger ships, IMO has developed "Guidelines for evacuation analysis for new and existing passenger ships" (IMO, 2007). However, since they are only guidelines it is up to every individual state to decide in which extent they want to apply them (RINA, 2016c).

Suggested by the guidelines *(MSC. 1/Circ. 1238)*, there are two methods of making an evacuation analysis. The first method is a simplified analysis and is suitable in the early stages of ship design to calculate the evacuation times. According to The Royal Institution of Naval Architects *(RINA)* this method "treats passengers like particles moving in a liquid flowing through a pipe". The second method is more advanced and is based on computer simulations where the passengers and crew are seen as individuals (RINA, 2016b).

The guidelines give recommendations, which are based on fire risk analysis, on the total evacuation time. This time is defined as, the time from when the people are notified of an emergency until the time when the total number of persons on board has abandoned the ship. For ships with less than three main vertical zones and ro-ro passenger ships, the total evacuation time should maximally be 60 min. If the passenger ship has more than three main vertical zones, the maximum evacuation time should be 80 min (IMO, 2007). Considering this, the total evacuation time, according to the guidelines, should be in the range of 60-80 min.

3. CASE STUDIES

This chapter contains case studies of past passenger ship incidents. The information is collected through investigatory reports and media reporting. The purpose of the case studies is to give information, which can be analyzed through an evacuation point of view so that issues can be identified and used to learn lessons from.

3.1 Norman Atlantic Fire 2014

In December 28, 2014, the ro-pax ferry M/S Norman Atlantic was bound on a route from Patras (Greece) to Ancona (Italy). The navigation of the route is displayed in Figure 16.

Figure 16 shows MS Norman Atlantic ferry pre-incident. Picture taken from: (Cyprus, 2015)

Figure 17 show the planned route of MS Norman Atlantic during and scene of incident. Picture: (BBC News, 2014)

The ship was carrying, according to the passenger and crew lists, 419 passengers and 55 crew members (Marine Invesigations, 2015). However, it is known that the number of occupants was in reality more because there were persons on board that were unaccounted for. The exact number of occupants is unknown (Straughton, 2016). According to navy Admiral Giovanni Pettorino, 80 of the rescued persons were not on the passenger list (BBC News, 2014). Considering this, the total numbers of passengers can be estimated to around 500. For its disposal, Norman Atlantic had the following LSA *(Life-saving appliances),* evenly distributed on both sides, shown in Table 7.

Table 7 shows the safety equipment available on MS Norman Atlantic (Marine Invesigations, 2015).

LSA	Capacity
2 Lifeboats	150
2 Rescue boats	
10 liferafts	8 for 101 persons 2 for 25 persons
24 lifebuoys	
Lifejackets	

3.1.1 Reconstruction of events

At the time this paper was written, the investigation of the accident was not completed. However, a preliminary report has been released by the Ministry of Infrastructure and Transport in Italy and have been presented by the head of investigation Fabio Croccolo, in Copenhagen in 2015. This information and the reporting of media have been used to reconstruct the chain of events during the incident. The result is shown in Table 8. Fabio Croccolo claimed, during his presentation that it was difficult to piece together what has happened in a chronological order. The reason for this is that it has been problems to retrieve the information from the VDR recorder *(data recording system)* (Maritime Executive, 2015).

Table 8 shows the sequence of events during the fire on MS Norman Atlantic.

Time	What happened
December 27th, 16.50	MS Norman Atlantic ship left Patras to Igoumenitsa (Marine Invesigations, 2015)
December 27th, 23.13	Stop in Igoumenitsa (Marine Invesigations, 2015)
December 28th, 00:50	The ship left Igoumenitsa to Ancona (Marine Invesigations, 2015)
December 28th, (time unknown)	Ignition starts in garage, deck 3 (Marine Invesigations, 2015)

04.18	Smoke detector activated on deck 4. Reports of smoke coming out of a truck (Maritime Executive, 2015)
04.23	The fire on Deck 4 was acknowledged by the crew (The ambient temperature at this time was 2°C and wind speeds of 45knots (Maritime Executive, 2015)
04.26	"Crew call" (Marine Invesigations, 2015)
04.28	"Chief Mate sent to deck 4" (Marine Invesigations, 2015)
04.32	"Captain informed about fire on deck 4" (Marine Invesigations, 2015)
04.33	"Captain orders Drench pump start from ECR" (Marine Invesigations, 2015)
04.34	"General Emergency alarm sounded" (Marine Invesigations, 2015)
04.36	"ECR abandon by ER personnel on duty" (Marine Invesigations, 2015)
04.41~04.54	A power blackout occurred, the ship lost propulsion. The emergency diesel generator did not start for, unknown reason. (Maritime Executive, 2015)
04.50	Greece becomes coordinator for SAR mission (Marine Invesigations, 2015)
09.00	Italy receives the authority of being coordinator for the SAR mission (Marine Invesigations, 2015)
15.44	111 persons have been rescued, according to the Italian Navy. (Keep Talking Greece, 2014)
19.30	165 persons have been rescued. Several of the survivors show symptoms of hypothermia. (Keep Talking Greece, 2014)
21.00	The ferry is reported to have a 7-degree list, due to water from the drench system. (Keep Talking Greece, 2014)
December 29th, 11.00	329 persons are rescued and 149 are reported to still be on board. (Keep Talking Greece, 2014)
14.15	The only remaining persons on board are reported to be the captain and 4 Italian Navy's officials. (Keep Talking Greece, 2014)

According to the investigation, conducted by the Ministry of Infrastructure and Transport in Italy, the wind condition and motion of ship changed the smoke plume in the ship's partially opened cargo space. This delayed the smoke detection considerably. The preliminary results of the investigation show that the fire started on deck 3 and continued spreading to other decks. It is estimated that the temperatures have reached over 1000°C on deck 4, which is the main ro-ro cargo deck. Fabio Croccolo says, in his presentation that the high temperatures make it impossible to determine the exact location and cause of fire. However, plausible ignition sources have still been identified. During the night of voyage, the ship was completely booked up and was therefore very crowded. It is not uncommon, mentioned by Fabio Croccolo, that unauthorized persons remain in the ro-ro deck to escape the congestion above. Since it was only

2°C during the night, it is likely that the remaining persons have used heating equipment. The investigation has identified the following potential ignition sources (Maritime Executive, 2015).

- *"unauthorized operation of portable gas fuelled heating equipment*
- *use of flammable liquids*
- *use of open flames*
- *electrical system fault*
- *failure functioning of electric users"*
  (Marine Invesigations, 2015)

Figure 18 shows MS Norman Atlantic burning and a rescue helicopter evacuating persons. Picture: AP Photo/SKAI TV Station.

When the information of fire on board reached the master (captain), he ordered promptly to activate the drench system on deck 4. The first engineer performed his duty accordingly, but made the mistake of opening the drench system on deck 3 instead of deck 4. The fire was therefore not suppressed and could continue spreading. According to Fabio Croccolo in his presentation, the activation of the correct drench system would have not extinguished the fire. This statement was based on a similar incident, occurring on M/V Sorrento, where the correct drench system was activated in the early stages of fire but did not extinguish it (Maritime Executive, 2015).

3.1.2 Evacuation

The master decided, without any substantial delay, to sound the general alarm and evacuate the ship (Marine Invesigations, 2015). However, according to several passenger statements no general alarm was sounded.

"There was no alarm; that much was absolutely clear. We just saw a girl from the crew banging on doors and telling people to get out. There was no muster station and no plan. By the time we made it onto the deck, the fire had spread, burning life rafts and life vests on one side." (Elafros, 2015)

The absence of the general alarm can perhaps be explained by electrical blackout that occurred. According to the investigation the backup generator did not start (Maritime Executive, 2015). Furthermore, the surviving passengers pointed out that the evacuation process was very chaotic, confusing and that limited help from the crew was given. A passenger of the ferry says, according to the news Ekathimerini:

"The crew was nowhere to be seen. Life jackets were being distributed to passengers by some truck drivers who had used an ax to smash open a storage cupboard. Even in the towing effort later, three Greek truck drivers risked their lives but not a one from the crew," says Vassalos. (Elafros, 2015)

Another statement of a survivor is made, by the same news source:

"From the start of the fire, there was nothing but confusion. Three Italian crewmen decided to release a life boat but witnesses say they appeared not to be sure how." (Elafros, 2015)

Furthermore, there is reporting by the passengers that there was no co-ordination by the crew during the abandonment of the ship (Keep Talking Greece, 2014).

The flames engulfed the starboard side of the ship. By this time, the evacuation had still not been completed. According to the presentation, performed by Fabio Croccolo, all lifesaving equipment on the starboard side was unusable due to smoke and high flames during the time of evacuation. The flames and high temperatures coming out through the garage openings destroyed all lifeboats and rescue systems on starboard side (Maritime Executive, 2015).

The port side, in the other hand, was now the only remaining side with means of evacuation available. However, it had its own shares of problematics. The high wind created problems with the safety equipment. As an example, the MES chute system did not function as intended, due to effects of the wind. Two persons evacuated successfully to the liferaft below. However, the following two persons using it were trapped in the chute and obstructed the path of evacuation. The remaining persons in the liferaft cut the rope, which connected the liferaft to the rest of the marine evacuation system, to escape and leaving the MES unusable due to the fact that the chute was no longer connected to a lifesaving liferaft. One of the two persons trapped in the chute died.

According to Fabio Croccolo's presentation, the master of Norman Atlantic stated, that the MES were being launched by the passengers themselves, without any guidance from the crew (Maritime Executive, 2015). It is reported by the news Business Insider, that the launching of lifeboats/rescue boats was impeded by loss of power (Pozzebon, 2015). Moreover, there was only one survival craft, which was successfully launched, reported by the Greek coast guard (Keep Talking Greece, 2014).

It is pointed out in the presentation by Fabio Croccolo, that there were substantial crew issues. Firstly, the crewmembers had only been working on the ship for 3 weeks. Secondly, the crew was employed by two different separate companies. Thirdly, the crew consisted of different nationalities, both Greek and Italian, depending on which company they were employed by. The knowledge of English was very limited. (Maritime Executive, 2015)

As the evacuation possibilities by survival crafts became limited and the intensity of fire increased, people went up to the bow of the ship, deck 8, hoping for rescue. According to the investigation, this was the only safe area available for the passengers (Marine Invesigations, 2015) . This can be seen in Figure 17.

Figure 19 shows MS Norman Atlantic on fire. Evacuees are waiting on deck 8 for helicopter extraction. Picture: Guardia Costiera/AFP.

When the distress signal was transmitted by Norman Atlantic, a large-scale SAR operation was launched, which included Greek, Italian and Albanian SAR resources. In the beginning the Greek were in charge of the co-ordination of the mission, but gave later the command to the Italian SAR organization. The following SAR resources, displayed in Table 9, were deployed during the rescue of Norman Atlantic:

Table 9 shows the SAR resources used during the rescue of MS Norman Atlantic (Marine Invesigations, 2015).

Origin		SAR resources
Greek		3 helicopters 1 aircraft
Italy		12 helicopters 3 aircrafts 4 patrol vessels 1 ship
Albania		1 patrol vessel
Miscellaneous		13 merchant vessels 5 tugboats

According to Fabio Croccolo, during his presentation, that the SAR operation was hampered by weather and fire conditions. The conditions created by the fire damaged the SAR resources. Strong winds and high seas made it very difficult to evacuate persons. The tugboats' ability to tug was impeded by the flames and smoke. Consequently, the tugboats had limited access to the vessel and could only assist by stabilizing the ship to reduce the roll movements and by steering the ship so that the direction of smoke plume could be controlled (Maritime Executive, 2015). The helicopters airlifted nonstop for approximately 35 hours to extract all persons. Several evacuees suffered from hypothermia due to the long exposure to cold, rain and wind (Eaglenews, 2014).

Figure 20 shows passengers being evacuated with helicopter. Notice the un-launched rescue boat. Picture take from: (Keep Talking Greece, 2014).

There were signs of competitive behavior over the remaining rescue spots. BBC news reports of passenger witnesses claiming that:

“Everyone there was trampling on each other to get onto the helicopter," and that *"There was no queue or order.”* and *"The jungle law prevailed"* (BBC News, 2014)

Table 10 shows the results of the evacuation and by which means the persons on board were rescued/evacuated. It can be observed that the majority of persons were evacuated by SAR helicopters and only a quarter by Norman Atlantic’s own safety equipment.

Table 10 shows by which means the persons on MS Norman Atlantic were evacuated/rescued (Marine Invesigations, 2015).

Mean of rescue/evacuation	Number of persons rescued
Helicopters	358
Survival Crafts	88
Patrol Boats	6

Norman Atlantic did not sink, but suffered severe damage from deck 3-7 damage and substantial on deck 8. The death toll of the incident is confirmed to be 18 (Maritime Executive, 2015). From the section of “Lessons learned” in the preliminary investigation Fabio Croccolo summarizes what has been leaned so far:

- *“open ro-ro cargo spaces on passenger ships (new construction) should not be permitted”*
- *“Enhancement of passive protection of LSA from fire (garage openings)”*
- *“different crews belonging to different companies on chartered ships should be avoided”*

(Marine Invesigations, 2015)

Figure 21 shows the burned out Norman Atlantic. Picture: AP Photo/Antonio Calanni

3.2 Sorrento Fire 2015

In 28th of April 2015 M/V Sorrento, a ro-pax ferry, was bound on a route from Palma de Mallorca, the capital of the Balearic Islands, to the port of Valencia in eastern Spain. The ship was carrying 196 persons on board, but is reported to have possessed a total capacity for 954 persons by media. The weather conditions were calm, with little wind and waves. The Sorrento ferry was a sister vessel to Norman Atlantic and was of the same model and had the same specifications. (Marine Invesigations, 2015; Global Justice Network, 2015; The Guardian, 2015a; Badcock, 2015)

Figure 22 shows MV Sorrento pre-accident. Picture taken from: (Aratino, 2014)

According to Fabio Croccolo, the head of investigation of the Sorrento ferry fire, the preliminary results of the investigation shows that a fire started in the cargo deck, deck 4, during the course of voyage. At 12.45 o'clock, a distress signal was transmitted by Sorrento, transmitting that a fire was on board. As a countermeasure, the drencher system was activated and a fire team was sent to the cargo deck to suppress the fire. However, the fire team had difficulties in accessing the fire, due to the small passages between vehicles. (Marine Invesigations, 2015; Maritime Executive, 2015)

For the SAR operation, the coastguard dispatched four ships and one helicopter. Spain's Guardia Civil police dispatched two ships and one helicopter. In addition, two nearby passenger ships, were directed to Sorrento's position to assist with the rescue (Suárez, 2015).

According to the reporting of news, the master did not initially consider an evacuation to be required. However, when it became clear that the firefighting effort had failed to control the fire, an order to abandon ship through the starboard side was given, because the intensity of fire was greater on the port side. The investigative report, by the Ministry of Infrastructure and transport in Italy, reports that the evacuation was performed through the ship's two lifeboats, one on each side. (Maritime Executive, 2015; Badcock, 2015; Suárez, 2015)

Four of the crewmembers, which were a part of the fire team, did not succeed to make it to the survival craft embarkation zones and were therefore evacuated with helicopter. Due to smoke inhalation, they were taken to hospital to receive medical treatment. (World Maritime News, 2015; Badcock, 2015; Petrov, 2015a) After the incident, a representative from the shipping company commented on the incident and showed his gratitude to all the organizations that helped in the rescue, in particular "search and rescue as well as the professionalism of the crew", he said (Suárez, 2015).

Figure 23 shows Sorrento on fire. Picture: Salvamento Maritimo.

Fabio Croccolo expressed in his presentation, that the incident was almost the identical to the case of Norman Atlantic, which had happened only one year before. The fire started in the same area and the ship had the same design. However, in comparison to Norman Atlantic, Sorrento's fire counteracting-measures were implemented during the early stage of fire and still Sorrento was totally destroyed (Maritime Executive, 2015).

3.3 Minor Incidents

In this section, case studies are conducted on minor incidents. The minor incidents are interesting as well, since they can have a substantial influence on a full-scale evacuation, even though they are regarded as minor. In addition, to assess the risks of evacuation, not only is the magnitude of the consequence to be taken into consideration but also the frequency.

3.3.1 Thomson Majesty – February 2013

The 10th February 2013, the Maltese cruise ship Thomson Majesty was docked alongside in Santa Cruz de La Palma, on the Canaries Islands. It was performing one of its regular lifeboat safety drills. At this particular day, three lifeboats were lowered. One of them was stopped during the lowering, due to a hydraulic fault. The lifeboat and the crew of eight were suspended one meter above the waterline for 40 minutes while repair was being made. The safety officer made then the decision to abort the lowering and hoist the lifeboat up again. When the lifeboat was at the level of the embarkation deck, the forward wire fall suddenly parted, causing the lifeboat to swing 45° and putting additional load on the stern holding mechanism. This made it fail and consequently causing the lifeboat to fall down 20 m and landing upside down in the sea. Five of the crewmembers died and three were injured. The following marine investigation report, conducted by Transport Malta, concluded what the immediate cause of the accident was:

"The fall of the lifeboat was the result of a parted wire rope fall that was caused by severe internal corrosion at the break point". (Marine Safety Investigation Unit, 2014)

Figure 24 shows a close up of the internal corrosion on the wires, holding the lifeboat. Picture taken from: (Marine Safety Investigation Unit, 2014)

Additional conclusions in the investigative report showed that the crew did not detect the wire rope's deteriorating condition because they did not possess the knowledge of how to do it and because it is difficult to identify it. This conclusion was made, even though the personnel were trained and qualified according to the STCW regulations. The davit's wire falls were not old, since they were replaced in August 2010. The investigative authority performed break load tests on the broken wire ropes to evaluate its strength. The results showed that it did not fulfill the specifications of the davit's manufacturer or the specifications of ordered wire, ordered by Thomson Majesty during the replacement in 2010. According to the davit manufacturer, the break load should be 474kN. The ordered had 565kN, but the tested wire had only break load strength of 306kN, in its original condition. This means that a weaker wire rope was installed, than the specifications of the davit's manufacturer required. This error was not identified. In April 2012, a thorough examination was made of lifeboats and its launching appliances on Thomson Majesty, according to regulations of SOLAS. The examination included examinations for corrosion and performance tests during overload. All lifeboats and launching appliances passed the examination. (Marine Safety Investigation Unit, 2014)

3.3.2 Pride of America – July 2015

On July 28th 2015, the Pride of America was docked in Hilo Harbor, in Hawaii, and performing one of its routine abandonment drills. Whilst lowering one of the rescue boats with two crewmembers aboard, the wire ropes gave away. This caused the rescue boat to fall down, around 15m, and impact against the water below. The two men were seriously injured and taken to hospital for treatment. (Khon2 Staff, 2015; Petrov, 2015; Cruiseminus, 2016)

3.3.3 Costa Mediterranea – August 2015

The 24th of August 2015, the cruise ship Costa Mediterranea was anchored in a port of Montenegro. It was lowering lifeboats to take passengers on excursions in the fjord of Kotor. Whilst lowering one of the lifeboats a cable broke causing the lifeboat to fall and hang in a vertical position. No one was on board during the lowering and there are no reports of injuries. Costa Cruises commented on the incident and explained that they experienced technical problem while lowering the lifeboat and that during the incident neither the safety of crew or passengers were put at risk. (Stuards, 2015)

Figure 25 shows the lifeboat hanging vertically. Picture: Drago Brdar, Shipspotting

3.3.4 Norwegian Breakaway – July 2016

The 20th of July 2016, an incident occurred concerning the cruise ship Norwegian Breakaway. The ship was at the time positioned in port, in Bermuda, and was performing one of its routine lifeboat safety drills. During the launching of one of the rescue boats, which had four crewmembers on board, equipment failure occurred, which caused the boat and crew to fall down. According to Cruise Bruise Investigations, an organization that reports on and investigates incidents on cruise ships, a Bermuda Maritime Operations representative made the statement regarding the incident:

Figure 26 shows the rescue boat after incident. Picture captured from: (Schuler, 2016)

"the lifeboat was left hanging from one wire after it broke free from the tethering, resulting in the four crew members falling into the water."

The crewmembers at question were taken to hospital, where they received medical attention. Two of them died following their injuries (Cruise Bruise Investigations, 2016).

3.3.5 Harmony of the Seas – September 2016

The 13th of September 2016, an incident occurred in the port of Marseille, France, involving the largest cruise ship in the world, Harmony of the Seas. With the length of 362m, it is more than 50 m longer than the Eiffel tower in Paris (Newton, 2016).

Figure 27 shows world's largest cruise ship, Harmony of the Seas. Picture: (MercoPress, 2016)

When the ship was having one of its weekly lifeboat safety drills, a lifeboat broke free under the launching process. As a consequence, it fell around 10 m to the water below causing injuries to four crewmembers and killing one, operating the lifeboat. According to an article at Cruise Bruise, Marseille's marine emergency service spokesman stated what happened,

"The lifeboat became detached" from the boat"

The cause of failure was the combination of internal corrosion within the wire, holding the lifeboat, and unrecognition of the problem by the personnel. Harmony of the Seas, had only been in duty for one year and was launched the 19th of June 2015 (Cruise Bruise Investigations, 2016a).

4. INTERVIEWS

This chapter contains information about the interviews, which were conducted in this research. It describes how the interview was conducted and the results, which were received.

4.1 Overview

A visit was made to the SSRS *(Swedish Sea Rescue Society)* and to JRCC *(Joint Rescue Coordination Centre)* in Gothenburg, in Sweden, to conduct interviews. Moreover, to increase the amount of data, additional persons were contacted and interviewed for the purpose of this paper. All of the persons, which were selected for the interview, were selected because of their expertise in the maritime field. In total 14 persons were participating. The interviews were conducted in a semi-structured way, which is a combination between two other common-used interview methods, the unstructured and structured method. The unstructured gathers information with open-ended questions, thus allowing the interviewees to express themselves in their own way (Cohen & Crabtree, 2006a). The structured in the other hand uses the same questions and allows little room for variation in the responses thus allowing the responses to be easily compared (Cohen & Crabtree, 2006b). The benefits of semi-structured interview, comparing to an unstructured and structured interview, is that it can provide both comparable qualitative data and give respondents the opportunity to express themselves in their own way, so that ideas, which might have been overlooked can be taken into consideration. (Cohen & Crabtree, 2006c)

The interview was performed with a questionnaire (presented in Appendix A) consisting of a structured and an unstructured part. The selection of questions in the first part (structured) is based upon a list of issues that may affect the evacuation of ships negatively, which was created based on previous research such as the case studies. The list of issues is:

1. Technical malfunction during launching causing the lifeboat/rescue boat to fall down (e.g. minor incidents)
2. Human error during launching causing the lifeboat/rescue boat to fall down (e.g. minor incidents)
3. Deficiencies in the skills of the crew on how to launch lifeboats/rescue boats (e.g. Norman Atlantic, Costa Concordia (Kvamme, 2016, pp. 24-29))
4. Weather/wind conditions preventing launching of marine evacuation system (MES) (e.g., Norman Atlantic chute problem)
5. Passengers trying to use survival crafts on their own (e.g. Norman Atlantic, Costa Concordia (Kvamme, 2016, p. 23))
6. Competitive behavior over space in lifeboats/liferafts /rescue boats (e.g. Norman Atlantic helicopter, Costa Concordia (Kvamme, 2016, p. 24))
7. Loss of power causing the failure of rescue boat launching (e.g. Norman Atlantic)
8. Required escape time (RSET) exceeding available escape time (ASET) (caused by e.g. delay in the evacuation order or detection of the problem) (e.g., Norman Atlantic, Costa Concordia (Kvamme, 2016))
9. The angle of heel/list preventing the launch of lifeboats/life rafts (e.g., Costa Concordia (Kvamme, 2016))
10. Evacuation only possible on one side of ship due to fire making lifeboats/life rafts/rescue boats unusable (e.g., Norman Atlantic, Sorrento)
11. Regulation of maximum 30 min to launch lifeboats/life rafts not met (SOLAS 21.1.3) (e.g. Norman Atlantic, Costa Concordia (Kvamme, 2016, p. 31))

12. Error in the crew evacuation procedures caused by language barriers (e.g., Norman Atlantic)
13. Muster drills not performed for passengers on short voyage (only long voyages), prolonging evacuation times
14. Too many people onboard ship comparing to the admissible numbers in the regulations
15. Communication on coordination between the ship crew and Search and Rescue is sub-optimal.

The first part of the interview aims to receive a response on the list of issues (factors), by letting the interviewee grade the importance of the issues on a scale 1-5. The second part gives the respondent an opportunity to add new ideas and comment on part one.

4.2 Review

In this section the answers received in the interviews are presented. The results are based on replies from 14 interviewees, which all gave answers on the first part of the questionnaire. In the second part in the other hand, only 10 answers were received. The reason behind this can be explained by the second part consisting of an unstructured structure, as mentioned in Section 4.1. This allows the interviewees to add own opinions voluntarily. If non additional information is added, then the answering fields remain unanswered. For that reason, interviewee 6, 11, 12 and 14 are not listed within the answers in the second part below. Figure 28 shows the results from the first part of the questionnaire. Mean values of the grade of importance were calculated from the answers in the questionnaire, see Appendix B.

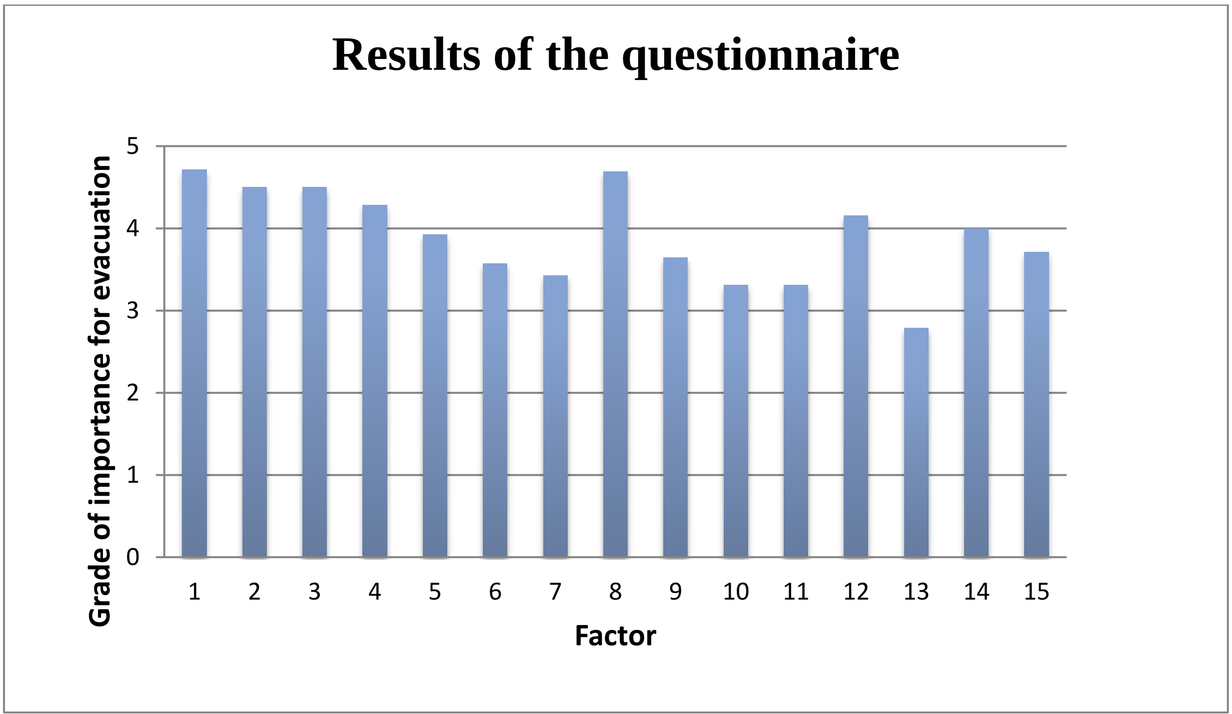

Figure 28 shows the mean value of considered importance for every factor, where: 1 = not important, 5 = very important.

The following text represents the answers received in the second part of the questionnaire.

Interviewee 1

Background information

Name: Thore Hagman
Title: Director of Research and Development
Affiliation: Swedish Sea Rescue Society
Education: Ph.D. Technology Management and Economics, M.Sc. Transportation Engineering B.A. Social Science
Years of experience in the field: 20+

Open comments:

Commenting on factor 3: Dr. Thore Hagman states that the competence-level, in how to handle an evacuation, differs among crewmembers. The variation depends on the length of training. The catering crew undergoes only a few days course and acquires therefore less knowledge than the deck crew. Furthermore, Dr. Thore Hagman points out that the abandon ship drills do not reflect what happens in reality. There are several reasons for this. Firstly, it is too dangerous and expensive to reconstruct a real event. Therefore, only limited exercises are conducted, which does not reflect the real sequence. Secondly, the population in the drill does not match the population of real evacuees. Often in drills, the evacuees are in fit condition and good health, while during the evacuation this is not the case. Hence, the crew may encounter difficulties during real evacuation, which they are not prepared for. Thirdly, he explains that the layout of ships and the position of the evacuation crafts differ depending on every ship, in contrast to e.g. airplanes. It is therefore harder to maintain the consistency in training for the crewmembers. Furthermore, Dr. Thore Hagman adds that in reality, the crew tries to save themselves also. This affects the evacuation negatively.

Commenting on factor 11: Dr. Thore Hagman explains that problems exist in the organization of crew to achieve a good flow in the movement of evacuees.

Commenting on factor 12: It is considered by Dr. Thore Hagman that crews consisting of multi-language/different nationalities are more prone to get problems, especially during stressful situations.

Commenting on factor 13: That muster drills are not performed on short voyages is not considered a problem. However, during nighttime, when the evacuation time is usually longer, the absence of drills may influence the success of evacuation.

Furthermore, Dr. Thore Hagman shares his opinions on which additional factors are affecting the success of evacuation. The design, of open cargo decks on ro-ro ships, can hinder the process of evacuation during a fire. The reason, he explains, is that the smoke ventilation, from the open cargo deck, will limit the use of evacuation crafts on embarkation decks. An additional issue, he considers, is hypothermia. When the general alarm sounds, e.g. at night, all passengers are going out in their sleeping clothes. They are therefore not properly prepared for a harsh environment outside, since the use of survival suits for passengers is not mandatory.

Interviewee 2

Background information

Name: Johan Mårtensson

Title: SAR coordinator

Affiliation: Maritime Administration

Education: Ship Officer and Engineer

Years of experience in the field: 20+

Open comments:

Johan Mårtensson points out that even though the evacuees have abandoned the ship they cannot be considered safe. The evacuees also need to be transited to shore. There is a lack of rescue resources to do this, he explains. Furthermore, there is a lack of experience in real cases, in how to handle mass rescue operations by ship crewmembers and SAR organizations. In addition, he considers that the amount of training and exercises between neighboring countries' SAR organizations should be increased, to achieve better efficiency and cooperation during mass evacuations.

Furthermore, Johan Mårtensson adds that the Swedish SAR organization has performed test on how many passengers helicopters can evacuate. The results showed that mass evacuation with helicopter is inefficient. As a result of this, it is important that the passenger ships' internal evacuation systems do not fail and that helicopters should only be only should be used for extra aid support.

Interviewee 3

Background information

Name: Tobias Nilander

Title: SAR-mission coordinator

Affiliation: Sjöfartsverket, JRCC

Education: Master Mariner

Years of experience in the field: 11-20

Open comments:

Tobias Nilander points out that weather has a significant influence on the success rate of evacuation. In addition, he states that there is often lack of rescue resources on the scene of evacuation.

Interviewee 4

Background information

Name: Fredrik Forsman

Title: - Scientist in the field of Human factors and SAR: Chalmers University of Technology
- Former head of education: Swedish Sea Rescue Society (SSRS)
- Former head of education: Swedish Navy
Education: Master mariner
Years of experience in the field: 20+

Open comments:

Commenting on factor 3: The shipping industry is a very demanding business, Fredrik Forsman explains. It must be profitable and there are many deadlines to be met. Therefore, overall, as little as possible is done in order to meet the safety requirements. As a result, many crewmembers receive too little training for their role and are generally not prepared for a real emergency.

Commenting on factor 4: Fredrik Forsman has been involved in rescue operations, both in low and high seas. He points out that the state of weather is a crucial element for the success of evacuation. In high seas, he adds, the current evacuation system is insufficient.

Commenting on factor 8 & 11: According to Fredrik Forsman, the regulations and guidelines for escape times are only met in the most favorable conditions with well-trained and synchronized crew with healthy passengers. If for example, a significant wave motion or another unfavorable factor is added, he is certain that the criteria for evacuation times are not being fulfilled. “We have tried this in experiments”, he adds. These regulations do not work in reality.

Fredrik Forsman points out, that the evacuation is not completed when the occupants have abandoned the ship. In worst case, they can be in even more danger. The first rescue resources to reach the scene of emergency are often other merchant ships. Fredrik Forsman considers the SOLAS regulations to be insufficient, since they do not provide any requirements on how these ships should retrieve the evacuees. This is the main problem with ship evacuation, he states. Firstly, the evacuees get into less seaworthy crafts. Secondly, the vessels arriving to help has limited resources to provide it.

Interviewee 5

Background information
Name: Emanuele Gissi
Title: Deputy Fire Commander
Affiliation: Italian Fire and Rescue Service
Education: Ph.D. Mechanical Engineering
Years of experience in the field: 11-20

Open comments:

As a comment to factor 4, Dr. Emanuele Gissi considers that the condition of weather should not be of importance for the success of evacuation, since bad weather conditions at sea can be expected and therefore prevented.

As a comment on factor 7, Dr. Emanuele Gissi explains that ships should never experience total loss of power. The launching of rescue boats should always work in normal order. Therefore, he does not consider this factor important for the success of evacuation.

Commenting on factor 12, he explains that ships are carrying more and more persons with different nationalities who are not sharing the same mother language. The language barrier, which this entail is not easy to prevent, thus this can affect the evacuation negatively. This factor can therefore be seen as very important.

According to Dr. Emanuele Gissi, the main problem during evacuation is the crew management. It is considered that all aspects of the crew management are of importance, e.g. the training, organization and procedures. The management of the crew can be improved by respecting the current regulation. The technical malfunctions, in the other hand, should be preventable with a thorough inspection of technical equipment. Dr. Emanuele Gissi considers that the SOLAS regulations are not followed completely and that more inspection work should be done in order to meet the requirements.

Interviewee 7

Background information

Name: Anonymous
Title: SAR mission coordinator
Affiliation: JRCC Sweden
Education: Master mariner
Years of experience in the field: 16

Open comments:

An additional factor of importance is considered to be the transferring of persons from the vessel in distress to the rescue unit. It can especially be problematic and entail a high risk during rough weather. Furthermore, the main problems that would have major impact on success rate of the evacuation are listing due to water intake or fire on board.

Interviewee 8

Background information

Name: Anonymous
Title: SAR mission coordinator
Affiliation: JRCC Sweden
Education: Master mariner
Years of experience in the field: 11-20

Open comments:

The interviewee considers that the transferring of persons from the disabled vessel to the rescue units is a factor of importance, due to its problematics. This process is especially impeded during rough weather.

Interviewee 9

Background information

Name: Jonas Malmstedt

Title: SAR mission coordinator

Affiliation: Sjöfartsverket

Years of experience in the field: 20

Open comments:

Additional factors, which are considered to be of importance by Jonas Malmstedt, are the state of sea and cold weather, which is a cause of hypothermia.

Interviewee 10

Background information

Name: Stefan Johansson

Title: SAR mission coordinator

Affiliation: Sjöfartsverket, SSRS

Years of experience in the field: 12

Open comments:

The interviewee considers that the main problem during evacuation is the weather, since it hinders the rescue.

Interviewee 13

Background information

Name: Anonymous

Title: Safety Director

Affiliation: Anonymous

Education: Master Mariner

Years of experience in the field: 11-20

Open comments:

The interviewee considers that adequate training is a key factor in successful evacuation.

5. DISCUSSION

In this chapter, identified issues during evacuation and which precautionary measures can be taken are discussed. The information gathered in the case studies has been carefully pieced together with the use the available material. However, it cannot be guaranteed to be completely accurate according to what happened. To achieve more correct data, direct access to information, from investigations and persons acquainted to what happened should be strived for. It is of interest to mention, that it is possible that there may be differences in how investigations are carried out depending on the state. The priority of what to investigate such as technical aspects, human factors or criminology can consequently influence the results. Furthermore, even though issues are revealed in a specific case study, it does not need to imply that there is a general problem with it.

5.1 Norman Atlantic Discussion

Due to the complexity, the evacuation of Norman Atlantic was a challenging task. It was hampered by factors such as rough sea, strong winds, pouring rain, tired crew, cold weather and power blackout. The evacuation can perhaps be seen as an achievement from a SAR operation point of view. However, it was not a successful evacuation, since the internal evacuation systems did not work as intended. Norman Atlantic was carrying an estimated amount of 500 persons and only 88 out of them were evacuated with survival crafts. There was only one successful launching of a survival craft, reported by the Greek coast guard mentioned in section 3.1.2. The majority of persons on board were saved by extraction of SAR helicopters. According to Interviewee 2, helicopter extraction is not suitable for mass evacuation. This could be observed in the case of Norman Atlantic, as it took approximately 35 hours to evacuate the passengers. The consequences of this, as seen in the case, was hypothermia and competitive behavior over rescue spots. The continuation of fire spread to the bow of deck 8 or change in the SAR's ability to aid could have led to a deadlier outcome.

It is clear that there was a problem with evacuation times during evacuation of Norman Atlantic. According to Interviewee 4, there are problems with the existing prescriptive evacuation times in SOLAS and IMO guidelines. They are only met in the most favorable conditions and in reality, they are not followed, he states. This could be envisioned in the case of Norman Atlantic. The evacuation did not comply with the current guidelines and regulations regarding evacuation times. The IMO guidelines state that it should take no more than 60 min to evacuate a ro-ro passenger ship. In addition, SOLAS regulation states: *"All survival craft required to provide for abandonment by the total number of persons on board shall be capable of being launched with their full complement of persons and equipment within a period of 30 min from the time the abandon ship signal is given after all persons have been assembled, with lifejackets donned." (SOLAS, Chp III, regulation 21.1.3)* (IMO, 2014) Furthermore, the LSA code states: *"Every passenger ship lifeboat shall be so arranged that it can be boarded by its full complement of persons in not more than 10 min from the time the instruction to board is given."(LSA code, 4.4.3.1)* (IMO, 2010a) To understand why evacuation times did not comply with the current guidelines and regulations, the evacuation process can be evaluated from an ASET/RSET analysis point of view. The main problem identified leading to the failure of evacuation, was that RSET (the required evacuation time) exceeded ASET (the available evacuation time). The cause of this can be explained through the time-egress model, seen in section 2.1.1, Figure 2.

RSET was prolonged due to the following factors:

- Prolonged detection by smoke detectors - The motion of air created in the open ro-ro deck hindered the detection of smoke plume. Hence, the detection time ($\Delta \mathbf{t_{det}}$) was prolonged.
- No general alarm - According to statements and reports from passengers, some were awakened by the crew banging on the doors and some by the smell of smoke. The lack of general alarm, prolonged the warning time ($\Delta \mathbf{t_{warn}}$) and pre-evacuation time ($\Delta \mathbf{t_{pre}}$).
- Nighttime - Pre-evacuation time ($\Delta \mathbf{t_{pre}}$) was prolonged, since the responsiveness and awareness is worse during nighttime.
- Crew procedures – The procedures were not preformed according to the common evacuation procedures, which could be seen by that e.g. no mustering occurred; passengers handed out lifejackets by themselves; reports of survival craft being lowered by passengers. This prolonged RSET in general.

ASET was shortened due to the following factors:

- The drencher system did not suppress the fire
- MES was not working properly
- Survival crafts were destroyed by fire coming out through garage openings

The prolonging of RSET and shortening of ASET caused RSET to exceeded ASET. Consequently, there was insufficient time for the abandonment phase. This could be observed during the evacuation of Norman Atlantic as the evacuation was impeded and the passengers needed to be rescued from the rooftops. The successfulness of the abandonment using survival crafts is therefore dependent on the successfulness of the preceding phases and the functionality of the safety systems, which affect ASET. In conclusions, the main problems why evacuation times are not being met can be linked to technical malfunctions and crew procedural problems. Therefore, these are the areas in need of improvements.

Furthermore, as mentioned in section 3.1, only one survival craft was successfully launched during the evacuation. According to Table 7, Norman Atlantic had survival crafts with accommodation for 1158 persons, 858 in liferafts and 300 in lifeboats and was in addition equipped with two rescue boats. The approximate 500 persons aboard should have therefore been able to evacuate with the means provided. Yet, only 88 were evacuated with the survival crafts. How could this have occurred?

Firstly, according to the investigation, presented by Fabio Croccolo, all LSA *(lifesaving appliances)* on the starboard side got unusable due to fire and smoke coming out from garage openings. During the interview with Interviewee 1, it was acknowledged by him that this problem in fact exists. He considers that the design of cargo decks on ro-ro ships can impede the evacuation on embarkation decks due to smoke plum coming out from the garage openings. This is a problem within the SOLAS regulations regarding construction and passive fire protection. To improve it, the SOLAS regulations concerning passive fire protection of garage openings, on ro-ro ships, or survival crafts should be improved, which also is stated during Fabio Croccolo's presentation.

Secondly, the MES chute systems did not function as intended during the evacuation. Passengers became stuck and died during the use of MES. According to LSA code: *"A marine evacuation system shall be capable of providing a satisfactory means of evacuation in a sea state associated with a wind of force 6 on the Beaufort scale" (LSA code, 6.2.2.1.7)* (IMO, 2010). Although the regulation was not violated, since the wind speeds during the time of incident were 45 knots, which corresponds to level 9 on the Beaufort scale, the performance of the system was inadequate to provide evacuation. According to a regulation *(SOLAS, Chp. III, regulation 21.1.2)*, passenger ships on short international voyages, as the Norman Atlantic was, only need to carry lifeboats that can accommodate 30% off the total number of persons on board. This means that remaining persons are to be evacuated by MES. Having the LSA code regulation in mind *(LSA code, 6.2.2.1.7)*, means that evacuation cannot be guaranteed for up to 70% of the persons on board in wind force 7 or more on the Beaufort scale. It is inevitable that future evacuations will occur in rough weather and therefore the evacuation systems should be designed in such manner that they can function under those conditions. The root of the problem can be linked to regulations and the performance of MES chute systems being too poor. To improve the problem, the regulation *(LSA code, 6.2.2.1.7)* should be enhanced so that MES are required to perform above Beaufort 7 conditions.

Thirdly, in section 3.1.1, it is reported that power blackout occurred and according to the statements from the passengers, the survival crafts could not be launched due to the loss of electricity. It can be seen in Figure 18, that the rescue boats have not been launched. The launching is however, according to regulations, independent from the source of electricity of the passenger ship. **"***A launching appliance shall not depend on any means other than gravity or stored mechanical power which is independent of the ship's power supplies to launch the survival craft or rescue boat it serves in the fully loaded and equipped condition and also in the light condition". (LSA code, 6.1.1.3)* (IMO, 2010) Therefore, it is questionable whether the launching was impeded due to loss of power.

Fourthly, the evacuation of Norman Atlantic show signs of breakdown in crew procedures. Information from the investigation and passenger statements, mentioned in section 3.1, show the following deviations:

- Mustering not occurring
- People waking up due to the smell of smoke and sound fire, instead of alarm signals or crew
- Passengers distributing lifejackets themselves
- The crew nowhere to be seen
- Lack of co-ordination
- Lack of knowledge in how to launch lifeboat
- Passengers trying to launch survival crafts by themselves
- Lack of general alarm
- Rescue boats not launched
- Competitive behavior over rescue spots

An additional sign that the evacuation procedures failed, was the fact that people were airlifted from deck 8. This is not a normal procedure for mass evacuation. The following factors have been observed to be contributing causes to the breakdown of crew evacuation procedures:

The statements of passengers and the investigatory report show that the crew was not prepared to cope with the evacuation. It is likely to believe that the cause of this was lack of adequate training and skill of the crew. In addition, according to Fabio Croccolo, see section 3.1, the crew had only been working on the ship for three weeks, which might have been a supplementary cause contributing to the insufficient preparedness. According to the interviews with Interviewee 1 and 4, ship crews receive too little and not adequate training to be prepared for real emergencies, even though the requirements of regulations are met. The reason for this is that the training does not reflect the real sequence of evacuation nor the real the population. From this, a conclusion can be drawn that there is a gap between regulations and reality. That crews are not being sufficiently prepared, can be linked to a regulatory problem in STCW and SOLAS regarding training. To improve the problem, enhancement can be done to STCW and SOLAS regulations so that the amount of training is increased and so that the training corresponds to more realistic settings.

The investigatory report and interviews show that language barriers might have been aggravating the crew evacuation procedures. According to the investigation of Norman Atlantic, the crew was employed by two separate companies and consisted therefore mainly of two different nationalities. In addition, it is reported that the crew had limited knowledge in English. Consequently, the co-ordination within the crew and with passengers could have been hindered due to language barriers. Information from the interviews point to that it is more and more common that crews consist of more than one nationality. The language barrier, which this entails, has according to Interviewee 1 an aggravating effect on the evacuation procedures. The investigator of Norman Atlantic, Fabio Croccolo, considers that crews contracted by multiple companies should be avoided. The problem of crews being contracted by different companies is currently not regulated. Although regulations exists to support communication, as e.g.

(SOLAS, Chp. III, regulation 8.2) that states that in the case of emergency, clear instructions shall be given to all persons on board in English and in the ship's Flag state's language, it could be seen in the case of Norman Atlantic, that the communication was not adequate. To improve the problem of language barriers, the occurrence of crews consisting of multiple companies should be avoided or regulated.

A factor to take into consideration, which can have negatively affected the crew evacuation procedures, is that the procedures were subjected to an extra load of stress, e.g. the general alarm and drencher system was not working properly and the survival crafts were destroyed on one side. These abnormalities might have disrupted the normal procedures and could therefore be an explanation to why it is reported that mustering did not occur. In addition, it is reported by the passengers that the crew was nowhere to be seen. As the critical conditions continued to arise on the ship, it is likely that the crew started to rescue themselves. According to the interview conducted with Interviewee 1, crews tries to save themselves also during evacuations and this can negatively influence the evacuation procedures. In conclusion, this shows that the crew evacuation procedures have difficulties to function when put under stress. To improve the problem, enhancement can be done to STCW and SOLAS regulations so that the amount of training is increased and so that the training corresponds to more realistic settings, so that the crew evacuation procedures become more resilient during emergencies.

An additional factor, which have been observed to affect the evacuation negatively was that the lifeboat, which was launched during the evacuation of Norman Atlantic, carried only 88 passengers even though it had the capacity for 150 persons. This can be seen as a problem, since around 400 persons were left behind on board Norman Atlantic. The problem can be improved by regulatory measures in STCW and SOLAS regulations so that the amount of training and emphasis regarding the issue is increased.

In the late hours of evacuation, it was reported that Norman Atlantic had started to tilt (7-degrees) due to the effects of water from the drencher system. According to SOLAS regulations, as written in section 2.4.3, launching should be possible up to a 20-degree of list. Therefore, the tilting occurring on Norman Atlantic should not hinder the evacuation with survival crafts. Research, which was mentioned in the same section, shows that the walking speeds are affected negatively by the tilting of a vessel. However, the evacuees were at the time of tilting on the top deck of the vessel and were awaiting rescue. Therefore, they can be considered to have been stationary. Consequently, the tilting that occurred on Norman Atlantic can be assumed to had negligible effects on the evacuation.

5.2 Sorrento Discussion

The information on the Sorrento incident was very limited. The official investigation was still ongoing during the time this report was being written. Nevertheless, the case and what have been observed is discussed in this section.

Interestingly, it can be noted that the incidents of Sorrento and Norman Atlantic were very similar. The ships were of the same models and the fire started in the same area. Yet, the result of the evacuation was completely different. Norman Atlantic had death casualties and the evacuation took considerably longer. Which were the underlying causes? Comparing Sorrento to Norman Atlantic, from an evacuation theory point of view (explained in section 2.1.1), the following factors are likely to have contributed to the better outcome of the evacuation of Sorrento:

- Detection time (Δt_{det}) is likely to have been shorter due to better weather conditions. This generated less wind in the cargo area, enabling earlier smoke detection of the plume.
- The alarm time (Δt_{warn}) was significantly shorter, because the general alarm was sounded in normal order.
- The pre-evacuation time (Δt_{pre}) was also shorter, because it was daytime comparing to Norman Atlantic's nighttime evacuation.
- The travel (Δt_{trav}) and embarkation time (Δt_{embark}) were shorter, due to less influence of the motion of waves and wind on Sorrento.
- No reports indicate breakdown of the crew's evacuation procedures. Therefore, it can be assumed that the occupants did receive better instructions and directions from thr crew. Consequently, lowering the response (Δt_{resp}), travel (Δt_{trav}) and abandon time (Δt_{aband}) during the evacuation.
- There were fewer passengers on Sorrento, reducing RSET (required evacuation time) in general.
- In Sorrento, the fire was suppressed, by the drench system, which prolonged the ASET (available evacuation time).

In conclusion, RSET was significantly lower and ASET longer in the case of Sorrento, thus explaining the success of evacuation comparing to Norman Atlantic. In addition, RSET can be estimated to have been lower than ASET. Thus, allowing occupants to escape safely, except for the four crewmembers, which had to be airlifted with helicopter.

There are no reports or signs of equipment malfunctions or procedures deviating from the normal during the evacuation of Sorrento. However, the media reports that the master did not initially consider the evacuation to be necessary, thus the order of evacuation was delayed. A study conducted in the human perception of fire growth, shows that the *"subjective estimation of fire growth does not conform to the real fire growth."* (Fridolf, 2010, p. 5). When the order was finally given, it was ordered to evacuate through the starboard side, due to intensity of fire on port side. This suggests that the port side's embarkation zones and LSA had already gotten into a degraded state, due to the effects of smoke and fire from the garage openings. The ship was in this scenario low populated and subjected to favorable conditions. If the circumstances had been different, e.g. more passengers, then a delay in the initiation of evacuation could have had serious consequences and result in a degradation of conditions on embarkation decks and to LSA to such degree that evacuation becomes impeded during the time of evacuation, as was seen in the Norman Atlantic case. Therefore, the initiation of evacuation early is crucial for the outcome of the survival craft usage. This potential problem can be improved by training and educating master and officers more in the "decision support system for masters" provided by SOLAS regulation *(SOLAS, Chp. III, regulation 29).* In addition, this problem can also be improved by enhancing the regulations regarding the passive fire protection on garage openings.

5.3 Minor Incidents Discussion

The case studies of the minor incidents are based on investigation and media reports. It can be of value to keep in mind that some incidents do not appear in media. Hence, the minor case studies are a reflection of what is happening in the media. Accidents with a higher consequence are more prone to get more attention of the media and therefore overrepresented. Therefore, incidents that may be of value for mass evacuation can be overlooked in the process.

From the minor cases studies, it appears that lifeboat and rescue boat incidents are more likely to occur than incidents concerning MES and life rafts. However, accidents and the hazards with MES should not be excluded. As seen in Norman Atlantic, they do occur. According to regulations, all lifeboats on a ship should be launched and tested by the crew at least once every three months *(SOLAS, Chp. 3, regulation 19.3.3.3)*. The MES in the other hand needs to be launched and tested by the crew with full deployment drills at least once every two years *(SOLAS Chp 3, regulation 19.3.3.8)* (IMO, 2014). Based on this information, the lifeboat drills are by far more common. This can be an explanation to the overrepresentation of lifeboat accidents comparing to MES. Furthermore, an incident in MES, which does not have a deadly or serious outcome, is not likely to be reported in media due to the low consequence. A failure in MES however, e.g. blockage in chute, can be more dangerous from a mass evacuation point of view than a failure of lifeboat. Since, the MES, depending on system, can hold a higher evacuee capacity than lifeboats. Therefore, the hazards with MES should not be excluded.

Nevertheless, a conclusion can be made that lifeboat and rescue boat launching is dangerous. Accidents do occur in the process of launching, due to technical problems, causing lifeboats/rescue boat to fall down. The issue is mainly caused by wire breakages, due to the weakening effect of corrosion. The regulations state that wire falls should be *"renewed when necessary due to deterioration of the falls or at intervals of not more than 5 years, whichever is the earlier." (SOLAS Chp 3, regulation 20.4)* (IMO, 2014). This regulation is shown to not be enough to prevent the accidents from happening. All of the minor incidents happened in ports during safety drills. The launchings were performed in calm and static conditions with only the crew on board. Looking upon the reality of evacuation at sea, the launching appliances are subjected to more stress due to the dynamic rocking movements of the sea and due to the additional weight when the lifeboats are loaded with its full complement of people. Since the accidents do occur on a regular basis, we are potentially looking on a lifeboat to fall down with 150 persons, or 370 in case of mega lifeboats, during a real-time mass evacuation. According to the LSA code all life-saving appliances should be corrosion resistant *(LSA code, 1.2.2.4)* (IMO, 2010). The problem can therefore be associated with not adequate quality of the wires holding the lifeboats. The case studies show that it is very difficult to identify the corrosion in the wires, even though regular maintenance is conducted and that the crew does not possess the knowledge of doing this. Therefore, to prevent the problem, the maintenance of wires should be improved, the exchange period of the wires shortened and the reliability of wires increased by higher demands on corrosion resistance. This can be achieved by regulatory enhancements in SOLAS regulations and LSA code.

5.4 Miscellaneous Discussion

Numerous interviewees consider hypothermia to be an issue during evacuation. The passengers are not considered to be properly prepared for the effects of the environment and are therefore prone to get affected with hypothermia. According to regulation, blankets should be taken to survival crafts during emergencies *(SOLAS, Chp. III, regulation 37.6.5).* However, there are no mentions of providing blankets for passengers in case the evacuation is impeded. This problem could be observed in the case of Norman Atlantic, where the occupants remained on board and suffered from hypothermia. It can be understandable that when put under stress procedures like distributing blankets can be overseen. To improve this, regulations can be instated so that anti-exposure suits are available for passengers. In addition, more emphasis can be put, during training of crews, on hypothermia preventing measures, e.g. bringing blankets.

It appears that the interviewed SAR mission coordinators agree that weather conditions and state of sea has a major influence on the success of evacuation. High seas hinder the possibility of transferring the evacuees from the survival crafts to the rescue units significantly. According to Interviewee 4, the transferring system in itself is insufficient and abandoning the ship can potentially put the evacuees in even more danger. Often, the first ships to arrive at the scene of accident are other merchant ships and are not prepared to handle a mass evacuation. To improve this problem, systems need to be developed and implemented in survival crafts and rescue units, which ease the debarkation process. This can be achieved with regulatory measures.

The results of the questionnaire, Table 11, show that the launching of survival crafts, the evacuation times being exceeded, passengers trying to use survival crafts on their own, language barriers and too many passengers on board, are factors considered to have a major impact on the ship evacuation at sea. This information has been used to reach the conclusions, on the following page.

The location of the survival crafts on board Norman Atlantic and Sorrento ferry can be discussed also. The location of survival crafts was centralized, which is possibly beneficial for the distribution of passengers and accessibility. However, it also makes the survival crafts vulnerable to the affects from e.g. sabotage or fire. The later one could be seen in the two cases. Therefore, I suggest that the vulnerability should be taken into account when determining the location of survival crafts. However, I believe that larger ferries and cruise ship do not suffer from the same issue, because the number of lifeboats needed on the ship is so immense that it occupies the whole port and starboard side.

6. CONCLUSIONS

With the use of official investigation reports, passenger statements and reporting of media, past ship incidents have been studied, in order to reach the conclusions of how evacuation of ships with survival crafts can be improved. In addition, interviews have been conducted with experts in the maritime field for the purpose of this study. A number of issues have been identified to affect the evacuation at sea negatively. The following conclusions are drawn:

- **The prescriptive evacuation times might not be always met** and may be followed only in ideal conditions. The issue can be linked to technical malfunctions and crew procedural problems. Therefore, these are the main areas in need of improvements.
- **Delays in initiation of evacuation procedures** contribute to a narrow time frame for the embarking and launching phase. A solution to this problem can be more thorough inspections so that technical systems reliability is increased and by training and educating master and officers more in the "decision support system for masters" provided by SOLAS regulation *(SOLAS, Chp. III, regulation 29)*
- **The embarkation of survival crafts can be impeded by fire** and smoke coming out from ro-ro ferries' garage openings. To improve this problem, SOLAS regulations regarding passive fire protection of garage openings or survival crafts should take this issue into account.
- **Lifeboats and rescue boats may fall down during launching** due to corrosion on wires. To prevent the problem, the maintenance of wires should be improved, the exchange period of the wires shortened and the reliability of wires increased by higher demands on corrosion resistance. This can be achieved by regulatory enforcements in SOLAS regulations and LSA code.
- **The capacity of lifeboat may not be filled during launching**, consequently limiting the evacuation possibilities for the remaining persons on board. The problem can be improved by regulatory measures in STCW and SOLAS regulations so that the amount of training and awareness regarding the issue is increased.
- **MES chute system may not perform well in high wind speeds**. To improve the problem, the regulation *(LSA code, 6.2.2.1.7)* should be enhanced so that MES (marine evacuation systems) are required to perform above a wind force of 7 on the Beaufort scale.
- **Crews may not be prepared** sufficiently by training**.** Consequently**,** the evacuation procedures can be affected negatively. To improve the problem, enhancement can be done to STCW and SOLAS regulations so that the amount of training is increased and so that the training corresponds to more realistic settings.
- **Communication issues due to language barrier may occur** when a crew consists of several companies. This affects evacuation procedures negatively. To improve the problem, the occurrence of crews consisting of companies lacking a shared

communication language should be avoided or regulated. Also, the predicted language spoken by the passengers should also be taken into account.

- **Crew evacuation procedures may have difficulties to function when put under stress.** To improve the problem, enhancement can be done to STCW and SOLAS regulations so that the amount of training is increased and so that the training corresponds to more realistic settings, so that the crew evacuation procedures become more resilient during emergencies.
- **Hypothermia affecting passengers** may be a problem during evacuation. To improve this, regulations should be included so that anti-exposure suits available for passengers. In addition, more emphasis can be put, during training of crews, on hypothermia preventing measures, e.g. bringing blankets.
- **The transferring system from survival crafts to rescue units is problematic,** especially during high seas. To improve this, systems need to be developed and implemented in survival crafts and rescue units, which ease the debarkation process. This can be achieved with regulatory measures.

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Appendix A

Issues associated with Ship Evacuation at Sea

This questionnaire is part of the thesis work of the Lund University student Martin Pospolicki. Please answer the following questions concerning the factors that are deemed to affect the evacuation process at sea using lifeboats, life rafts and rescue boats. The questionnaire will take you no more than a few minutes and you are free to choose if you prefer that your responses are anonymous or not. The results will be published in a thesis work at Lund University and related publications.

QUESTIONNAIRE

State the degree of importance of the following factors affecting ship evacuation at sea

1) Technical malfunction during launching causing the lifeboat/rescue boat to fall down

1 (not important)	2	3	4	5 (very important)

2) Human error during launching causing the lifeboat/rescue boat to fall down

1 (not important)	2	3	4	5 (very important)

3) Deficiencies in the skills of the crew on how to launch lifeboats/rescue boats

1 (not important)	2	3	4	5 (very important)

4) Weather/wind conditions preventing launching of marine evacuation system (MES)

1 (not important)	2	3	4	5 (very important)

5) Passengers trying to use survival crafts on their own

1 (not important)	2	3	4	5 (very important)

6) Competitive behavior over space in lifeboats/liferafts/rescue boats

1 (not important)	2	3	4	5 (very important)

7) Loss of power causing the failure of rescue boat launching

1 (not important)	2	3	4	5 (very important)

8) Required escape time (RSET) exceeding available escape time (ASET) (caused by e.g. delay in the evacuation order or detection of the problem)

1 (not important)	2	3	4	5 (very important)

9) The angle of heel/list preventing the launch of lifeboats/life rafts

1 (not important)	2	3	4	5 (very important)

10) Evacuation only possible on one side of ship due to fire making lifeboats/life rafts/rescue boats unusable

1 (not important)	2	3	4	5 (very important)

11) Regulation of maximum 30 min to launch lifeboats/life rafts not met (SOLAS 21.1.3)

1 (not important)	2	3	4	5 (very important)

12) Error in the crew evacuation procedures caused by language barriers

1 (not important)	2	3	4	5 (very important)

13) Muster drills not performed for passengers on short voyage (only long voyages), prolonging evacuation times

1 (not important)	2	3	4	5 (very important)

14) Too many people onboard ship comparing to the admissible numbers in the regulations

1 (not important)	2	3	4	5 (very important)

15) Communication on coordination between the ship crew and Search and Rescue is sub-optimal

1 (not important)	2	3	4	5 (very important)

OPEN COMMENTS

A: Do you want to provide comments on any of the factors listed above?

B: Is there any other factor that may be important?

C: What do you consider is the main issue evacuating ships with lifeboats/life rafts/rescue boats from your experience?

BACKGROUND QUESTIONS

Name	
Surname	
Title (work title at your institution)	
Affiliation (Main Institution in which you currently work)	
Education	
Years of experience in the field (<1; 1-5; 6-10; 11-20; >20)	
Do you want your responses to be anonymous? (YES/NO)	

THANK YOU FOR YOUR RESPONSE!

Appendix B

The answers from the questionnaire are showed in table 11. The mean value in the table is used as input data for the diagram (Figure 26).

Table 11 shows the answers received in the questionnaire. It shows the grade of importance for every factor and interviewee, where: 1 = not important, 5 = very important. It also shows the total number of votes for each factor and a calculated mean value.

	Interviewee														Number Votes	Mean Value
Factor	1	2	3	4	5	6	7	8	9	10	11	12	13	14		
1	5	5	5	4	5	3	5	5	5	5	4	5	5	5	14	**4,7**
2	5	5	5	5	4	4	4	4	4	5	4	5	4	5	14	**4,5**
3	5	5	5	5	4	4	5	5	4	5	3	5	5	3	14	**4,5**
4	5	5	5	5	1	4	4	4	5	5	3	5	5	4	14	**4,3**
5	5	5	5	-	5	5	3	3	3	4	2	4	4	3	13	**3,9**
6	5	5	5	4	3	3	3	3	3	4	2	4	3	3	14	**3,6**
7	4	3	2	4	1	3	3	3	3	4	4	5	4	5	14	**3,4**
8	5	5	5	5	5	4	5	5	4	5	-	4	5	4	13	**4,7**
9	4	3	3	4	2	3	5	5	3	5	4	4	2	4	14	**3,6**
10	3	4	5	-	1	4	3	3	3	5	2	4	2	4	13	**3,3**
11	-	3	3	4	1	4	3	3	3	3	4	4	5	3	13	**3,3**
12	5	5	5	-	5	4	4	4	4	4	2	4	4	4	13	**4,2**
13	3	3	2	2	4	1	3	3	4	4	1	3	2	4	14	**2,8**
14	5	5	5	-	5	1	5	5	3	4	4	3	2	5	13	**4,0**
15	5	5	5	4	1	2	4	4	3	5	3	4	3	4	14	**3,7**