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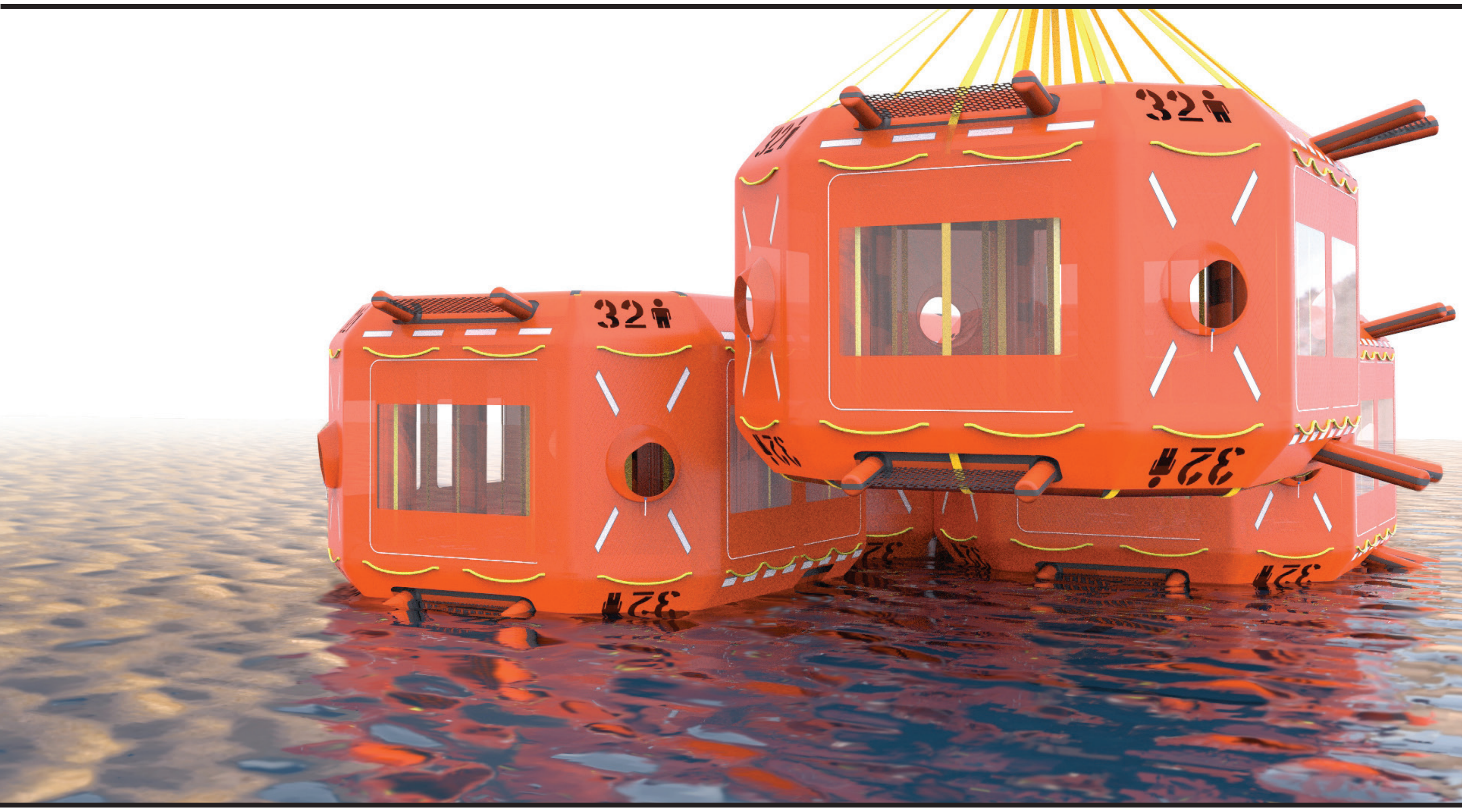

Mass Rescue at Sea

Development of a system for recovery to nearby ships

M.Sc. Thesis in Industrial Design Engineering

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CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2015

Department of Product- and Production Development
Division of Design & Human Factors

Master of Science Thesis

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Abstract

This master's thesis was conducted at the department of Product and Production Development at Chalmers University of Technology in Gothenburg, Sweden. The project members, Niclas Drevinger and Frida Halt, were students at the Master's program in Industrial Design Engineering during the time of the project.

The project was carried out in collaboration with the Swedish Sea Rescue Society (SSRS), which is a non-profit organization responsible for approximately 70 % of all rescue operations in Swedish waters. The project was also a part of SSRS's and Stena Line's longstanding project FIRST, regarding mass rescue at sea.

The SSRS had identified a need to make use of commercial ships during mass rescue operations, when their own resources are overwhelmed. The aim in this project was therefore to develop a solution that would give these so called 'ships of opportunity' a means to efficiently help in mass recue operations at sea, by recovering people in distress to safety on board.

The project started with extensive background research on the subject, including visits to the most important stakeholders. The research results were analysed, and eight recovery principle concepts on how to get people from liferafts to helping ships, was created and evaluated. The conclusion was that relatively small, liftable units combined into a large system was the best solution. These results were compressed into a design brief for a product concept using the chosen recovery principle.

The following product development process was highly iterative. Concepts was presented to, and discussed with, Stena Line and other shipping companies. Discussions were also held with Survitec Group, the world's largest liferaft manufacturer, during a visit to their factory and R&D department in Belfast, Northern Ireland.

The final concept, a Mass Rescue and Recovery System (MERS) for up to 832 passengers, was presented during the quadrennial World Maritime Rescue Congress in Bremerhaven, organized by the International Maritime Rescue Federation (IMRF) and the German equivalent of SSRS. The MERS system is at the end of this thesis project at a conceptual state, however, intended to be prototyped and tested as soon as possible.

Key words: Product development, Liferaft, Marine evacuation system, Mass rescue, Search and Rescue.

Acknowledgements

The success of this project rests upon a number of dedicated and amazing people supporting us and sharing their knowledge. First of all, we would like to profoundly thank the Swedish Sea Rescue Society for giving us the chance to work with this inspiring project. Thanks to everyone at the office in Långedrag, Gothenburg, for being so interested, positive and supportive. A special thanks to Fredrik Falkman who has been our always helpful supervisor from SSRS. To Mikael Hinnerson who has been essential for getting us in contact with the right people and audience. And to Matthew Fader for contributing with useful knowledge as well as tolerating our excessive use of desk space and our loud discussions.

Thanks to our examiner Oskar Rexfelt, and supervisor from Chalmers, Erik Ohlson who both have helped us stay on the right track and prioritize well during the project.

A big thank you Stena Line's Jonas Tullock and Jörgen Lorén who has shown great interest and support for this project. Especially to Jörgen for listening to many of our presentations and sharing most appreciated feedback. Stena Line has given us hope on shipping companies by always putting safety at the top of their agenda.

We would also like to thank Richard McCormick from the Survitec Group for being a perfect host during our visit at the RFD Beaufort factory in Dunmurry, Belfast. Of course thanks also to the rest of the gentlemen from the design department for sharing their valuable knowledge in raft design and manufacturing. Thanks also to the personnel at Survitec Group Gothenburg for showing us how raft maintenance is done and enlightening us on a sometimes forgotten aspect in product development.

Also thanks to Emil Henricsson, Emil Karlsson, and Lukas Riedel at Öckerö Maritime Centre, Göteborg, for letting us take part during the important job they do educating in safety at sea. This visit was one of the most important we did for understanding the context we had to work with.

Without the help from ÅForsk and Chalmers Vänner neither important parts of our research, nor presentations to the important international audience, would have been possible.

Lastly, a warm thank you to our fellow master thesis students at Industrial Design Engineering for the inspiration, patience, discussions, and moral support. A particularly humble thanks to Erik Dellborg who saved us a lot of headache and sleep deprivation by coming to the rescue when our CAD model stopped co-operating.

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Glossary

Abbreviations of frequently mentioned organisations

EMSA - European Maritime Safety Agency
IMO - International Maritime Organisation
IMRF - International Maritime Rescue Federation
SSRS - Swedish Sea Rescue Society
UNHCR - UN High Commissioner for Refugees

Other commonly used abbreviations

FIRST - First Independent Responder Safe Transfer
FRB - Fast Rescue Boat
FRC - Fast Rescue Craft
LSA - Life-Saving Appliance
MES - Marine Evacuation System
MOR - Means of rescue
MRO - Mass Rescue Operation
Pax - abbreviation for passengers
Rescuerunner - Rescue craft, a type of jet ski, developed by the SSRS
Ro-pax - Vehicle and passenger ferry
Ro-ro - “Roll on - roll off” vehicle ferry
SAR - Search And Rescue
SOLAS - Safety Of Life At Sea

Frequently used expressions

Ships of opportunity - the first ships arriving at the scene of an accident that are not normally dedicated to search and rescue. The expression is established among SAR organisations even if other terms are used in some regions.

Recovery Principle - the technical solution used for moving people from a survival craft to safety aboard a ship, i.e. used for recovery. The expression is defined by the authors.

Lifting point - the shackle that all lifting lines are attached to.

Total lifting height - the height from the bottom (excluding water bags) of the liferaft to the crane hook.

01. Introduction

For a passenger ship in distress, current regulation stops after successful evacuation. Recovering the evacuees is no one's legal responsibility. The current definition of mass rescue at sea is a situation in which rescue services are overwhelmed. Whoever comes to the rescue can only help one or a few persons at a time. Getting people from lifeboats or liferafts to any place of safety is time consuming and exhausting even under benign conditions. Today it is most often solved by lifting people with a helicopter, which takes on average roughly seven minutes per person, or by people climbing pilot ladders up ship sides.

(Falkman, interview, 2015)

This master thesis project will be conducted in collaboration with the Swedish Sea Rescue Society (SSRS), as a part of their ongoing project FIRST (First Independent Responder, Safe Transfer), in which the goal is to make passenger ship catastrophes a thing of the past. This goal is to be reached by figuring out new ways to improve mass rescue, to test these ideas under realistic, harsh conditions, and by trying to convince the world that radical improvements are not only urgently needed, but also practically feasible and economically reasonable.

The SSRS have proposed that all ships carry liftable liferafts for use in case of an evacuation, and that all suitable ships have means to connect and lift these rafts, filled with people, to safety on board. A solution have been tested and proved to work effectively with 39 person davit launched liferafts, a type of liferaft constructed to be lowered from a ship to the sea surface filled with people. However, mass evacuation systems (MES) such as RFD Beaufort's system Marin Ark, that can carry up to 860 people in one raft system, is becoming increasingly popular and hold more than half the market share. These systems have many advantages to current liftable liferafts but there is no solution for efficient recovery from them. This master thesis project will investigate possible solutions and create a product or system concept to solve this.

The SSRS are in the long run aiming for a worldwide implementation of a solution for this issue, in order to save as many lives as possible. This aim can be acquired in several ways, but at some point the current regulations has to be changed. For such a change to occur, the legislators need to see a working solution used by some ships for some time. The short time goal for SSRS is therefore to implement a solution on some Swedish ferries.

1.1. Purpose

To decrease the number of casualties in major passenger ship accidents at sea.

1.2. Objective

To create a scalable solution that enables all suitable ships to efficiently aid in mass rescue operations at sea, by recovering people in distress from survival crafts to safety on board.

1.3. Scope

Focus will be on improving the recovery from survival crafts to safety, not on the evacuation from a ship in distress. Any solution can however not be allowed to cause problems during the evacuation phase.

Another limitation for the project is that a final solution has to be compatible with the current evacuation chutes and slides without changing them, in order to have a reasonable amount of work for the project.

Focus will also be on liferafts, not on lifeboats, since the timeframe does not allow dealing with both categories, and the issues with liferafts are currently more serious.

It will also deal with large passenger ship accidents with great numbers of people at risk, not leisure crafts or smaller boat accidents.

Communication equipment will not be addressed even though it is one of the most important aspects in a mass rescue operation. There are current projects working in that area, and also a great variety of solutions available. Thus, communication issues are mainly a question of sufficient funding, regulation, and training and does not have direct effect on this project.

The end result is furthermore to be a well-developed product concept, highly implementable, but it will not be production ready or tested against present regulation on the matter.

1.4. Research questions

- Is it possible to utilize existing life rafts, possibly with minor adjustments, or is a completely new liferaft design necessary?
- Can a solution work with existing cranes, such as those for rescue boats?
- Is it possible to create a solution that works without the aid of rescue services, and without anyone having to get into the water?
- Can a new solution both improve the situation and fulfil the strict demands on cost and space efficiency of shipping companies, so that some companies are motivated to implement it without being forced by legislation?
- Can this project together with FIRST inspire to new international legislation?
- Can the project create a product or system that in a first stage could be implemented on a few ships of Swedish shipping companies?

02. Background Research - Methods & Execution

The goal of the background research was to explore and learn about context, users, stakeholders, technology etc. relevant to the project in order to create a profound knowledge base for the continuation of the project. This chapter contains a description of the methodology for this phase. The knowledge gained from these experiences and studies are what the following sections are based on, and these activities will therefore be referred to as sources.

Reading guide
This chapter should be read for understanding how the information gathering in the project was conducted.

2.1. Literature study

In order to get in the loop on the project area, a large initial literature study was conducted. This included written reports and video material on ship accidents, legislation, reports from previous projects, and a lot of material from the SSRS regarding the FIRST project. The specific sources will be referenced to when the information is presented later on in this chapter.

2.2. Market analysis

Another important activity during the background research was studying existing products on the market. This was restricted to inflated survival crafts and lifesaving products such as liferafts, marine evacuation systems and means of rescue. The market analysis was conducted by identifying the largest manufacturers of marine safety products and the relevant products in their product lines before studying them during visits to stakeholders (see later in this section).

2.3. Interviews at SSRS

Initial semi-structured interviews at SSRS was held, followed by regular discussions with the personnel there. The following persons have been advising the project regularly about the corresponding areas.

Fredrik Falkman, sjösäkerhetsavdelningen
Fredrik is an industrial designer working with innovation at SSRS. He was the mind behind the development of the Rescuerunner, and has been thoroughly involved with the FIRST project for long.

Thore Hagman, sjösäkerhetsavdelningen
Thore has long experience from working as a shipping officer and manager in the shipping industry. He also has a Ph.D. in Technology Management and Economics, along with a M.Sc. in Transportation Engineering from Chalmers, making him a huge asset for SSRS, FIRST and this project.

Matthew Fader, maritima avdelningen
Matthew has experience from working as Department Head at Sahlgrenska for ten years, while also being supervisor of a psychological and psychiatric catastrophe management group there. He also has experience of working as a sea rescuer, and is now responsible for parts of the training of new volunteers.

Mikael Hinnerson, sjösäkerhetsledare
Mikael is head of staff at the sea safety department at SSRS, has experience from working at sea, being a sea rescuer himself and has a leading role in the FIRST project.

2.4. Visit at Survitec Gothenburg

To gain more extensive knowledge on the construction and maintenance of liferafts a visit to a licensed service station was conducted. At the site a semi-structured interview with the manager was held during the tour of the service station.

Figure 1. Packed evacuation chutes

2.5. Rescuerunner & survival suit training

In order to increase the understanding of sea rescue from the perspective of people in the water being rescued, as well as SAR personnel, a training session was conducted with SSRS. Putting on a survival suit, training swimming and survival techniques in 3 °C water, being rescued onto a Rescuerunner and driving one was part of the session.

2.6. Visit at Öckerö Maritime Center

To investigate how training and education with liferafts is done, and what is taught to people who will handle the systems, Öckerö Maritime Center (ÖMC) was visited. ÖMC is a facility where courses for personal safety at sea, and specific introductory courses for employees at Stena Line, are held.

Figure 2. Instructor demonstrating a liferaft for future crew members from Stena Line

The visit included participating observations during a full day of a course for new Stena Line employees, extra time to explore a Marin Ark 2 unit, and semi-structured interviews with two ÖMC instructors.

Figure 3. The surprisingly effortless process of being picked up by a Rescuerunner (despite hands numb from the 3 °C water)

2.7. Search & rescue exercise

To see search and rescue in real life an exercise the 6th of May in the Gothenburg archipelago with four SSRS vessels and two pilot vessels from the Swedish Maritime Administration was studied. The purpose of the exercise was to train practical and tactical cooperation between local Gothenburg SAR resources. The first half of the day was spent overviewing planning, management and all communication in the lead boat. During the second half participating observation from one of the small SSRS crafts, including steering, planning & VHF communication, lookout, and aiding recovered people onto the ship was carried out.

The exercise consisted of two rounds with the lead boat placing 12 people in simulated distress in liferafts or on small islands. The vessels would position themselves randomly and then begin the search as the lead boat, acting as MRCC (Maritime Rescue Coordination Centre), sent out a call for help. After the first round participants were interviewed, just as they had been recovered after more than 1 hour in the liferafts.

2.8. Visit at Survitec Group & RFD Beaufort factory

Together with Mikael Hinnerson from SSRS the project group conducted a two-day study visit at the Survitec Group's factory for RFD Beaufort in Belfast, Northern Ireland. Initially, the Group Head of Sales - MES, provided a presentation of the company's history and their current product development. This was followed by two separate tours of the factory also joined by a technical manager.

The tours mainly consisted of observations with explanations of process as well as product features, but also included workstation demonstration by factory workers. Factory sections covered included cutting, joining, assembly, product testing, and material lab for all types of liferafts; marine, defence, offshore, and aviation, with capacity of everything from 1 - 158 people, and also life jackets.

Figure 4. Participants being dropped off by the lead boat at the start of the exercise

Figure 5. Inspection of 20 person davit launch liferaft undergoing testing

03. Background Research - Results

This chapter includes a summary of relevant information from the research, and for most sections also an explanation of how it affects the project.

Reading guide

This chapter represents the basis for most decisions taken during the project. It can be used to get an understanding of the field, or as reference while reading the rest of the report.

The research is presented in the following categories:

- Survival crafts
- Liferaft maintenance
- Sustainability of liferafts
- Maritime accidents
- Physiological aspects & consequence for equipment
- Search & Rescue
- Evacuation systems training
- Cranes & winches
- Legislation
- FIRST project
- Existing solutions & concepts for recovery

3.1. Survival crafts

There is two main types of survival crafts used in the maritime industry today, lifeboats and liferafts. Small ships such as fishing vessels or freight ships with a small crew size usually utilize liferafts, but bigger ferries or ships have regulations stating that a percentage of the passengers should be evacuated in lifeboats, and thus have a mix between the two types.

3.1.1. Lifeboats

The typical lifeboat is used by filling it with passengers at deck height, then lowering it down to the surface by davits. There are also free fall lifeboats, which are stronger and stored in a sloping construction ready to be dropped directly into the water when filled to capacity. These are however only required on bulk carriers according to current regulation.

Figure 6. Lifeboat undergoing maintenance (Wikipedia Commons, 2006)

All lifeboats are rigid, stable and have engines to be able to move at low speed. They can be open, partially enclosed or fully closed, and what types to use when is controlled by regulation. The perks of lifeboats, compared to liferafts, is their high stability and safety in water, but they are however more difficult to launch during evacuation.

3.1.2. Liferafts

Liferafts come in a variety of types, classifications and sizes. Rafts constructed for 1 person up to 158 persons are available today, but there is no upper limitation for capacity in the regulation.

Davit launched

Small and medium sized rafts (from 10 to 50 persons) are often launched similarly to lifeboats; by being filled with people at deck height and then lowered down by a davit. These rafts therefore withstand being lifted fully loaded with passengers, but are not constructed for being lifted back up after launching.

Figure 7. An eight person davit-launched liferaft being lowered to the water (Mercator Media, 2015)

Marine Evacuation Systems (MES)

Getting more popular today are marine evacuation systems such as ramps, slides or chutes connected to liferaft systems swallowing large amounts of people very quickly. The most popular system today is the Marin Ark, which is a four to six raft complex with up to 840 person capacity filled by sending down passengers in two chutes. The perks of these solutions are that they are very easy to launch by being stored in huge packages automatically falling or being lowered into the water and then inflating by themselves. They are already connected to the chutes and ready to be filled with people in a relatively short amount of time.

Figure 8. Deployed Marin Ark 2 system (Mercator Media, 2011)

Throw overboard

The last type is rafts thrown overboard to inflate by themselves, and then being entered from the water or a low deck or platform. This solution is used for small rafts, or on very large ones that are supposed to be added to a MES-system after launching.

Figure 9. RFD throw overboard liferafts mounted on a ship (Survitec Group, 2014)

Classifications

Rafts for inshore or offshore use have different classifications and different properties. Inshore it is allowed to have open rafts, whereas offshore use requires closed rafts and more extensive survival gear in them.

Construction

Rafts can either be self-righting or rightable, which gives a rounded top making it flip back around to its stable position if capsized, or enabling that flipping being performed by a user. It can also be horizontally symmetrical, which means it does not matter if it turns upside down because it is fully operable both ways. Lastly there are standard and arctic rafts that are simply one-way functioning, not self-righting or rightable, and have a more cone shaped top.

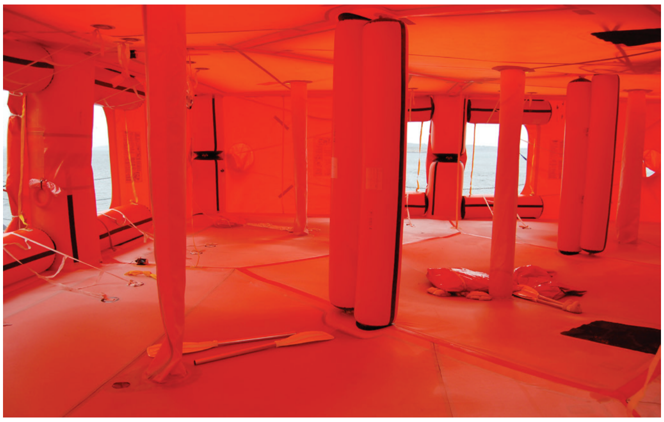

Figure 10. Inside the horizontally symmetrical Marin Ark 2

Figure 11. Building of RFD Beaufort Marine Ark systems at Survitec Group manufacturing plant, Belfast.

Inflation process

Rafts are inflated by one or several carbon dioxide gas containers in the pack, released by a pull on a connected wire, which is attached to the rafts ripcord. The ripcord is pulled manually or triggered automatically by throwing the raft container overboard.

Liferafts require a mechanism called hydrostatic release, which makes it release and inflate by itself in case of a fast listing process that makes it impossible to evacuate properly. This mechanism firstly includes a hydrostatic release which when being exposed to a few meters underwater pressure will cut the raft container fastenings to the ship, setting it free to float up to the surface. The other part is a weak-link connecting the ripcord to the ship. This weak-link will allow enough force to let the ripcord trigger the inflation, but will break before pulling the raft down with the ship.

Material & manufacturing

The inflatable parts of liferafts are almost exclusively constructed out of natural rubber or a nylon fabric coated with polyurethane (PU), on one or both sides. Both materials are characterized by high elasticity, which is required for the strains rafts have to endure. The floor is usually the same as the inflated parts. There are different variants with a range of characteristics and colour. For instance there is yellow nylon fabric with single PU coating that is used for aviation liferafts which has lower weight, cost more, and is less durable. Many colours are available but orange and black are most common. Most materials receive a UV resistance treatment and all require extensive testing to be approved and for quality control.

Inflatable parts are assembled either by gluing or welding (infra-red or hot air). Generally glue is used with rubber and welding with PU. In modern factories working with PU the main buoyancy chambers are normally manufactured with hot air welding since that allows for a continuous joint, making it stronger and less expensive to make. In contrast endcaps, and details such as valves, are attached using infra-red welding.

The cylinders can have any dimensions, but since the material is delivered in rolls it is practically limited by the roll width. The introduction of hot air welding has enabled the use of 90° angles in the main buoyancy chambers, however sharp angles like that are more difficult to make. Furthermore those angles cannot be used with the high pressure needed for liferafts that are lifted, then angles such as 30°, 45°, and 60° need to be used. Manufacturers use as much mmechanical joints as possible, particularly hinges connecting endcaps, since they are economic, strong, and have a long lifespan. They also further enable sub-assemblies which is preferred to welding or gluing large sections.

(Transportstyrelsen, 2010)
(Survitec Group, interview, 23 April)

3.1.3. LifeCraft

A hybrid between a lifeboat and a liferaft was recently released from the manufacturer VIKING with the goal to combine the perks from the two different solutions. This survival craft is basically a large inflatable raft with engines for propulsion, which is evacuated by using slides or chutes (MES).

(Transportstyrelsen, 2010)
(Survitec Group, interview, 23 April)

Figure 12. The VIKING LifeCraft (Mercator Media, 2014)

3.2. Liferaft maintenance

This section describes the liferaft maintenance time interval for service, also who are performing the maintenance, and how it is done.

3.2.1. Time interval for service

Regulations says a ship's full liferaft capacity should be tested in whole during a five year period of time. In practice this means ships send in some of their liferafts at a time for service. Shipping companies that are equipped with the Marin Ark often have a spare system to be able to keep the service cycle going without interrupting business.

3.2.2. Service stations & employees

Service stations are situated all over the world, often in the same cities as large shipping companies. The service stations are certified by the manufacturers to handle their products, in order to make sure they are treated correctly. The certification usually includes a weeklong education for maintenance personnel, provided by the manufacturer, and has to be renewed every two or three years.

3.2.3. Maintenance procedure

Liferaft maintenance generally includes a number of tests, inspection of parts, and change of provided equipment.

Pressure test

The raft is manually inflated with air and the pressure of each air compartment is measured over time to make sure they are not losing pressure too fast.

Figure 13. 16 pax liferaft inflated for pressure test

Gas inflation test

The raft is inflated by the gas cylinder to make sure that it is working.

Floor seam test

The floor seams are inspected carefully to make sure nothing is damaged.

Figure 14. Unpacked and deflated, open and reversible liferaft during maintenance

Load test

All davit-launched rafts go through this test, where they are lifted filled with water bags to the weight they are supposed to endure.

Inspection of parts

All valves, tubes, attached lines etc. are checked for damage. Valves are always date marked to show when they have to be replaced.

Change of included equipment

Food & water included in the survival kit has to be replaced every year, medication has to be replaced every second year, and pyrotechnics (such as flares) has to be replaced every third year.

Deflate & pack

Lastly the raft is deflated, the last air is sucked out, and the raft is packed after very thorough instructions provided by the manufacturer.

(Survitec - Gothenburg, interview, 12 Feb)

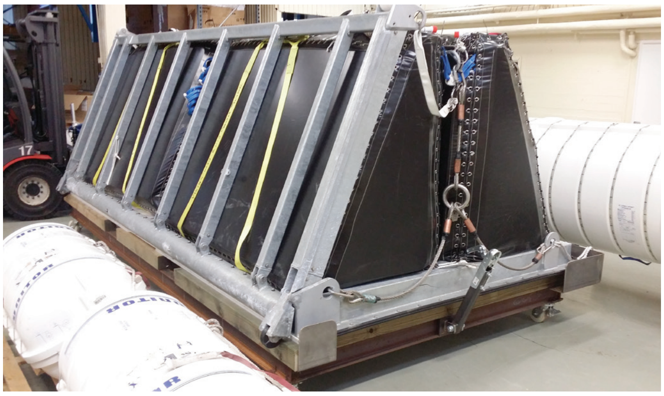

Figure 15. Packed Marine Ark 2 system with capacity for 632 people

3.3. Sustainability of liferafts

By looking at liferafts and their manufacturing process from a sustainable perspective the following conclusions could be drawn.[1]

Reduction of material use

Minimizing the use of material in the raft construction will of course improve its environmental effects. This includes both the inflated rubber and the plastic structure, but also all parts added to the construction later in the process, and the gas cylinders. By removing an inflated air compartment, one also gets rid of an entire gas cylinder package including release mechanisms and valves needed for that part.

Prolonged lifetime

Liferafts have a pre-set lifetime after which it has to be discarded due to decrease in performance, if it has not already been used in a real evacuation and thus discarded earlier. Prolonging this is deemed to have great effect on the product's environmental impact.

Avoid glue

Trying to minimize use of strong adhesives when assembling the rafts is important for several reasons. It reduces cost since glue prolongs the manufacturing time, but it is equally important to avoid in order to reducing negative effects on workers as well as the environment. Glued parts are furthermore impossible to disassemble for maintenance and at disposal.

Debris left in the water

When rafts are used during a real situation of evacuation, the container and all parts used solely for the launching phase will be left in the water. This is not a sustainable solution for that part of the product and is an issue for SAR personnel, but normally have very low priority during product development.

(Survitec - Gothenburg, interview, 12 Feb)
(Survitec Group, interview, 23 April)
(IMO, 2010)

3.4. Maritime accidents

While the Maritime Safety Committee (MSC) within IMO have agreed that large passenger ships should be designed to be "its own best lifeboat" accidents still happen. Norske Veritas summarised 109 international ship catastrophes that occurred in 1951 - 1997 of which there were 49 cruise ships, 38 ro-ro ships, 17 high-speed vessels, and 5 conventional ferries. Everyone was evacuated and rescued in 82 cases whereas 27 accidents led to a loss of 9550 lives in total. Interesting is that helicopters were only helpful in 13 cases, and also that the authors conclude that the ship's own evacuation systems were the most important asset, and that ships of opportunity were most often used for the recovery.

In Swedish waters there was 120 accidents or mishaps in 2007 (including leisure boats), although no one under Swedish flag has died since 1992. This is partly because many ships that are considered Swedish are not under Swedish flag anymore, as was the case with MS Estonia. An issue when studying ship disasters is that there is simply not enough data for any statistical conclusions to be drawn about e.g. causes.

(Ulfvarson, 2008)
(IMO, 2015)

Studying IMO's 'lessons learned' it can be noted that they have categorized incidents into capsizing (including sinking, flooding, and listing), contact/collision, injuries, fire/explosion, grounding, and others. Collisions are numerous and it seems like there is often one large and one small ship (such as fishing vessels) involved. There are also a lot of examples of accidents with lifeboats, often due to faulty use and/or maintenance of winch breaks and relatively complicated release hooks.

(IMO, 2015)

The following accidents are typical examples of events this project are addressing. The scenarios described later in the report are modifications of these accidents.

MS Estonia - 27 Nov. 1994

MS Estonia was a ro-ro passenger ship that went down on its way from Tallinn to Stockholm. The ship carried 989 people, whereof 803 where passengers. The listing was caused by breaking parts due to high strain from the rough sea, causing the bow visor and ramp to fall open and allowing large amounts of water into the car deck. The full cause of events was very quick; it took only 15 minutes until the ship was lying flat on one side, and another 20 minutes until the ship was lost completely. This meant evacuation was impossible to perform and most people went down with the ship. The majority of the ones who managed to survive did so by climbing onto liferafts floating up from the ship (by hydrostatic release), and were thereafter rescued by two ferries (34 persons) or by helicopters (104 persons).

> *"Then I started to think rationally and took the decision to use our own liferafts. I remember that we had the chefs out, among others. You can't crank for long so you stood in line and cranked for a while, and then the next took over, and the next, and the next. It went rather slow so that's why we didn't have time to save any more than we did. But it worked in some way at least." – Jan-Tore Thörnroos, former Captain at the ship Mariella that was first on the scene on the Estonia accident*

(SVT, 2014)

1 Since areas important to the design, with significant impact on sustainability, and with room for improvement could easily be identified no Life Cycle Analysis (LCA) or similar method was used. Instead additional focus was put on these aspects, especially reduction of material.

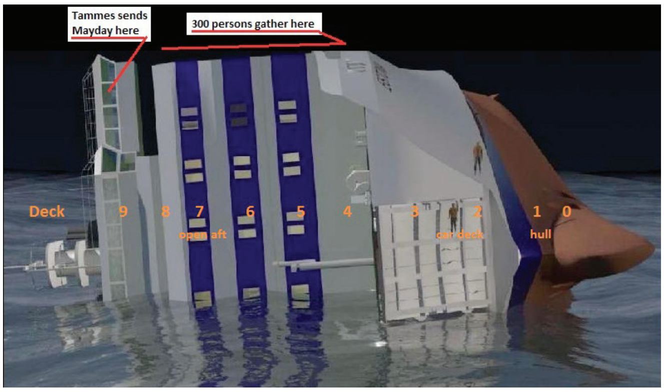

Figure 16. Animation of the loss of the MS Estonia (Vinnova, SSPA & Safety at Sea, 2008)

The accident cost 852 lives in total (one died later in hospital), and is considered one the worst maritime disasters of the 20th century.

(Den gemensamma haverikommissionen, 1998)

SV Concordia - 17 Feb. 2010

Concordia was a Canadian sailing ship used as a school at sea under the name 'Class Afloat'. It went down during a sailing from Recife, Brazil to Montevideo, Uruguay at a position 550 km southwest of Rio de Janeiro. The listing is considered to be caused by a rare weather phenomenon called 'micro bursts' causing extremely strong winds knocking down the ship on its side in 15 sec. The ship then filled with water and sunk 20 minutes later. On board were 64 people, consisting of crew, faculty members and students, who all managed to abandon ship and enter four liferafts. After 41 hours lost at sea, they were finally rescued onto two woodchip carriers by climbing pilot ladders up the shipside. It took about 8 hours from them being spotted until all survivors were at safety, this due to rough weather conditions making it too dangerous to enter the ships for a long time, and thereafter a difficult and time consuming operation to get the rafts in the right place and letting everyone climb up one at a time.

(Curry, 2010)

Figure 17. The S.V. Concordia (Carruthers-Wood & McGaw, 2014)

MS Costa Concordia - 12 Jan. 2012

An Italian cruise ship that was carrying 4229 persons (3206 passengers and 1023 crew members) when it suddenly hit a rock outside Giglio Island, Italy. The accident happened because the ship sailed too close to the coastline, in darkness and at high speed, at the captain's command to do a risky salute manoeuvre. The rock damaged five watertight compartments in the hull, the ship immediately lost propulsion, eventually drifted on ground due to lucky circumstances and stayed grounded with an increasing heavy listing for the rest of the rescue operation finally reaching 80 degrees. The rescue operation took approximately seven hours and survival crafts was towed into the Giglio harbour only a few hundred meters away. However, when the last usable survival craft was launched 500 persons still remained on the ship. In total 32 people were killed and 157 injured during the rescue operation, and the captain was later sentenced to 16 years in prison for manslaughter, causing the accident and abandoning his ship ahead of the passengers.

(Ministry of Infrastructures and Transports, 2012)
(The Independent, 2015)

Figure 18. Passengers climbing down ladders during evacuation of MS Costa Concordia (Guardia Costeria & Reuters, 2012)

MS Prinsesse Ragnhild - 8 July 1999

A fire in the main engine room and a malfunctioning fire extinguishing system forced the Norwegian passenger ferry Prinsesse Ragnhild to evacuate the 1339 persons it carried. It was located outside of Gothenburg at the time and due to very favourable weather conditions, calm and 18 C°, the evacuation went very smoothly but still took around 1 h and 15 min. The recovery of the evacuated passengers was carried out by letting people climb over to ships of opportunity such as passenger ferries (Stena Danica and Älvsnabben), rescue boats, combat boats (Stridsbåt 90) and fishing vessels, in total 28 vessels. The passengers were then transferred to Gothenburg city. The calm weather made this possible, but it was still time consuming and complicated due to height differences of the involved vessels. The fire had started at 2 a.m. but the rescue operation was not completely finished (meaning every passenger was safe and ashore in Gothenburg) until around 8 p.m., even though the conditions were optimal.

(Sjöfartsverket, 1999)

Figure 19. Liferaft being aided during recovery of MS Prinsesse Ragnhild passengers (Aftonbladet, 1999)

MS Norman Atlantic - 28 Dec. 2014

A fire on lower car deck of this ro-pax passenger ferry carrying 478 people (422 pax and 56 crew) between Patras, Greece to Ancona, Italy forced the Norman Atlantic to evacuate. The information about this accident is still not confirmed but due to the violent fire and heavy wind the evacuation were according to survivors very chaotic and not successful. Only about 50 people are said to have reached a lifeboat (meant for 150 people), why is not yet known since the investigation is not finished at the time. Most evacuation was done by lifting people off the ship with helicopters, which took 36 hours to finish. At least 10 people are confirmed dead and about 30 more are missing at the time.

(The Mirror, 2015)
(BBC, 2015)
(Svenska Dagbladet, 2015)

Figure 20. Helicopter over the burning Norman Atlantic (Italian Navy, 2014)

Figure 21. Refugee ship in the Mediterranean (Sestini, 2014)

Refugee ships

The amount of refugees and migrants trying to enter Europe via the Mediterranean increases every year, last year (2014) reaching 218 000 persons. This extremely dangerous travel overseas can take up to four days in an overcrowded, unseaworthy vessel without food, water or safety equipment, in the hands of cold-hearted smugglers. During 2014 at least 3500 people were lost during travels like these, and the numbers are expected to rise during 2015. The UN High Commissioner for Refugees (UNHCR) are continuously calling for European governments to take action and establish adequate search and rescue operations, with focus on saving lives rather than providing border control. Right now a vast majority are rescued by the commercial shipping fleet.

(UNHCR, 2014)
(UN News Centre, 2015)

3.5. Physiological aspects & consequence for equipment

This section describes physiological effects on people in distress and how this affects the design of any equipment to be used under these conditions. The first section deals with aspects that have greater effect in cold water, causes of deaths and how this affects design. The later part treats other relevant aspects such as dehydration, chafing, and fatigue.

3.5.1. Immersion

When immersed in cold water there are four main stages where a person is at risk of dying according to the Survival in cold waters by Transport Canada.

Stage 1: Initial immersion responses or cold shock (0-3 min)

At immersion in cold water there is a fourfold increase in severe hyperventilation after the large initial gasp. This in itself can cause muscle spasm and drowning. Furthermore there is a massive increase in blood pressure and heart rate that can cause death for less healthy people.

Stage 2: Short-term immersion or swimming failure (3-30 min)

Death seems to occur during the first 30 minutes for people who try to swim regardless of their ability to do so in warm water. There are different theories whether this is due to respiratory or cardiovascular responses.

Stage 3: Long-term immersion or hypothermia

Death by drowning will occur for a lightly dressed individual even if wearing a lifejacket after being immersed for approximately:

- 1 hour in 5 °C
- 2 hours in 10 °C
- 6 hours or less in 15 °C

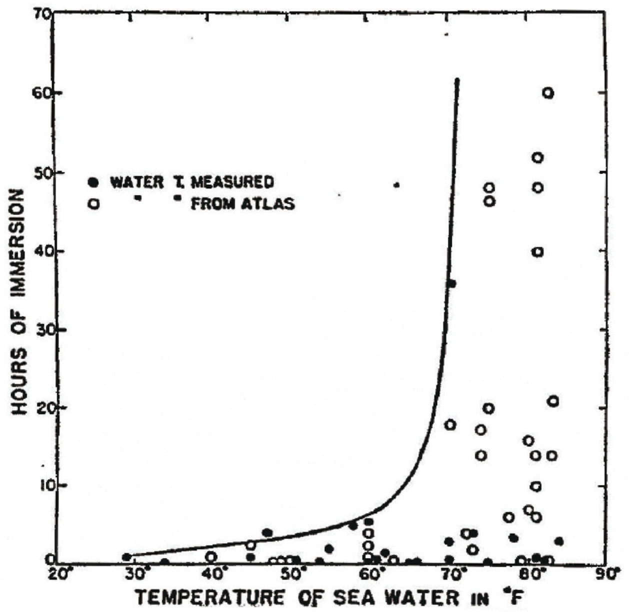

Figure 22. Duration of immersion of shipwreck survivors in ocean temperatures (after 1946)[1] (Brooks, 2001)

Stage 4: Post-rescue collapse

Up to 20 % of immersion deaths occurs during extraction from the water, or within hours after rescue. There are numerous recorded examples of post rescue deaths from recent accidents as well as back to WW2 and RMS Titanic, also in warmer waters such as with the TSMS Lakonia off Madeira in 1963 (where the water was 18 °C).

These stages represents the effect of being immersed and it clearly shows the importance of helping people get out of the water quickly. Equipment from the evacuating ship needs to address initial immersion responses, and even differences in response of just a minute makes a big difference if people end up in the water. Ships of opportunity could arrive when people in distress are either in stage 2 or 3 of immersion, ease of getting out of the water is therefore of almost equal importance as during evacuation.

3.5.2. Thermal protection & ventilation

Apart from immersion, cold water will have a significant effect on survivors inside a liferaft. A Canadian study tested the required thermal protection of a system for functional (core temp. 34 °C) and survival time (core temp. 28 °C) of 36 hours for various temperatures. The green and red lines represent the needed thermal insulation at 20 °, 10 °, 0 °, and -10 °C to be able to move and survive respectively.

1 It should be noted that this is the time survivors who have been rescued have been in the water, there are those who could have lasted longer and a lot who did not survive that long.

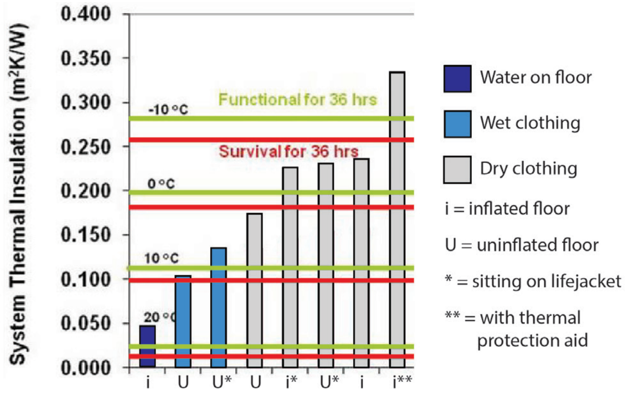

Figure 23. Bars showing thermal insulation for varying conditions in a liferaft, a higher bar means a person can survive for 36 hours at lower temperatures (Boone, James, et al., 2009)

(Boone, James, et al., 2009)

- Dry clothing means people in a liferaft can survive for 36 hours at much lower temperatures.
- A wet floor makes the situation significantly worse, only allowing people to survive for 36 hours at about 16 °C.
- An inflated floor in the liferaft (or similarly insulated) makes a big difference.
- If the floor is uninflated sitting on your lifejacket increases survival time significantly.

Keeping a dry floor is difficult in most current liferafts.

> *"A lot of water coming in, difficult to get out and the one who is heaviest gets all of it. You get cold when you are sitting in the wet" - SAR exercise participant*

> *"It was leaking through one of the zippers, covered it with a blanket. Lost the cup sized bailer for a while among all the legs so it was difficult to get water out" – Mathew Fader talking about the 30 h liferaft exercise*

The main consequence when designing equipment here is the importance of keeping people dry and providing insulation. This will greatly affect how long time during a search and rescue operations people are able to aid themselves in a recovery, and ultimately how long they will survive without help.

Apart from thermal protection the study also investigated the correlation between ventilation, temperature, and CO^2 levels. To keep both an appropriate temperature and an acceptable CO^2 level it is important to enable adjustment of the ventilation. The study showed that maintaining minimum ventilation (compared to a normal setup which gave eight times more than the minimum) would enable 16 occupants to survive for 36 hours at an outside temperature of -4 °C instead of 6 °C.

(Boone, James, et al., 2009)

3.5.3. Factors of death during rescue

A lot of focus is often on hypothermia, which is of course important, but only one of the factors that causes death during accidents at sea. Some of the most common are:

- Immersion
- Removal from water and restoration to the full influence of gravity (as when lifted by helicopter)
- Hypovolemia (decreased circulating blood volume)
- Hypothermia
- Hard physical work by victims during rescue

While listed separately, they are interlinked and much more dangerous when combined. One of the perhaps less known times of death is when people are lifted with helicopter. For example U.Hallberg (head of Swedish Maritime rescue) reported two deaths during helicopter winching in 1992. After the MS Estonia accident in 1994 Times Magazine wrote;

> *"of those who managed to scramble overboard, only 139 survived. The rest died of shock and hypothermia before rescuers could pluck them from the storm tossed sea; some expired even as they were being winched to safety"*
>
> (Golden, David & Tipton, p.6, 1997)

P.Rydell, one of the winch men, accounted for how a survivor lost consciousness two meters above water, fell out of the strop, and died in the water.

The main additional consequences of these factors are that people should not be lifted positioned vertically after being cooled down and the recovery should not require hard physical work from the people in distress.

(Golden, David & Tipton, 1997)

3.5.4. Decreased physical abilities, dehydration, exhaustion & fatigue

Being exposed to cold and wet conditions over time leads to impaired physical performance leading to inability to self-help, especially when combined with dehydration, exhaustion, and fatigue. As described by Survival in cold waters:

> *"if rescue does not occur within the first 10 - 20 minutes, then the ability to cling to floating debris, becketed grab lines, and do any physical self-rescue action decreases".*
>
> (Brooks, p.29, 2003)

Furthermore, cold waters significantly reduce grip strength and manual dexterity almost immediately. Research show that the maximum voluntary grip strength (MVGS) was reduced by 16 % following immersion of the hand in five sets for two minutes each in 5°C water. Since the majority of reduction occurs during the first two minutes a survivor's abilities are lowest when they are needed the most.

(Tipton, & Vincent, 1988)

A Chinese study found that all survivors of a maritime distress in tropical seas suffered from physical exhaustion, infection of skin wounds, sleep loss, medium or severe dehydration, blood concentration, metabolic acidosis, and azotaemia. Also many had experienced attacks by marine animals (22,7 %), stress ulcer, and shock. To sum up, survivors in tropical waters may not suffer from hypothermia but will likely not be in the condition to perform any major physical self-help action during recovery.

(Ding, Wang, & Chen, 2002)

3.5.5. Position in the liferaft, blood circulation & chafing

Apart from aspects directly related to survival other factors such as comfort, blood circulation, and chafing etc. affects the mental and physical state of people in liferafts. Space and how to position themselves proved to be one of the major issues in an exercise by SSRS were eleven participants stayed for 30 hours in a liferaft at sea. While they were all in survival suits and not suffering from the cold or the real psychological pressure of a life threatening crisis, having their legs firmly stuck under the others' produced anxiety and panic. "Cramped!" was also the spontaneous reaction of everyone exiting the liferafts after one hour in it during the observed SAR exercise.

> *"Cramped! The legs in the way and damn uncomfortable. The straight sides means you have to sit at 90° and no floatation element in the middle means that part sinks down. Would have been much better if you could lean back" - participant in SAR exercise*

> *"Did absolutely not want to leave the spot at the window after lookout, but later we had to close" - participant in 30 h liferaft exercise*

Apart from psychological effects as anxiety, the combination of not having enough room, sitting with your back straight, and getting stuck at the bottom in a pile of legs results in reduced blood circulation. Additionally the combination of water and rubber quickly results in serious chafing as reported by survivors from SS Concordia.

(Carruthers-Wood & McGaw, 2014)

3.6. Search & rescue

3.6.1. Organisations

During the SAR convention organised by IMO in 1979 the waters of the world was divided into search and rescue areas in which one country's government have the obligation to rescue people in distress. What authorities and organisations there are to perform this responsibility differs from country to country, in Sweden the responsibility lies on the Swedish Maritime Administration (Sjöfartsverket) who have immense support from the non-profit organisation Swedish Sea Rescue Society (SSRS).

3.6.2. Resources

What resources are available also vary between states and organisations. In Sweden the general resources of SSRS are small to medium sized rescue boats and Rescuerunners, whereas the Swedish Maritime Administration have helicopters, pilot ships and other ships used for maritime labour to their disposal. During larger rescue operations resources from the coast guard, police, military and other authorities are also at full disposal. Furthermore, according to the SAR Convention every ship, ferry, fishing vessel, cargo ship etc., are obligated to aid in rescue operations by all means as long as they are not endangering their own crew. These ships, in case of involvement in a rescue operation, go by the name "ships of opportunity" within SAR organisations.

The vessels of SSRS who performs the vast majority of rescue operations at sea have a speed of approximately 35 knots in calm water (approximately ten to twelve knots in moderate waves) and a five- hour range. They can take ten to 30 people on board according to regulation but could fit more in a serious crisis. Ice coverage of the waters could make all these vessels unusable, and while there are hovercrafts at the lakes, the coast is not covered.

(Fredrik Falkman & Thore Hagman, interview, 2015)
(IMO, 2015)
(Räddningsverket, 2008)
(SSRS, 2015)

In coastal areas in the EU and the USA there is good helicopter readiness but in most cases the rescue systems of the ships themselves along with ships of opportunity have recovered the people in distress.

> *"In Sweden a system with helicopters are located in five places around our coast with urgent preparedness. The capacity of this system is to rescue people in distress within 60 minutes in territorial waters and 90 minutes in international waters belonging to the Swedish search and rescue region (SRR). This system can take care of about 35 persons in distress within an hour. For mass evacuation and rescue this system is not adequate..."* [1]
>
> (Ulfvarson, p.4, 2008)

1 60 and 90 minutes is set by a letter of regulation from the Swedish government.

Figure 24. Rescue helicopter from the Swedish Maritime Administration and a boat from SSRS (Swedish Maritime Administration, 2014)

The MS Estonia disaster showed that when many people are in need of rescue the current systems with helicopters are not sufficiently efficient.

(Ulfvarson, 2008)

3.6.3. Practical SAR operations & training

The participation in the local search and rescue exercise clearly displayed the issues of locating people in distress. As is often the case the resources searching do not know exactly what they are looking for. In the exercise, which is based on regular cases, information was only given about a lost boat (and vague passenger numbers) why the search was not primarily for the liferafts the "survivors" were actually in. The importance of high visibility and possibility to identify survival crafts, including number of people, can therefore not be emphasised too much. It was noted that the highly visible orange was fairly easy to notice from a long distance by eye, while not clear on photographs (relevant if photo or video search is available from search drones or such).

Figure 25. Participant struggling to get into the liferaft after falling into the water as transferring from the lead boat

Another expected observation was that moving people between vessels is an issue even in calm conditions as during the exercise. One participant fell in the water trying to get down into one of the liferafts from a boat, and could not get up in the raft from the water without aid. With the relative motion produced even in moderate seas, moving people would be a major concern for any procedure on sea. This have been mentioned in numerous interviews such as with Thore Hagman regarding the Princess Ragnhild incident.

Even if the exercise accident only produced debris in the form of one cylindrical packaging for the liferafts including straps etc. it still meant rescuers had to take care approaching. In a full-scale situation this would also be a concern.

There are numerous context factors that affect practical operations, as well as training, such as:

- Sea state, temperature, wind speed
- Condition, physical characteristics, clothing of people in distress
- Contaminants (oil, fuel etc.)
- Condition of rescuers
- Type of incident and number of people in distress
- Need to lift people into boats[1]

(Golden, David, & Tipton, 1997)

When it comes to recovery of people in distress in real conditions there are even more aspects influencing the operation greatly. In the SAR exercise it was fairly easy with few people in distress, access to a boat with extremely low freeboard, and completely flat sea. With a larger number of people the condition changes;

> *"if you are lucky it is close to the coast and there are small boats available. Still takes many hours even if a large quantity of small boats available as with Princess Ragnhild when it was perfect conditions, including vessels monitoring match race in Marstrand" - Fredrik Falkman, SSRS*

3.7. Evacuation systems training

This section describes training with evacuation systems and what can be learned from the training instructors' experience of participants' skills as well as handling the equipment. According to the instructors at Öckerö the focus in the training is on taking care of passengers in case of emergency, the other main part is personal safety.

> *"All crew have two jobs. Some are very aware of their different roles and make sure they are well prepared, they make sure they remember the training. Others just see it as they have one job and don't really put any effort in their emergency role" – Instructor at Öckerö Maritime Center*

1 The large number of factors affecting the situation means it is difficult to get a full view of their consequences. Thus it is important to evaluate solutions against scenarios.

Figure 26. In their training, the crew get to test most of the equipment, but usually only once and will at most be familiar with it if they have to use it during the 5 years the training is valid.

There is normally around 7 - 10 people for handling evacuation in a Marin Ark system, and instructors think it should work fine in rough seas, even if the chute might be a problem. However mistakes are always made in an emergency, even if it works during training. It is good to use familiar equipment since people seem to trust things they recognize more, such as slides.

> *"They have trouble with complex systems. Even if something is quite easy, but looks advanced, that's a problem for people." – Instructor at Öckerö Maritime Center*

Figure 27. Participants get instructions on how to handle passenger and Marine Evacuation Systems (MES) in an emergency.

While the instructors think most things with MES work well they conclude that it can be very dangerous to move between rafts if they are not placed tight together. Also that in training climbing up into rafts is the most difficult part for participants and if they could change one thing it would be to lower the liferaft entrance. Generally, they emphasize a need to remove bottlenecks in the rescue process Once inside a liferaft, survivors could stay several weeks if everything is managed correctly and the circumstances are right. One thing they are particularly worried about are liferafts classified as self-righting considering how it works in a calm harbour.

> *"The participants, especially smaller ones, have troubles turning the raft around when tipped over. The one they practice with is only for 12 people, but it's still difficult. They are not prepared for turning over big rafts."*
> *- Instructor at Öckerö Maritime Center*

3.8. Cranes & winches

A very high percentage of international ships have a crane with capacity for hoisting a four ton vessel in order to comply with rules for passing through the Suez Canal in Egypt. Those cranes are required to enable pilots to easily get on board and otherwise ships have to be towed through the canal. No further information on the state of those cranes, and how well their manoeuvrability is, could be found.

(Suez Canal Rules of Navigation 2007, Art. 20)

Since liferafts are not lifted other than in the testing by SSRS the recovery by installation crane of Fast Rescue Crafts (FRC) was deemed the most similar realistic situation. FRC's are generally 9.5 - 11.5 meters long, 3.2 meters wide and weigh 4200 - 6750 kg (for the UK North Sea). Launching (and thus recovering) those FRC's with crane have a limitation of maximum four to six meter significant wave height and winds up to 50 - 60 knots. The hoisting speeds are 23 or 45 meters per minute depending on setup (single or double fall).

An evaluation of launching the FRC's found that there were several hazardous elements, especially connecting the crane to the FRC with the auto release setup required. Furthermore pendulum movements and partial rotation were major issues. Modern cranes can however effectively reduce this but it is depending on operator experience.

(Block, 2006)

3.9. Legislation

International Maritime Organization (IMO) - SOLAS & the LSA Code

In the field of maritime safety there are different levels of regulations to follow. The highest level of regulation is issued by the UN organ IMO, and will apply to all countries signing on the decisions. In 1974 the IMO held the SOLAS Convention, which lead to maritime safety regulation signed on by 161 countries, and applying to almost 99 % of the tonnage shipped over the world. Based on this 1974 SOLAS Convention, IMO have published a collection of requirements for life saving appliances (including liferafts) in a document named the LSA Code. Since almost all ships present in the waters of the world today follow these regulations, it is of highest interest to fulfil those demands in this project.

European Maritime Safety Agency

The next level of regulations are from the EU organisation EMSA. This organisation publishes European standards, are concerned with protecting the maritime environment, accident investigation, maritime information etc. These standards are not taken into account in this project, but should be included if a product should be made realized in the future.

Swedish Transport Agency

At the last level, relevant for this project, there is the Swedish Transport Agency, which issues rules for the Swedish maritime industry. Sweden is a leading country when it comes to maritime safety, why this level of regulation often is harsher than rules issued from higher instances. These regulations will not be taken into account in this project either, but should be included if a product should be made realized in the future.

(Eklund, 2012)

3.10. FIRST project

In this section the mass rescue and the project FIRST will be presented. An explanation of why transfer to other ships is the logical solution will be provided partly as a further rationale for this master project. Furthermore a brief review of finished, on-going and future development by SSRS regarding mass rescue will be included.

Figure 28. Commercial ships in Danish and Swedish waters (Falkman, 2014)

3.10.1. Background

While the fundamental viewpoint from IMO is that the ship is its own lifeboat, there are still situations when ships has to be abandoned according to Ulfvarson, 2008. He continues arguing that there is need for new development of recovery systems. Current regulation mandate orderly evacuation but accountability stops short when people have been evacuated from the ship.

(SSRS, 2015)
(Ulfvarson, 2008)

So why are ships of opportunity a solution? The definition of mass rescue at sea, "a situation in which rescue services are overwhelmed", in itself states that resources in addition to the regular SAR organisation is needed. There are numerous reasons for why ships of opportunity is and should be that resource; they already cover the area in question, are the closest place of safety, have sufficient capacity, and by not being primarily dedicated SAR units it is economically logical from a SAR and a governmental perspective.

While local implementation of concepts from FIRST is encouraged, change in international regulation is the only realistic way for the system to become a reality, and thus this is the long-term goal.

3.10.2. Subprojects

The sea calming turn

In close co-operation with Stena Line and Captain Jörgen Lorén a sea calming turn that provides slack water in a large area on the lee side of a turning vessel have been developed. Slack water inside a turn is already utilized for picking up pilots but by doing a full circle a ship can provide calm conditions for launching and recovering rescue boats, or more interestingly, for this project to recover people from liferafts. While more testing is needed with different types of ships and in even harsher conditions with more controlled measuring, the turn has been proven effective in up to eight meter waves with M/S Stena Jutlandica.

Figure 29. A ship from Stena Line performing the sea calming turn during testing of lifting liferafts (Lifeguard 901, 2011)

Close Range Rescue CRAFT with cradle

A SOLAS approved Rescuerunner and a matching drive-through cradle have been developed to improve the risky and scary process of launching and recovering a rescue boat. The Rescuerunner is much smaller and lighter than regular rescue boats, and with the cradle the situations becomes much more controlled and safe. Another massive advantage is that a vessel like the Rescuerunner is much better suited for interacting with a liferaft, and one or two units could be a great resource in the recovery phase of a mass rescue operation.

Figure 30. Rescuerunner being lowered in the drive through cradle (Matsson & Åslin, 2012)

Prototyped and tested cradle for lifting smaller liferaft

With the idea of providing equipment that could lift any liferaft SSRS prototyped and tested a cradle but concluded that the concept was a no go. The testing showed it was complicated, slow, personnel intensive, questionable how well it would scale to larger rafts, and clearly not as good as liftable liferafts.

Figure 31. The liferaft lifting cradle (Falkman, Forsman & Hagman, 2009)

Testing crane recovery of davit launch liferafts to ro-pax ship

Since 2007 the FIRST project have shown that lifting liferafts with people inside is effective and realistic even in harsh conditions. Even with a non-purpose, retrofitted, and temporary crane in relatively rough conditions a davit launched liferaft with capacity for 39 people have successfully been lifted within seven minutes from starting to launch the rescue craft until the raft was on board. Subtracting the time to launch the rescue craft (approximately two minutes) this would mean a pace of 468 people per hour. Test has also been completed at night, with a raft fully loaded with water bags onto a coast guard ship, and in rough seas. For this thesis project this is viewed as a proof of concept for any concept involving lifting liferafts.

Figure 32. VIKING self-righting liferaft being lifted by a temporary crane on-board Stena Line vessel during testing in the FIRST-project (Swedish Sea Rescue Society, 2012)

Putting Mass Rescue on the agenda

The FIRST project have played an important role in putting mass rescue at sea on the agenda. One example is showcasing the issue with simulator scenario testing at the third International Maritime Rescue Federation (IMRF) mass rescue conference in Gothenburg in 2014.

More on-going and further projects

There are several on-going projects within FIRST that is closely related, and could be of great interest, to this thesis project. One is the RIM jet, which would allow rescue crafts to get close to rafts even in a situation with a lot of debris in the water, without risking anything getting caught around the driveshaft. Another project is a remote connection of a crane hook to a liferaft without the need of anyone getting into the water. Although, neither of these has yet been developed far enough for serious consideration in this project. A container based station with crane and Rescuerunner is however one subproject which could be of more immediate interest.

(SSRS, 2015)

3.11. Existing solutions & concepts for recovery

In this section currently used solutions and concepts for recovery will be presented.

Pilot ladders

Pilot ladders have often been used in mass rescue operations according to Thore Hagman, and many ships are required to have them. IMO states in their regulation that a straight ladder can be used for ships with a freeboard up to nine meters. An additional "accommodation ladder" similar to a stairway secured to the side of the ship needs to be added if the freeboard is higher than nine meters.

(IMO Resolution A.1045(27) 2011)

Figure 33. Man climbing up a pilot ladder (Tingley, 1969)

One example is the accident with SV Concordia where all passengers were rescued to the cargo ships Crystal Pioneer and Hokuetsu Delight after 42 hours lost at sea. The recovery process took ten hours and most people were recovered via pilot ladders. Here follows some quotes regarding the recovery process from passengers and crew from Concordia.

> *"We would have to climb 60 feet on ladders and I was more afraid we would lose someone in that process than at any other time" - Kim Smith, Chief mate*
>
> *"Looking up the side was just like a steep mountain, a steep steep mountain" - Lachie Woofter, student*
>
> *"I just thought: We have been here for so many hours and we are going to be killed by our rescue... no, can't be happening" - Hector Rode, student*
>
> *"That was when it was the coldest, that was when everyone was the crappiest. Frustrations were coming out, emotions were coming out, our liferafts were slowly sinking... people were still puking, people were still sick"- Lachie Woofter, student*
>
> *"When we got on the ship we were so traumatized by the conditions that we could barely walk" - Kim Smith, Chief mate*
>
> (Carruthers-Wood & McGaw, 2014)

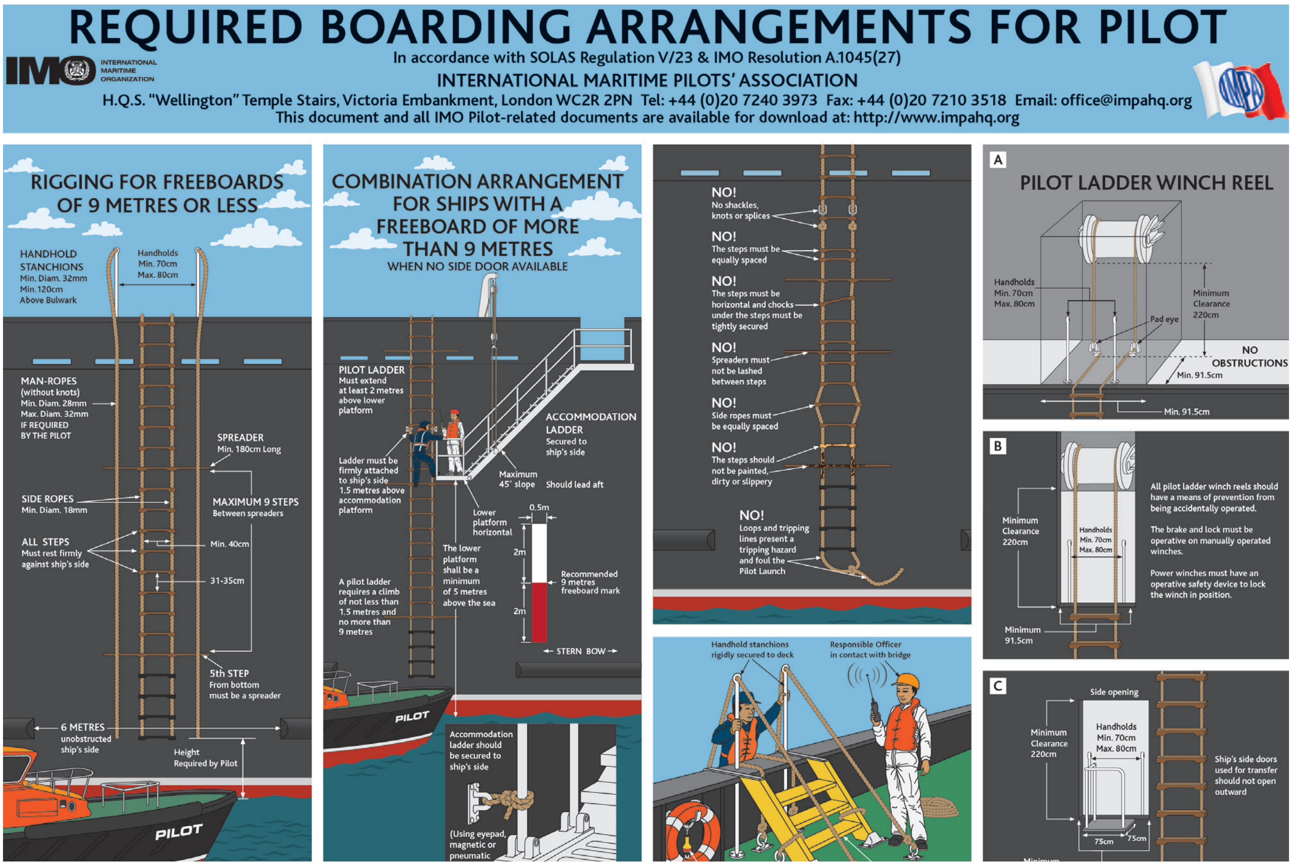

Figure 34. Illustration explaining IMO regulation for pilot ladders (International Maritime Pilots' Association, 2012)

Figure 35. People climbing a scramble net (Markus Lifenet, 2013)

Scramble nets
Scramble nets can be used on ships with low freeboards and have often been used in military rescue operations, but in those cases there is obviously a different demographic.

In military mass rescue operations the solution have often been to position the ship coming to rescue right next to the ship in distress and use ladders or nets. Something, which would not be possible for civilian ships due to a lower acceptance of putting people at risk. Rescuing ships are required to help in any way they can without putting their ship, crew, and passengers in danger.

(Hagman, interview, 2015)

Figure 36. Historical image of troops climbing up cargo nets (Granville Caldwell, 1941)

Figure 37. Rescue helicopter lifting with a foldable rescue basket (US Coast Guard, 2014)

Helicopter
Helicopters can lift people from a wreck in calm weather. When there are large relative movements between wreck and helicopter, this is no longer possible. Then, the helicopter can only lift people one by one wet from the sea surface or from soft life rafts, which takes approximately seven minutes per person.

Baskets are better than ropes or slings for recovering people from the water. A person cold from immersion should be lifted horizontally. However, people responsible for helicopter safety consider lifting and putting down the larger baskets fully loaded onto or from moving decks in heavy seas is out of the question. The issue is slacking and strong jerks in the wire, which could damage the fastening to the helicopter and possibly have even worse effects. Thus the pilots are very reluctant to use it.

(Ulfvarson, 2008)

Means of Rescue (MOR)

The purpose built inflatable Means of Rescue by Zodiac and VIKING have capacity for lifting 25 persons sitting, or twelve persons lying down. They are intended for ro-ro ferries to enable rescue of survivors from the water or another vessel according to SOLAS regulation. They are lifted with a crane and stabilized by bowsing lines. However, these are not used to any great extent, e.g. RFD Beaufort sells ten units in a good year.

(VIKING, 2015)
(Survitec Group, 2015)
(Survitec Group, interview, 2015)

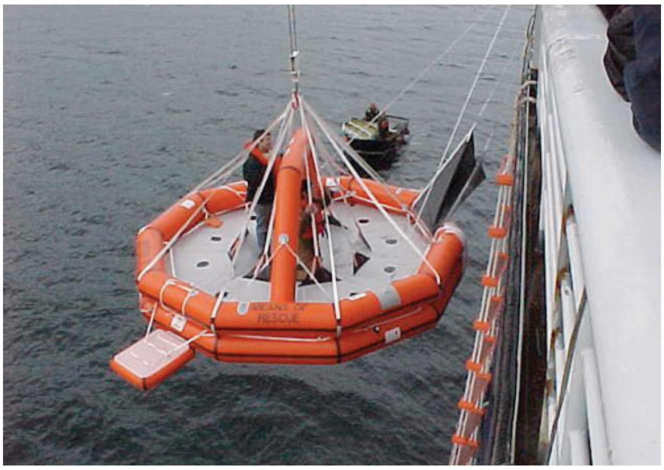

Figure 38. Means of rescue from Zodiac (SurvitecZodiac, 2015)

DESSO project

The Design for Survival On-board (DESSO) project describes an evacuation system in which liferafts with capacity for 100 people each are to be filled with passengers and lowered to the water surface. The idea is for them to be possible to tow with for example FRB's and lifted up the same way. No such davit liferaft exist on the market but Zodiac responded that it would be possible to make.

Another concept involved lifting liferafts with helicopter such as the "Russian MI 26", which has a 56 ton lifting capacity. Even though the capacity is enough it is highly dangerous to lift from a moving foundation considering jerks in the lifting wire. The DESSO-project concluded that technology for keeping a constant distance between the helicopter and raft, as well as a wire with high damping and elasticity would be interesting.

(Ulfvarson, 2008)

Easily recovered liferaft - Canadian Coast Guard

The Canadian coast guard carried out a project on easily recoverable liferafts fit for the weather circumstances of their area. After some ideation and evaluation they ended up with two possible solutions. Firstly, adding an inflatable ramp on rescue vessels with a low freeboard, where rafts could be dragged onto deck. Secondly, developing liftable rafts to be lifted onto deck with cranes. After further evaluation liftable rafts seemed the most appropriate and testing of lifts with VIKING 16 pax rafts was conducted successfully in Canadian waters.

(Paterson & Sullivan, 1997)

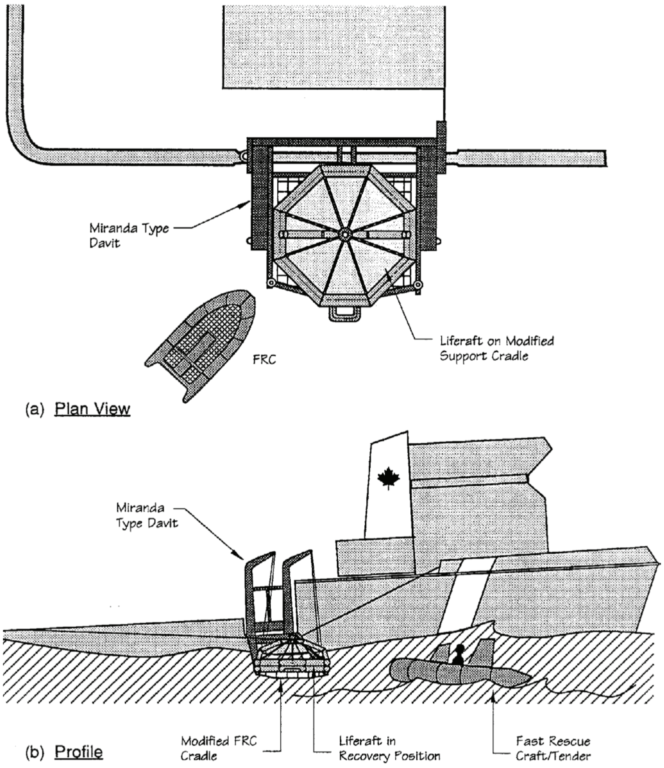

Figure 39. Illustration from a Canadian study of a liferaft being recovered by a special type of davit (Paterson & Sullivan, 1997)

Ark in an ark

A bachelor thesis project from Chalmers University of Technology came up with a concept for making use of the current Marin Arks in efficient mass rescue. The idea was to integrate inflatable and liftable units on standby inside the Marin Ark, to be able to lift approximately 16 persons at a time onto a ship of opportunity when given a chance.

(Roos, 2014)

04. Research Analysis

This phase was conducted to dive deeper into, and to make use of, the information gained during the research phase. In this chapter the analysis methods used during the phase will be presented one at a time. Each method will be described shortly, motivated, and its result will be presented accordingly.

Reading guide
This chapter should be read for deeper understanding of the insights and conclusions drawn in the project, based on the background research. It contains stakeholder analysis, consequence analysis, scenarios, and a user mapping.

4.1. Stakeholder analysis

Early in the project a stakeholder mapping were done, listing all parties concerned in the project (Bligård, 2011). This listing was based on the knowledge gained during the research phase. A brief analysis of the different stakeholders' needs and expectations followed (see appendix).

While there are many important stakeholders that needs to be considered, the crew, passengers, and SAR personnel are primary users. They are the ones in direct contact with the equipment in critical situations, whereas manufacturers, educators, and maintenance worker are secondary users.

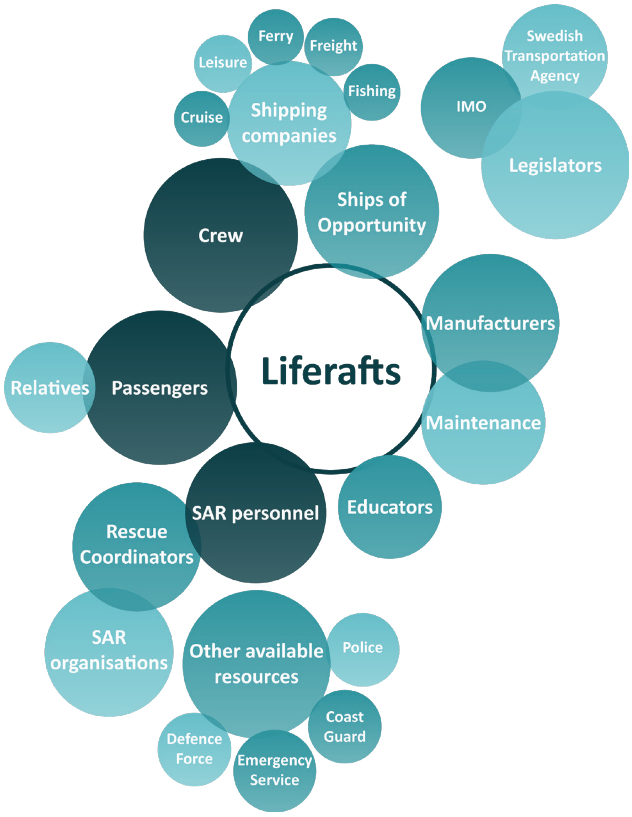

Figure 40. Stakeholder analysis

4.2. Hierarchical Consequence Analysis (HCA)[1]

Based on the knowledge gained on accidents during the initial research a consequence analysis was conducted on different types of accidents, and different circumstances around them. By stating a number of different starting points and mapping all possible consequential problems of that event, a hierarchical structure of possible problems was formed. By then grouping all the different possible problems through a KJ-analysis[2], a summary of problem areas to take into account was gained. A summary of the results are presented below, the full HCA is found in the appendix.

4.2.1. Accident types

- Fire aboard ship
- Grounding
- Collision
- Equipment failure
- Terror act

Consequences

- Uneven distribution in survival crafts, both filled under or over capacity possible.
- No responsible and trained person in raft
- Injured people to evacuate e.g. decreased mobility or unconsciousness
- People in the water (some or all if hydrostatic inflation occur)
- High panic and stress levels of people (decreased cognitive skills, aggressive, irrational, etc.)
- Pollutants (oil, chemicals, etc.)

4.2.2. Context factors

- Wind speed
- Wave height
- Air temperature
- Precipitation (rainfall, snowfall etc.)
- Fog
- Ice coverage
- Time & position of accident

Consequences

- Chilling effect, thus shorter survival time in raft (due to wind, cold, wetness, improper dressing of passengers, etc.)
- Wet people and equipment
- Intoxicated persons
- Heavy movement of vessels and parts
- SAR units unavailable
- Decreased visibility & hearing (due to weather)
- Decreased strength & precision in hands (due to light hypothermia)

4.3. Scenarios

In order to better understand the situations a future product might face, a number of scenarios was constructed. The scenarios was also to be used to evaluate concepts later in the project.

These scenarios were all based on actual accidents, but modifications were made to make them more suitable and more stimulating for the project (see the originals in section 3.4 Maritime Accidents). The scenarios are described below, with the changes made clear, and with motivation for choosing them. For quantified details on the scenarios see appendix.

4.3.1. Estonia Today

Changed factors

A slower sinking process, where most people got evacuated into liferafts. This is more realistic today due to new IMO regulation for ships regarding hull division, as well as more efficient evacuation systems.

One of the ships of opportunity have been changed to a ro-pax ferry from Destination Gotland since the hope is to install the recovery system from this project on that completely Swedish route.

Why

MS Estonia is probably the most well-known MRO in Sweden and it is interesting to see how much have been learned in this area, and how recovery of this many people would be handled today.

Figure 41. Liferaft from MS Estonia floating upside down (Lambert, 1994)

1 The hierarchical consequence analysis was created by the authors based on a Hierarchical Task Analysis – HTA (Bligård, 2011)

2 The KJ method is useful to handle and analyse large amounts of data by dividing it into small parts and grouping these (Bligård, 2011)

Comment on conditions
Same very rough conditions as for the original catastrophe with relatively high waves and strong winds, which makes any manual action in the recovery process difficult.

Recovery situation
Moving people between units is exceptionally difficult and potentially highly dangerous. Every action, such as connecting units or towing, is very tricky even with a ship providing lee. Connecting any vessel to the side of ships would be hazardous.

4.3.2. Norman Atlantic

Changed factors
Most people evacuated to liferafts to make the scenario relevant. With a majority of passengers stuck on top deck there is not much that can be done with a recovery system. If the evacuation had proceeded as it is supposed to, this would have been the case, and the scenario is therefore deemed realistic.

Why
Fire is one of the main types of accidents that can result in a MRO and Norman Atlantic was chosen since it seems fairly typical, and the accident happened recently.

Comment on conditions
Same moderately rough sea conditions which makes evacuation and recovery more tricky, but not in any way impossible. This type of conditions are very common in many waters, why it works as a good example.

Recovery situation
Due to winds and sea state, towing and other actions in the water are difficult and tedious. A ship providing lee should make manoeuvres much more manageable. Connecting to the lee side of a ship should be possible.

Figure 42. The Norman Atlantic on fire (Guardia Costeria & Reuters, 2014)

4.3.3. Costa Concordia offshore

Changed factors
Same as the recent Costa Concordia accident but with moderate offshore winds and waves.

Why
Costa Concordia is a well-known accident and is useful for illustrating what happens with the increasingly common cruise ships with capacity for several thousand passengers.

Comment on conditions
Still fairly calm conditions and location very close to land, but with enough wind and waves to make liferafts drift out to sea, be difficult to tow, and will also make it practically impossible to swim ashore.

Figure 43. The Costa Concordia on ground and listing with lifeboats in the water during evacuation (AP, 2012)

Recovery situation
The calm conditions means most actions are fairly easy and all recovery principles should be possible to use. However the wind means liferafts drift fairly quickly.

4.3.4. High traffic area collision

Changed factors
An accident which fortunately have not happened yet.

Why
From studying IMO's "Lessons learned" one can conclude that a large number of collisions occurs in high traffic areas. Between Sweden and Denmark there is such an area, also with a lot of SAR resources available. However, in this scenario there is ice close to shore, which SSRS have considered a worst case scenario since they would not be able to get out with their boats. Furthermore, in very cold and windy conditions helicopters might not be able to aid in a rescue operation either, due to risks of icing of the rotor blades.

Comment on conditions
Rough conditions with high waves and strong wind but nothing out of the ordinary. Due to ice coverage, wind, and temperature neither helicopters nor SSRS units can get to the location. Thus the outcome is completely dependent on ships of opportunity.

Recovery situation
The combination of waves, wind, rain, and low temperature makes all actions difficult and some potentially dangerous. It is extra important to keep people dry and protected from the weather. The absence of SAR resources means the need for complicated rescue manoeuvres, such as e.g. driving a Rescuerunner into a cradle, should be kept at a minimum.

4.3.5. Refugee ship

Changed factors
Not modelled after a specific accident but placed in one of the areas with the highest amount of drowning deaths following sinking of refugee ships.

Why
This scenario illustrates the type of accident that takes the most lives at sea today.

Comment on conditions
Moderate sea state but few people in liferafts due to vessel being filled far over capacity and crew abandoning the ships to avoid capture by authorities. Heavy (not present in the other scenarios) rainfall, which is reducing visibility and making the recovery of people from the water more difficult.

Recovery situation
A different scenario since most people are in the water making the situation critical despite the moderate conditions. Getting people out of the water is most important.

Figure 44. Collision between M/T Gas Roman and M/V Springbok (Unknown, 2003)

Figure 45. Italian rib boat evacuating an overfilled refugee vessel (Sestini & Eyevine, 2014)

4.3.6. SV Concordia cold water

Changed
The accident of SV Concordia outside the Brazilian coast, but in colder waters instead.

Why
While the loss of Concordia did not involve that many people it can still be considered a MRO since it was very far out to sea. In the actual case everyone survived, but in relatively cold waters this would not have been the case considering the time it took to recover the passengers and crew from the liferafts.

Comment on conditions
Moderate conditions after the ship capsized, but cold waters making survival time in liferafts much shorter.

Recovery situation
The low temperature and the long time before arrival of ships of opportunity means a fast recovery that does not require any effort from the people in distress and keeps them protected, is important.

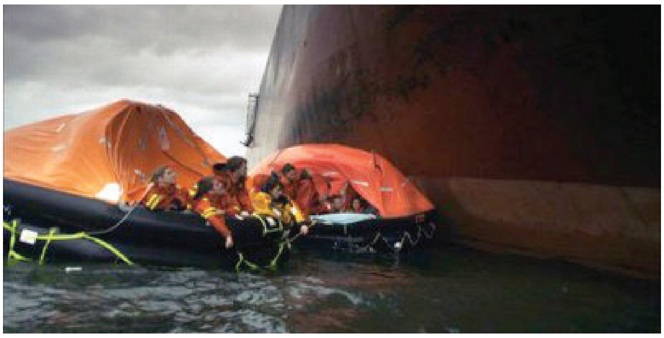

Figure 46. Liferafts from the SV Concordia next to merchant vessel before recovery (Carruthers-Wood & McGaw, 2014)

4.4. User mapping
Another important part of the project was to understand the users. Who they are, and what they want, was covered by the stakeholder analysis. In order to understand their behaviour better this user mapping was conducted. Since the context of the project is rather extreme, and the users will be under large amounts of stress and pressure, trying to predict or at least gain understanding of general human behaviour in similar situations was of great importance.

4.4.1. User types
Previous experience of the situation and equipment at hand greatly affects behaviour in stressful situations. Therefore, the users were divided into groups and based on level of experience regarding evacuation at sea. This division was based on insights from the visit at the training facility Öckerö Maritime Centre, and discussions with crew from SSRS.

Experienced

- Have gone through proper evacuation training, often several times.
- Are responsible for more advanced parts of the evacuation.
- Are expected to take authority during an emergency.
- Have naval experience.

Can be e.g.: Master of ship, experienced parts of ship crew, or SAR crew.

Familiar

- Have gone through basic safety training once or a few times.
- Are responsible for parts of the evacuation.
- Are expected to take authority during evacuation.
- Are familiar with equipment and/or procedure for other reason.

Can be e.g.: new or substitute crew members, or passengers with ship experience.

Novice

- Have no or very little previous knowledge of equipment or training.

Can be e.g.: Most passengers, or newly recruited crew.

During the training at ÖMC it became clear that the most experienced crew members are often assign to handle lifeboats and FRB's, since those vessels require more skill. Liferafts are often assigned to less experienced crew members such as summer substitutes or new crew members that are usually not sailors but rather service personnel (bartenders, shop keepers etc.).

4.4.2. Stress behaviour types
When exposed to extreme stress all humans are affected physically, mentally, and socially. How they react is different, and what makes people react differently is very complicated but has to do both with external stress factors and individual qualities. To simplify this one can say that a person that assesses their capability of handling a situation as high or at least possible, will have a positive stress reaction. A person that assesses their capability as insufficient will have a negative stress reaction. This mechanism leads to differences in performance during stress, why the users are here divided into three groups based on their change in performance during stress.

Improving
Some individuals improve both their physical and mental performance when exposed to highly stressful situations. This is a positive stress reaction, and is possible due to an adrenaline rush, which increases a person's focus, strength, and stamina for a while. These people will most likely be able to perform given tasks correctly, and might even be able to take initiative and think rationally by themselves.

This happens to approximately 25 % of all persons in a crisis.

(Fader, Interview, 2015)
(Bohgard et al., 2009)

Decreasing
Some people have a negative stress reaction that decreases mainly their cognitive skills. This is due to mental overload and inability to cope with all impressions and information they are exposed to. These people will most likely not be able to perform given tasks correctly, and will probably not take completely rational decisions.

This happens to approximately 50 % of all persons in a crisis.

(Fader, Interview, 2015)
(Bohgard et al., 2009)

Resigning
The last group of people are so overwhelmed by the stress that they completely resign. This can show in different ways, e.g. panic attacks or apathy. These people will most likely not be able to help at all or take any rational decisions.

This happens to approximately 25 % of all persons in a crisis.

(Fader, Interview, 2015)
(Bohgard et al., 2009)

4.4.3. Conclusions
The three types of experience levels, and the three types of stress reactions, will all be present in a real evacuation situation. A user could be any of the experience types combined with any of the stress reaction types, but it is more likely that a person with more training and experience has a positive stress reaction. The most important conclusion is however that in a case of evacuation, the user group is likely to mainly consist of people only familiar to the equipment and situation. And a large part of them will decrease their performance, or even resign completely. Relying on users to act correctly and perform difficult task is therefore not wise.

05. Recovery Principle

In the beginning of the project it was decided not to assume that liftable liferafts was the best principle for how to recover people to safety aboard a ship, this was investigated thoroughly. When the initial research phase was finished, deciding on a recovery principle was therefore the next natural step in order to continue the project.

Reading guide
This chapter should be studied to understand why the technical solution for recovery used in the final concept was chosen. It contains eight recovery principle concepts and an evaluation of them, using scenarios and criteria.

5.1. Methods & execution

This phase of the project involved a complete design iteration loop focused on recovery principle only. Ideation consisted of the 6-3-5-method[1], followed by brainstorming and brainsketching[2] until a satisfactory number of possible solutions was reached. These ideas were refined to some extent, and eventually reduced to the eight different principles of recovery.

5.2. Principle concepts

Here eight different alternatives for principle concepts are presented and explained.

5.2.1. Units

A system similar to the Marin Ark, but consisting of many small liftable units (capacity of less than 50 people). The units are connected when deployed at evacuation and disconnected just before being lifted to a ”ship of opportunity”. The actual recovery process is practically the same as SSRS have tested (see 3.10 FIRST project).

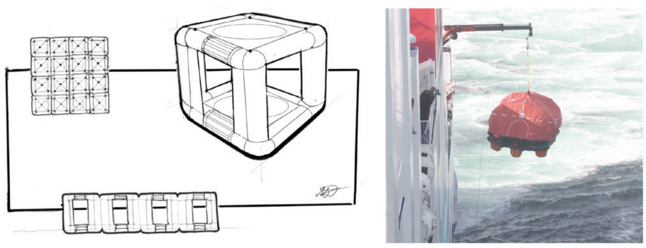

Figure 47. Units idea sketch and liferaft being lifted in the FIRST-project (Swedish Sea Rescue Society, 2012)

1 The 635-method includes 6 people sketching on 3 ideas for 5 minutes, the results are passed onto
the next person who continues on the idea. This process is repeated a number of times, quantity and not quality is in focus (Österlin, 2010).

2 Brainstorming and -sketching aim to produce ideas by letting your mind wander freely while discussing and/or sketching. Critique is not allowed during the session, and group members are expected to collaborate and inspire each other (Österlin, 2010).

5.2.2. Re-liftable units

Similar to the "Units" concept but with only a few small liftable units connected to large liferafts from the beginning (evacuation) to be used as shuttles. A unit is lifted to deck, evacuated, and then lifted down again to be filled with more people from the large raft before the process is repeated.

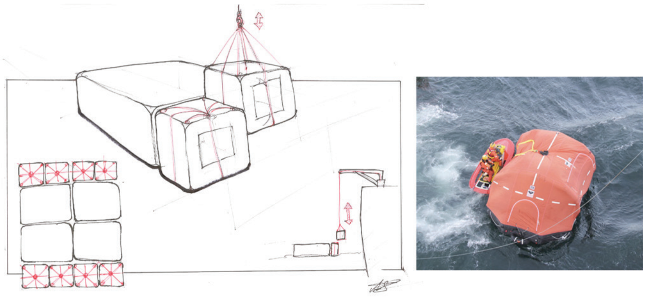

Figure 48. Re-liftable units idea sketch and SSRS personnel connecting the crane hook to a sling from the liferaft lifting point (Matsson & Åslin, 2012)

5.2.3. Internal liftable sections

A large liferaft with liftable sections inside, by opening the roof sections can be hoisted out leaving most of the raft in the water. This principle was suggested by a previous student project.

(Roos, 2014)

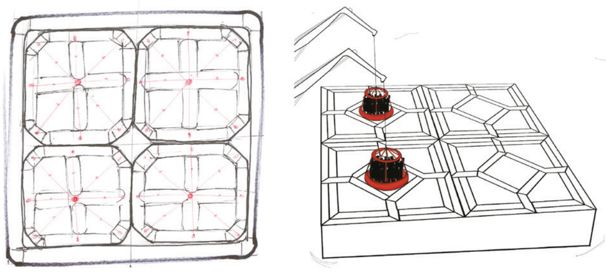

Figure 49. Internal liftable sections idea sketch and illustration of similar solution from previous student project (Roos, 2014)

5.2.4. Lift on platform

This principle concept involves the ship of opportunity deploying an inflatable platform next to it and using lifts operating from it to shuttle survivors to safety on board. Similar to the Means of Rescue available today but from a platform.

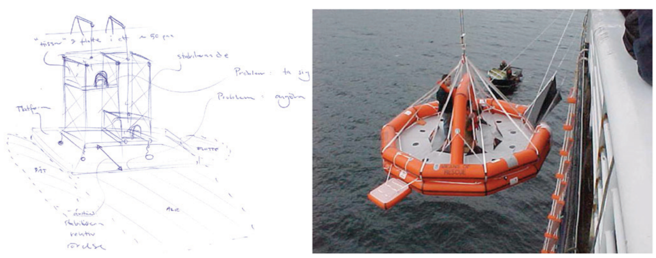

Figure 50. Idea sketch of inflatable lifts to the deck of a ship from a platform and the VIKING Means of Rescue (SurvitecZodiac, 2015)

5.2.5. Cradle

Using the principle of a cradle that can lift any small survival craft with no need for it to be constructed for lifting. The concept was inspired by the Rescuerunner drive-through cradle. SSRS have actually tested a similar concept, but in that case the cradle was towed to the liferaft, attached, then towed back to the ship before connected to the crane (see 3.10 FIRST project). For this concept the cradle would stay attached to the crane and the liferaft towed into it with the towing vessel driving straight through.

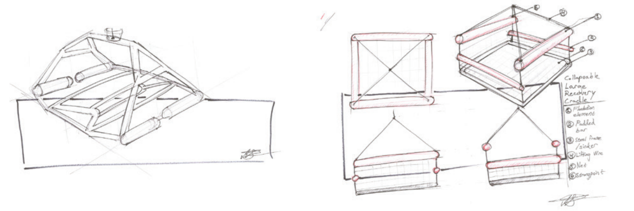

Figure 51. Idea sketches of liferaft cradle inspired by Rescuerunner cradle and one flat pack version

5.2.6. Survival craft ramp

An inflatable ramp that can be deployed to allow survival crafts to be hoisted up on deck, sliding instead of being lifted. This idea have also been mentioned in a Canadian report.

(Paterson & Sullivan, 1997)

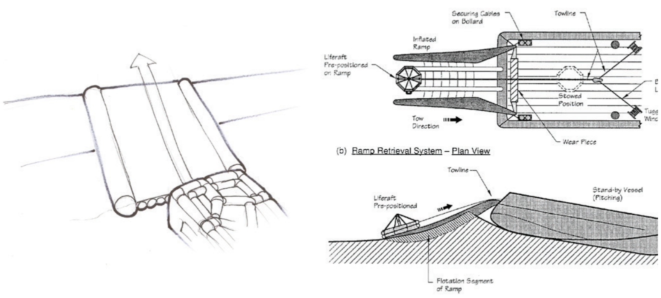

Figure 52. Liferaft ramp idea sketch and illustration of a similar idea from a Canadian study (Paterson & Sullivan, 1997)

5.2.7. Ramp or stairs from platform

Allowing people in distress to walk up a ramp or stairs from a platform deployed next to a ship. Practically a modified version of many evacuation systems but used reversed, could possibly be part of the evacuation as well (if the roles had been reversed with the ship of opportunity in distress).

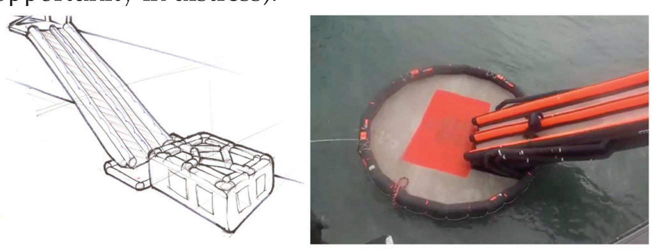

Figure 53. Idea sketch of ramps for recovery and image of a slide evacuation system (Farianos, 2013)

5.2.8. Towing platform

A concept with a large towing platform, made for towing in higher speeds and rougher seas, that liferaft would be placed on it before being transported to a safe haven. This concept also figures in a Canadian report. (Paterson & Sullivan, 1997)

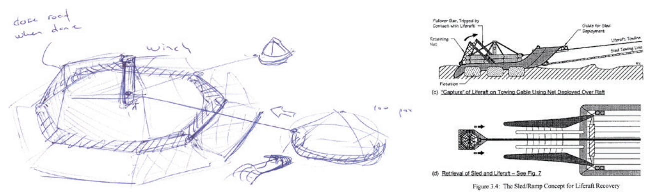

Figure 54. Idea sketch of a towing platform and illustration of a similar idea from a Canadian study (Paterson & Sullivan, 1997)

5.3. Evaluation

The evaluation of the principles was done by discussing suitability and performance when applied in the constructed scenarios, complemented by a weighed Kesselring matrix[1] evaluation against a number of set criteria.

5.3.1. Scenario evaluation

This section provides a motivation for which recovery principle(s) are most suited for each scenario. Scores for each concept can be found in the Kesselring matrix in next section.

Estonia today

Any recovery in this scenario will be both exhausting and potentially dangerous. A system where the people in distress remain in the survival craft would without any doubt be the best solution, since they are sheltered at all times (except possibly when exiting on board a ship of opportunity). Separate survival craft units would be preferred to minimize actions close to a ship and avoid moving people between units.

Norman Atlantic

Most recovery solutions would be possible but moving people between units would be difficult and dangerous. Furthermore, the relative movement between vessels means actions next to a ship should be kept to a minimum. The wind means towing longer distances is also undesirable. Thus, the unit concept is preferred.

Costa Concordia Offshore

Due to the amount of people, efficiency is really the most important part. Since it is close to land, solutions that make towing easy is preferred. Because of the calm conditions, a ramp or stairs from a platform would most likely be best, but all principles except a towing platform (easier to tow crafts individually) and a survival craft ramp would work well.

High traffic area collision

These conditions, with a high chilling factor, means people should stay in the survival craft and preferably not be transferred between vessels. Also considering difficulty of manoeuvres (due to risk of reduced abilities of anyone not wearing appropriate clothing or survival equipment) the unit principle should be the most appropriate.

Refugee ship

Efficiency in getting people out of the water is a priority and thus units, and a lift, a ramp, or stairs from a platform are the highest rated principle concepts.

SV Concordia cold water

Units gets the highest rating due to a combination of efficiency, weather protection, and absence of physical strain for the people being rescued. The towing platform gets the lowest rating here because of the extreme distance to land.

5.3.2. Kesselring matrix evaluation

The Kesselring matrix was a means to systematically summarise the concepts evaluations against criteria as well as scenarios. Otherwise choosing concepts would have been heavily dependent on what criteria each individual consider most important, something which is often subconscious. Different weighting of the criteria were tested, and while ranking altered with some changes the Units concept did keep getting the highest score. The weighting is based on the importance of the criteria, with safety of the people in distress the highest priority and helicopter recovery on of the lowest (as it is not the primary concern but needs to be possible).

5.3.3. Conclusions

The result of the evaluation was very clear and principle concept no 1 “Units” got the higher score for both scenarios and weighted criteria. This was consistent with the authors’ notion, and the concept is also the most proven through SSRS testing in the FIRST project. Thus the project proceeded with developing a raft system consisting of liftable units, in combination with slides or chutes for evacuation.

1 In a Kesselring matrix each solution is given a score for each criteria, which is multiplied with a weighting factor. The solution with the highest total score is regarded as the best one. (Bligård, 2011)

Criteria	Factor	Units	Re-liftable Units	Internal Lifatble Sections	Cradle	Lift From Platform	Survival Craft Ramp	Ramp / Stairs From Platform	Towing Platform
Efficiency	2	5	3	3	2	2	3	4	2
Safety of people in distress	3	5	3	3	4	1	4	2	3
Safety of personnel aiding in rescue	2,5	3	3	4	2	3	3	3	3
Weather protection	1	5	4	3	5	2	5	2	4
Cost	2	4	4	3	2	2	1	3	1
Deck space	1,5	5	5	5	4	3	2	3	2
Evacuation	2	4	4	5	5	5	5	5	5
Packing & inflating	0,5	3	4	2	5	5	5	5	5
Actions needed in water next to ship	1,5	5	5	2	1	1	1	2	2
Other actions needed in water	0,5	3	3	3	2	3	3	3	2
Works with current SC	1	1	2	1	3	5	2	5	3
Could phase out current equipment	1	5	5	5	3	1	1	1	1
Could aid any ships in distress	1	4	4	4	2	5	3	5	3
Works without aid from small craft	1,5	3	3	3	1	3	2	3	1
Ease changing regulation	1,5	5	5	3	3	3	3	1	1
Helicopter recovery	0,5	3	3	4	3	5	3	5	5
Total		63	60	53	47	49	46	52	43
Total (weighted)		95	85,5	78	66,5	63	66	70,5	58,5
Scenarios									
Estonia Today		4	3	2	2	1	2	1	2
Norman Atlantic evacuated		5	4	4	3	4	3	4	3
Costa Concordia offshore		5	4	4	4	4	3	5	1
High-traffic area collision		5	4	2	3	2	2	2	3
Refugee ship		4	3	2	3	4	3	4	3
Concordia		5	4	3	4	2	2	2	1
Total		28	22	17	19	17	15	18	13
Combined total		123	107,5	95	85,5	80	81	88,5	71,5

Figure 55. Kesselring evaluation matrix showing all criterias and scenarios (with weighting factors) in the rows, and the total scores for all principle concepts at the bottom of each column.

06. Design Brief

The design brief is based on the research and analysis, and provides guidelines for development of a product concept from the best chosen principle concept for recovery, “units” (see 5.2 Principle concepts). The brief consists of an expression board, a pro - con chart, and a design requirements list.

Reading guide
This chapter should be read for getting an overview of the starting point the project had when initiating the concept development phase.

6.1. Expression board

An expression board was created to clarify the intended expression of the future product. The board was used as a guiding tool throughout the design phase.

The expression board was constructed by choosing a main expression, clarifying that with five supporting terms, and lastly combining them with pictures expressing the chosen terms.

6.2. Pros & cons compared to existing MES

A pro - con evaluation to pinpoint areas requiring focus, further clarification of the strengths of the existing Marine Evacuation System (MES), and the weaknesses in the chosen recovery principle. The idea was to try to keep the strengths of the old system, and try to solve the possible weaknesses in the new system. The RFD Marin Ark 2 was chosen for the comparison since it is top of the line and have a large market share.

The next page shows a short description of strengths (+) and weaknesses (-) of the Marin Ark are listed in the left column, if the unit concept can keep or change it in the middle. Then possible foreseen consequences it can lead to, in the form of pros (+) or cons (-) for the unit concept to the right.

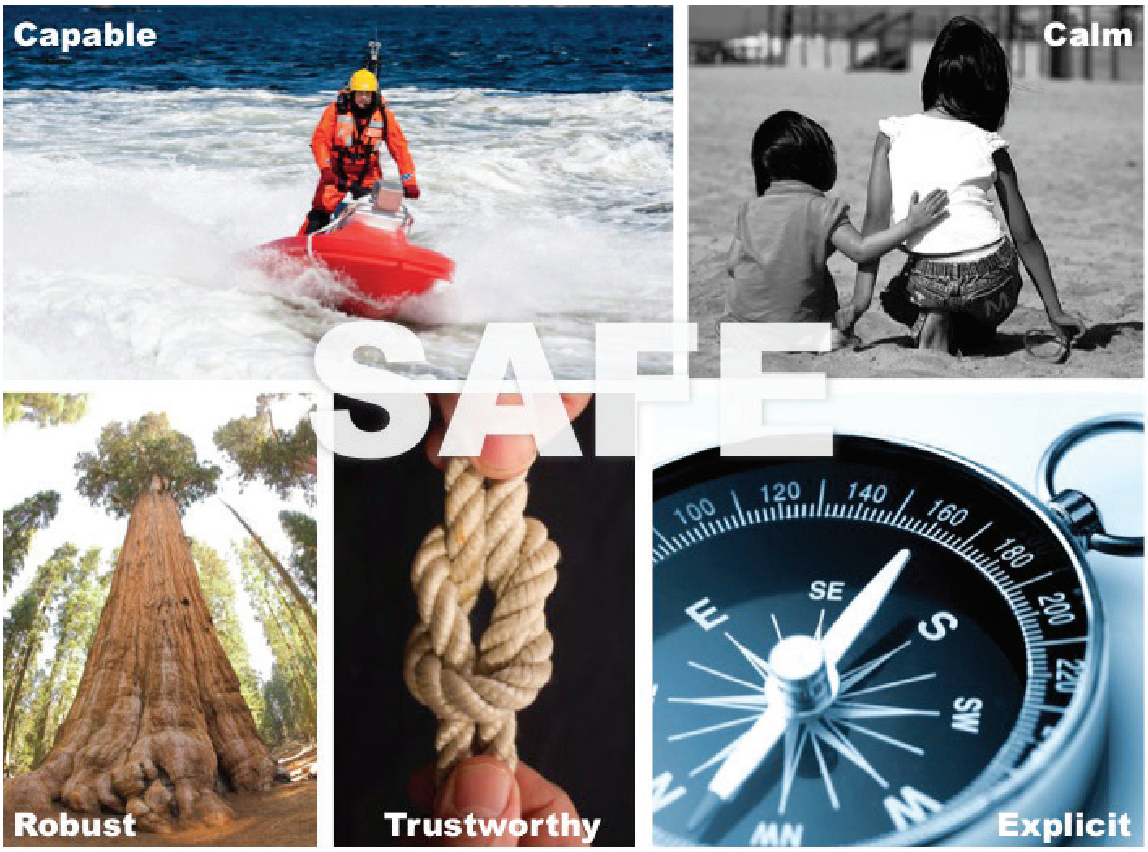

Figure 56. Expression board (Bonafede, 2014), (AwesomePlacesOnEarth, 2013) & (Unknown, 2015)

Marin Ark	Action	Unit Concept
+ Fast evacuation	Keep	- More transitions between rafts
+ One push launch	Keep	
+ One package on boat	Keep	- Possibly bigger package?
+ Stability by big size	Keep	- Stability for one unit unknown
+ Few crew per raft	Keep	- More crew possibly needed?
- Recovery is difficult	Change	+ Liftable units (efficient & safe recovery)
- High threshold at openings	Change	
- Big capacity jumps	Change	+ Smaller units, easier to adjust
- Difficult to get up in the raft	Change	
- Few units, failure sensitive	Change	+ Many units, low failure consequence

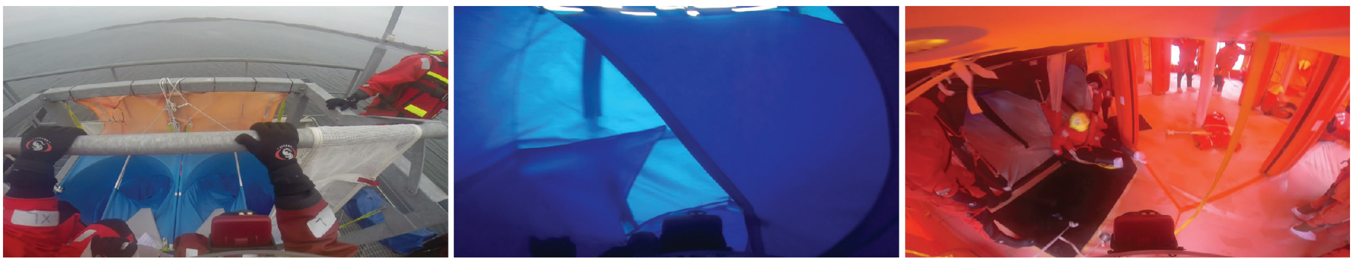
Figure 57. Efficient evacuation even from ships with high freeboards are one of the main advantages of current Mass Evacuation Systems that needs to be kept. Here during training with the Marin Ark 2 at Öckerö Maritime Center

6.3. Design requirements

A design requirements list was put together to make the demands on the product more explicit, and to use as a tool for evaluation further on in the project. Worth noting is that this is not a formal requirements list, why the requirements here are allowed to be more vague and does not have to be measureable. This is the level of detail that was deemed rewarding to the project. The design requirements are categorized in:

- General
- Evacuation phase
- Mid phase
- Recovery phase
- Construction
- Cost

6.3.1. General

Minimize required actions in the following situations;

- launch from ship
- evacuate people into raft
- separate units from each other
- connect to lifting equipment
- release from lifting equipment
- unload people from raft

Be simple enough to be usable for persons without training or experience (Have sufficient guessability[1])

Provide sufficient accessibility - it should be easy to move around in the raft, even for people with decreased mobility

Not requiring actions that need a lot of force (Considering weakened people in the raft)

Not require actions that demand high precision (Considering hypothermia symptoms)

Provide signs, symbols and instructions visibly clear enough for people with decreased vision to read them.

Not put people at risk of injury inside or outside the raft

1 The effectiveness, efficiency and satisfaction with which specified users can complete specified tasks with a particular product for the first time (Jordan, 1998)

6.3.2. Evacuation phase

Provide efficient evacuation within 30 minutes

Provide safe passage between raft units

Provide possibilities to connect a raft unit to (at least) one chute or one slide

Provide means to ensure each raft unit is filled to capacity

Provide means to get into the raft from the water

Enable getting unconscious persons into the raft from water

6.3.3. Mid phase

Keep people in distress as dry as possible

Keep people in distress at a proper temperature by;

- providing ventilation possibilities*[2]
- providing isolation against wind and sea

Minimize chafe on passengers

Minimize irregular raft movements in sea

Be highly visible in sea

Communicate if there are people inside it (desire)

Each raft should be possible to identify individually from a distance

6.3.4. Recovery phase

Each liferaft unit should be liftable

Enable recovery of at least three units per hour

Not require SAR personnel or personnel from ship of opportunity in water to perform recovery

Provide an automated connection to crane (desire)

2 *Requirement taken from the LSA Code, i.e. IMO regulation. Other requirements can be present in regulation as well, but they are concluded in this list as a conclusion from the research rather than taken directly form the legislation.

Provide possibility to connect liferaft unit to crane from;

- inside of the liferaft
- a small vessel in the water

Not weigh over 4 tons during lift

Not put people at risk of falling out of the raft unit during lift

Enable extraction of a person from raft with helicopter

Enable towing of a single unit, or a group of units by;

- Providing a clearly marked strong points
- Being easy to connect and release
- Withstanding towing in 3 knots speed

Cause minimum amount of obstacles in the water

6.3.5. Construction

Not sink regardless of weather conditions.

Every liferaft should be capable of withstanding exposure for 30 days afloat in all sea conditions*

Endure harsh weather conditions such as;

- high waves
- strong wind
- high or low temperatures

Be possible to recover in up to 8 Beaufort (waves 5,5 - 7,5 m, wind 17,2 - 20,7 m/s)[1]

The rafts main buoyancy section should be divided into at least two fully separated parts

Stay stable with one of the main buoyancy sections deflated (due to puncture or inflation failure)*

Stay stable with unevenly distributed load

Stay stable also when filled to overcapacity

The raft floor should not bend down too much and form a bowl during lift

Should provide water pockets of not less than 20 litres per passenger*

Fulfil air leakage limits

Have a total height from raft base to lifting point less than 6 meters

Provide sufficient grip for walking although being wet

Provide a safe and simple way to close and open raft openings

6.3.6. Cost

Minimize usage costs by minimizing;

- required maintenance on raft
- required number of personnel to operate the product
- required amount of education needed for personnel to operate the product

Keep down investment cost by minimizing;

- amount of material and parts
- production time
- use of expensive parts or construction details

Minimize required deck space needed for storage on ship

Provide as high passenger capacity as possible in regard to the set lifting weight limit 4 ton, and that every passenger weigh 75,2 kg*

Provide as high passenger capacity as possible regarding that every passenger need at least 0,372 m^2 each*

1 Provided a ship provides lee by performing the sea-calming turn (see 3.10 FIRST project)

07. Concept Development - Process

First in this chapter is a description of the overall process and execution, including a timeline giving an overview of when all the different parts of the project were carried out. Secondly, there is a presentation of the concepts and a summary of the feedback from different stakeholders.

Reading guide
This part should be read to understand the strategic decisions during the project, and the overall time schedule of when parts of the project was carried out.

7.1. Methods & execution

During the development, concepts were generated at different stages in order to present ideas and solutions to different stakeholders. Three mid concepts, that combined solutions from different parts into product concepts of raft units, were presented to representatives from Stena Line, SSRS, and Chalmers University of Technology. A merged concept, combining the best aspects of the mid concepts, based on feedback from the presentation as well as further evaluation, were designed and presented to the manufacturer Survitec Group at their RFD Beaufort factory in Belfast, Northern Ireland. Insights from that visit, combined with more evaluations and industry feedback, lead to the decision of making two separate final concepts.

The beginning and end of different processes are approximate since they are so interlinked it is difficult to separate them in some cases.

While focus shifted, the development in different areas was continuous. Evaluations were based on knowledge at the time, and some decisions have been changed after new information was obtained. New evaluations were only carried out when the changes were considered substantial enough to make it necessary. The concept development consisted of a highly iterative process shifting between ideation, evaluation, and refinement for specific aspects, as well as more complete concepts.

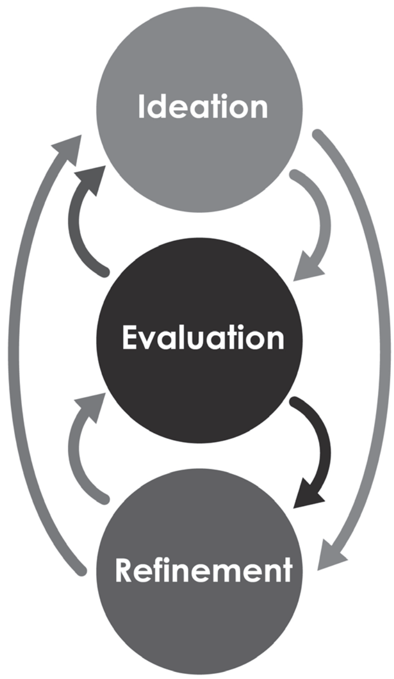

Figure 58. Illustration of the iterative development process

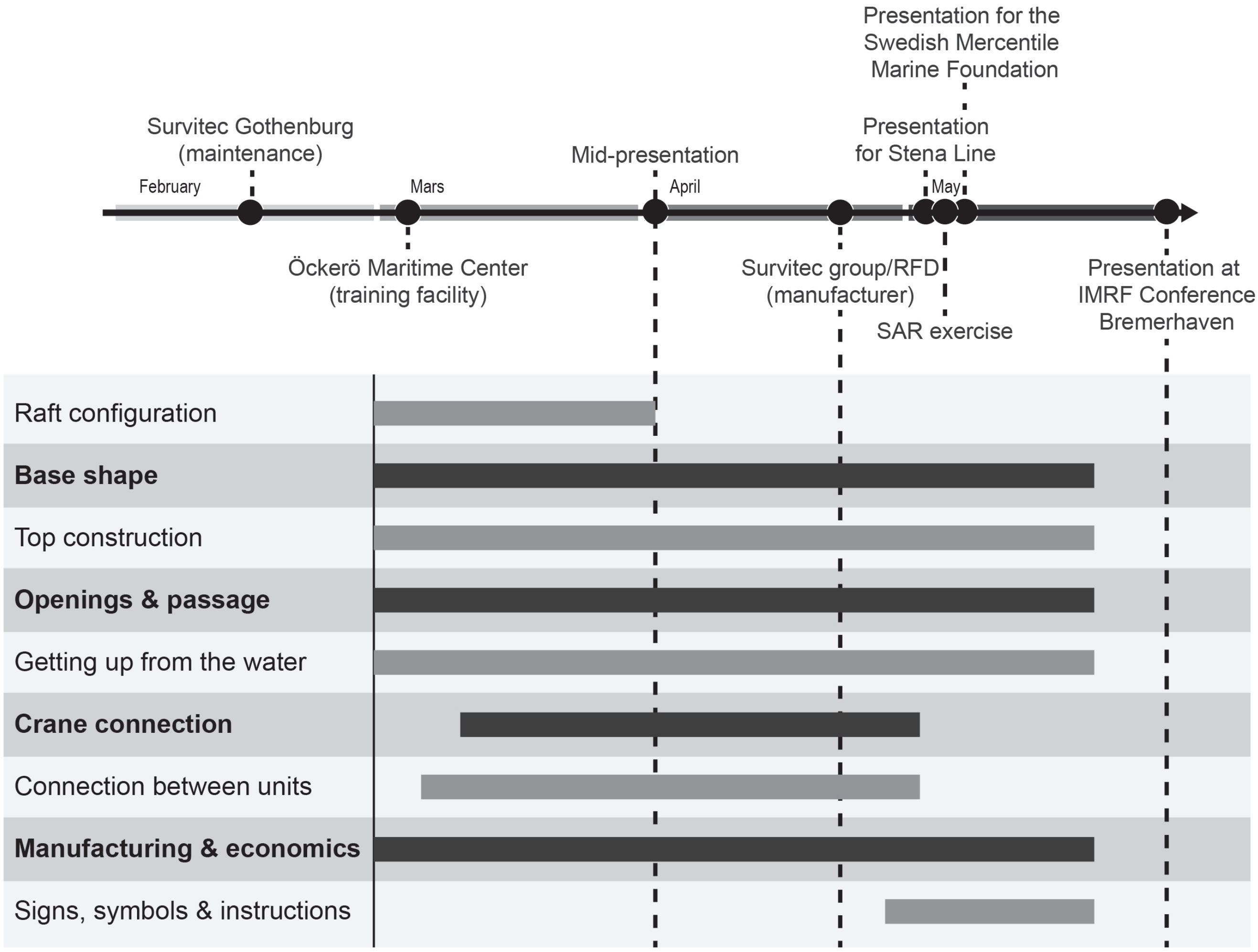

Figure 59. Timeline of important events and during which period's development of different aspects took place

7.2. Mid concepts

This section presents the mid-concepts and a summarized evaluation of how the concepts scores in different areas based on their combination of features. More detailed descriptions of the different features and the full evaluation can be found in appendix. The development of different aspects, up to and after the mid concept, is presented in chapter 8. Concept Development - Synthesis.

Reversible concept

Works in the same way upside down, uses a smaller upper cylinder to create a smaller threshold between units, have a symmetrical base, and multiple possible solutions to connect the crane hook.

Symmetric rightable concept

Is self-righting, have conventional positioning of cylinders on top of each other, have a symmetrical base, and is connected to the crane hook with a simple sling.

Oblong rightable concept

Is self-righting, have two large cylinders connected at a 45° angle, have an oblong base, and is connected to the crane hook with a simple sling.

Figure 60. Structure of the mid concepts. From the left: Reversible, Symmetric rightable & Oblong Rightable

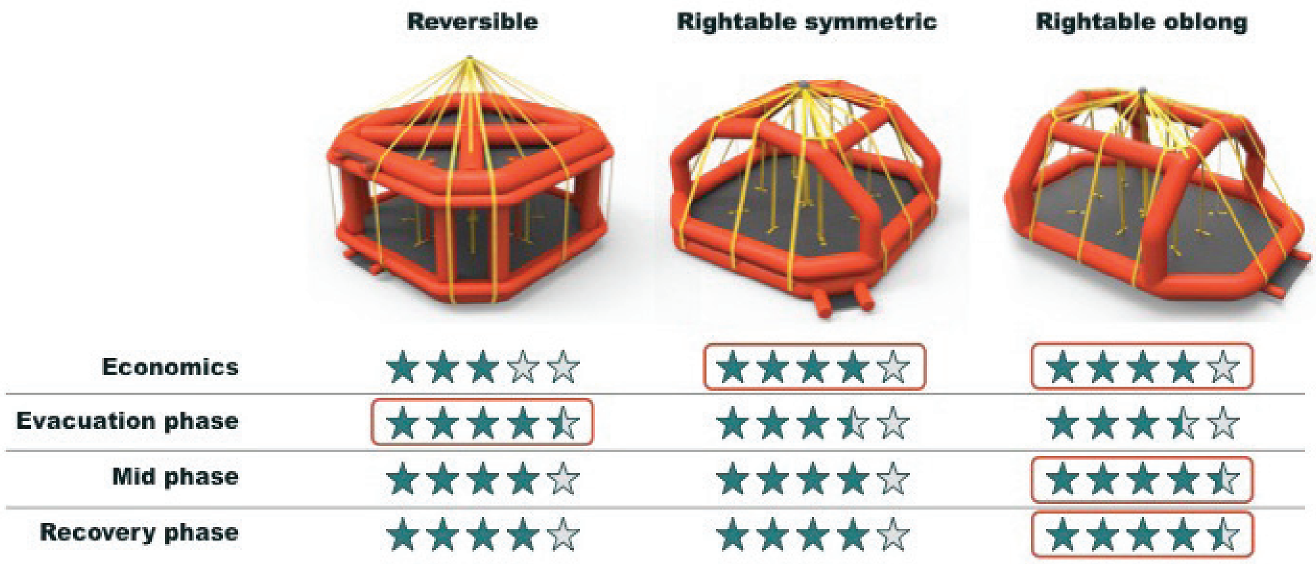

Figure 61. Summary of the mid-concept evaluation with the best scores highlighted.

7.3. Mid concept evaluation

This section contains a summary of the mid-concept evaluation[1] categorized into economics, evacuation phase, mid phase, and recovery phase. For more details on the evaluation see appendix.

Economics

The economics were evaluated based on investment, deck space used, and crew skill needed. The rightable concepts were concluded to be significantly better in terms of economics mainly due to less material and equipment needed.

Evacuation phase

Meaning the time from entering a raft unit until it has been disconnected from the ship. The reversible concept have a clear advantage primarily because it works upside down, the units are connected more stable, and has a lower step crossing between units.

Mid phase

The time spent in the raft waiting for rescue. Similar score but the rightable and oblong have better aero- and hydrodynamics which lowers drag force (thus drifting) and improves behaviour in waves. Furthermore the large angled cylinder provides better comfort.

Recovery phase

The oblong rightable is best suited for recovery due to lower total lifting height, easier towing, and simpler crane connection.

1 The evaluation was part of the mid-presentation

Conclusion

The concepts receive a very even score without any weighting of the evaluation factors, the differences in total score are negligible.

7.4. Mid presentation: Stena Line, SSRS & Chalmers

A 30 minutes presentation on research findings, development and the mid concepts was followed by an extensive discussion about the concepts and various issues. Present was, apart from the project group, Mikael Hinnerson, Fredrik Falkman and Matthew Fader from SSRS (their position and background is presented in section 2.3 Interviews at SSRS). Furthermore the following persons participated:

Senior Captain at Stena Line and chairman of the Maritime Officers Association

With extensive experience as captain and head of the FIRST-project very knowledgeable about recovery. Has from the ship bridge been responsible for the testing of lifting liferafts.

Professor at Chalmers - Department of shipping and marine technology, division of human factors and navigation

Normally a professor at Memorial University, Canada and have had a big part in their extensive research and testing on liferafts including towing, evacuation, thermal insulation and more.

PhD Student at Chalmers Marine technology division of human factors and navigation

Apart from his research at Chalmers has a long standing involvement with SSRS and for example lead the 30 hours liferaft exercise.

Feedback

The participants shared the concern about the capability of righting liferafts under realistic conditions. Comments were made that usually less than half of the crew can manage re-righting a raft during training in calm harbour conditions, and that is for rafts with capacity of eight to 16 people. Thus, there was a consensus that the reversible concept should be developed further.

Furthermore, everyone present shared the view of a need for reducing necessary actions during the use of the raft since people usually do not perform well in these extremely stressful situations. The need for simplicity was emphasised, along with clear instructions, and better signs. There was no clear view on which crane connection solution to use, but several participants were sceptical about a two-step process and concerned with misuse of the roof opening. It was also requested that raft units should be disconnected automatically when lifted.

7.5. Merged concept

The merged raft concept was developed based on feedback from the mid presentation and the mid concept evaluation. This section describes what was taken from the different concepts. More thorough explanations of why the chosen parts and solutions were the best options are available in chapter 8 Concept Development - Synthesis.

It was decided to use a reversible solution due to the known issues with righting a raft. Also due to other advantages of that structure, such as a more stable connection between raft units in a system. Additional drag of the flat middle sections of the walls, had to be accepted. It was concluded that the higher cost of reversible raft units was still motivated by its advantages.

An oblong shape was chosen since it enables a lower lifting height (for the reversible structure) and gives good hydro- and aerodynamic properties. The possibility of the raft turning with the short side towards the ship was accepted after making sure the openings were wide enough.

A compromise with the cylinder dimensions was made regarding having a low step height (and thus large opening height), and having a high edge for protection against waves and prevention of people accidentally falling out. A positive effect of the angled cylinders is a shape more similar to a boat hull, which makes towing easier, and should direct splashing water away from the opening.

A new solution for connecting the crane hook, with a sliding lifting eye, was added to minimize the total lifting height in a technically simple and user friendly way.

Figure 62. Structure of the merged concept, a combination of features from the mid-concepts

7.6. Survitec Group - manufacturer feedback

This section describes received feedback on the concepts that followed a 30 minute presentation. In addition to the project group, and Mikael Hinnerson from SSRS, the Head of sales – MES, Marine Systems Design Manager, Technical Director, and Senior Project Engineer was present from Survitec Group.

Survitec approved the concept recovery principle, but did at this stage not see a market for the merged concept. Mainly since their spontaneous approximation was that the cost per passenger would be at least double that of the Marin Ark 2, largely due to the multiple air compartments. This adds to both investment cost as well as maintenance cost since each air compartment needs to be tested thoroughly.

Furthermore, separate gas cylinders for inflation are needed for each raft, or alternatively valves between raft units that are possible to disconnect after completed inflation, which either way would greatly increase the cost. This part of the added cost will be difficult to overcome with the chosen recovery principle. Survitec concluded that since it was more expensive they would not be able to sell it, unless regulation starts putting demands on recoverability of liferafts. According to them it could possibly be an interesting alternative, if it would cost no more ten to fifteen per cent more than the second generation of Marin Arks. It was decided to also create a budget unit concept to try to meet this demand as well.

Regarding construction, they had no objection to constructing a raft with the upper cylinder of the main buoyancy chamber placed at an angle. Additionally, they advised that there is no point in considering packaging and inflation procedure before the construction is completely set, since it can be solved but needs to be re-worked even with small changes in the final construction.

It was commented that the unit connections are relatively similar to what they use today, the release lines would require lots of testing but it can be done. Additional components always adds cost, but this increase should not be significant.

7.7. Industry feedback

This section summarizes feedback from the Swedish shipping companies Stena Line and Wallenius during discussions (that included the view of the Survitec Group) following a presentation of the concepts. Representing Stena Line was their Senior captain, Technical Operations Manager, and a senior purchaser. The discussion with the executive vice president and Safety and quality manager at Wallenius Marine AB was informal and followed a presentation for the Swedish Mercantile Marine Foundation.
According to the Stena Line representatives they always have a focus on safety, and how the system would work in a realistic situation is their main concern rather than cost. They have recently installed the Marin Ark 2 on their ships[1] and thus will not be able to make another large investment in a new system for a considerable amount of time. However, they are very interested in the concept and recognize the need to create a solution for recovery, why they encouraged a formal request of help to continue the project. In the discussion it was clear that their other main concern is cost for maintenance, which have a much bigger impact than investment cost.

Figure 63. Two Stena Line ferries and some of their routes. Stena Lines ships are appropriate for the concept, and if they had means to help in a mass rescue operation, they could potentially be a reassuring safety resource covering large areas of the Scandinavian coastlines (Falkman, 2014)

Wallenius was very interested in the presented merged concept and opened up for large scale testing on their ships. This was very interesting for the project since the potential need of an efficient solution for freight shipping companies had not been fully comprehended in the stakeholder analysis. Wallenius ships regularly travel through the waters were many refugee ships go down and have recently rescued hundreds of people at a time. According to their representatives one of their main concerns is the safety and wellbeing of their crew, both physically and mentally. They want adequate equipment for their personnel to handle the situations they are, for a fact, exposed to. Apart from safety, there are significant economic incentives. They lose approximately 60 000 - 100 000 USD per hour of operation for each ship that deviates from schedule. By greatly reducing the time it takes to rescue people in distress, one single mass rescue operation could potentially cover the entire investment cost of such a system.

1 Stena Line have gone beyond the regulation and have capacity for evacuating 100 % of the passengers from both sides of their ships, i.e. a lot more survival crafts than required by law.

08. Concept Development - Synthesis

This chapter describes the development of the system and units after establishing that a large systems consisting of liftable liferaft units would be the principle for recovery. Different parts and aspects of the product were developed continuous and parallel. Even if they are all closely connected and heavily affect each other, this was partly done separately and is presented as individual sections in the chapter.
The chapter provides a detailed description of methods and execution, important aspects, solutions, and evaluation for the different parts of the concepts. In the end of each section there is a conclusion, which very briefly summarises what was finally decided upon.

Reading guide
This chapter should be read for a thorough descriptions of the development process and motivation for each part of the final concept. The different aspects presented separately are:

◦ System size & configuration
◦ Base construction
◦ Top construction
◦ Openings & passage between units
◦ Getting up from the water
◦ Lifting structure
◦ Crane connection
◦ Disconnection of units
◦ Colour Coding
◦ Signs, symbols, & instructions

Note that it is not necessary to read all sections to understand the final concept.

8.1. System size & configuration

This section explains the development of the raft system configuration; how many passengers to place in each unit, and how raft units are to be placed together in different situations.

8.1.1. Methods & execution

The raft and raft system sizes and configurations was settled by looking at existing marine evacuation systems and rafts for limitations, followed by calculating the largest possible sizes to use in this project. When alternatives in configuration was found the choice was settled by comparing pros and cons.

8.1.2. Important aspects

Manage evacuation in time

According to world-wide legislation, evacuation has to be finished in 30 minutes after its initiation if a decision is taken to abandon ship. Since the project will not change the current chute and slide used to evacuate, the system will have to stick to limits in passenger rate possible to get into one system before 30 minutes has passed. Today, a Marin Ark system can fit 860 people maximum into one system by using two chutes. 430 people per evacuation chute is therefore set as the maximum amount of people allowed in one system for this project as well.

(RFD, 2015)

Total lifting weight

Research showed that a large amount of ships have cranes that can lift up to four tons (see section 3.8 Cranes & winches). This weight limit is therefore set as the maximum allowed weight of a raft unit during lift.

Enable towing

Towing one or several raft units might be necessary in several stages of a mass evacuation. Making sure this is possible, efficient and simple to do can be a life saver.

Safety

Safety always comes first for a product like this. Configuring raft units together in a way that improves safety, if possible, should thus be prioritized.

8.1.3. Solutions

Raft unit size: 32 pax

According to the SOLAS LSA Code every passenger weights 75 kg, and per every passenger the rafts needs a 20 litre water bag on the bottom to keep stability in the water. This means every passenger adds 95 kg to the total weight. Additionally the weight of the raft itself including survival pack and gas cylinders, which is approximately 300 kg (seeing to what a raft of that size usually weights). According to tests made by the Canadian coast guard sea water often ends up on the raft floor, this means passengers might end up having wet clothes, and there might be water still in the raft during a lift. Because of this it was decided to keep quite a big safety margin, and set the pax number to 32, which will give an estimated total weight of 3340 kg without water in the raft.

If the four ton limit would be deemed unnecessary a bigger raft might be to prefer since it makes material use more efficient, and might speed up the evacuation and recovery process. However, weighs over four tons start to get difficult to handle during a lift, why an increase in raft size should be evaluated carefully.

(Survitec group, interview, 2015)

Raft section size: four or six units

The perks of having a group of units stay together for as long as possible are many;

- A bigger group of rafts makes them more stable in sea. This eliminates risk of them flipping over.
- If a raft or an air chamber in a raft gets damaged or does not inflate for some reason, a bigger group of rafts is less sensitive. People can move around to compensate for lower floating capacity in some parts if rafts are placed together.
- Towing a couple of rafts at the same time is more efficient than one at a time.
- Larger and fewer raft groups are easier to spot and find during a search and rescue operation.

Having small or no groups at all have the following perks;

- It makes them easier to tow since it then requires less power.

- Rafts that are fully filled up can detach from the whole system earlier during evacuation[1]

Since a unit of 158 people from the Marin Ark is possible to tow, that range in weight and size was considered possible to tow for this concept as well.

(SSRS, interview, 2015)

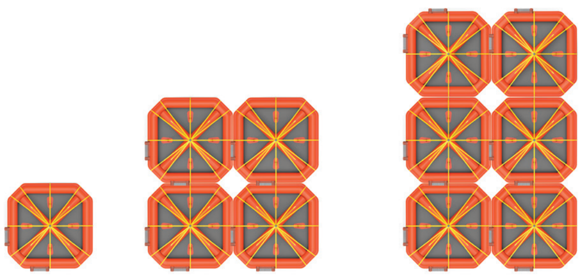

Figure 64. Top view of a single unit (reversible mid-concept), a section of four units, and a section of six.

Raft section configuration: group or row

Regarding how to place the rafts in a raft section a few options emerged, a group of four or six, or a row with the same number of rafts.

1 good if a ship is sinking quickly

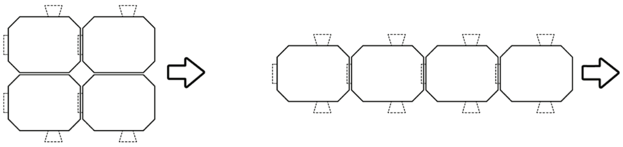

Figure 65. Illustration of four units combined into a group and a row

Raft system size: multiple of 4 up to 24 rafts

The maximum amount of raft units of 32 pax that stays under the limit of 860 pax (given two chutes are used) is 26 units. To be able to keep them in groups of four raft units after evacuation, a good system size would rather be any multiple of four e.g. 16 units (512 pax), 20 units (640 pax) or 24 units (768 pax).

Raft system configuration: symmetrically spread around two chutes

Since the concepts are to use two chutes, like the Marin Ark system does today, the best way to organize the rafts is placing the raft sections symmetrically spread around these two chutes. That is the best way to ensure the raft system will be filled up evenly by the evacuated passengers.

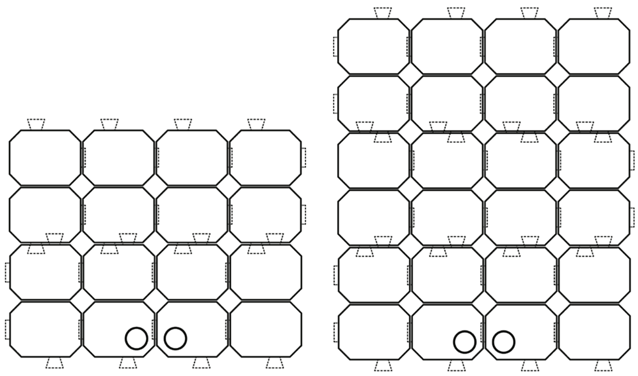

Figure 66. Illustration of systems with 16 and 24 units (capacity for 512 and 768 people) with circles representing the chutes

8.1.4. Evaluation of configuration

The configuration of the raft sections was the only part in need of comparative evaluation, why this is the only part handled here.

Group

A group of four units will make the rafts more stable in all directions, and if anything happens to one of the rafts people can easily move around between all of them. When preparing for lifting a raft unit, any of them can be detached and the others will still stay together.

Row

A row of four units will be easier to tow, it will be more stable in one direction, but moving around between the rafts will be difficult if a raft in the line gets damaged. When detaching a raft unit you have to pick one of the end ones not to break the row. Since safety is the main priority, and eliminating possible errors during evacuation is very important, the best choice is placing the rafts in a group[1].

Conclusion

The raft system will consist of raft units for 32 pax, grouped into sections of four rafts, and organized in a full system of any multiple of four rafts. These raft sections are to be symmetrically placed around two chutes per full system. During the rest of the project the raft system size will be set to 16 units in order to have a consistent example to work with.

8.2. Base construction

This section addresses the development of the bottom part of the raft, also called the main buoyancy chamber, which is the part that will keep the raft afloat. The shape of this part is closely connected to how the units should be placed together in a raft system, why this is briefly discussed here as well.

8.2.1. Methods & execution

Ideation on the issue was done by using brainstorming and brainsketching, and discussing continuously. Top view illustrations were made of numerous variations and those deemed most feasible were fully evaluated. The evaluation was based on a weighted Kesselring matrix, where the criteria (important aspects) were put together based on the research findings. This matrix was complemented by thorough discussions, area calculations, and elementary knowledge in solid mechanics regarding stability.

A quick user test was carried out by marking one quarter of the raft on the floor, and having nine persons walk in and sit down freely in four different variants. The variants consisted of an oblong as well as symmetric octagon, with two different pillar configurations (six or eight in a full raft) each.

In the refinement many variants were compared in excel and CATIA was used to optimize the measurements. The optimization was based on main buoyancy chamber volume, total sitting area, cylindrical section length, opening width, total raft width and length.

1 If towing is seen as the best way of getting people to safety, due to context factor of a specific ship, a custom configuration with rows could be better

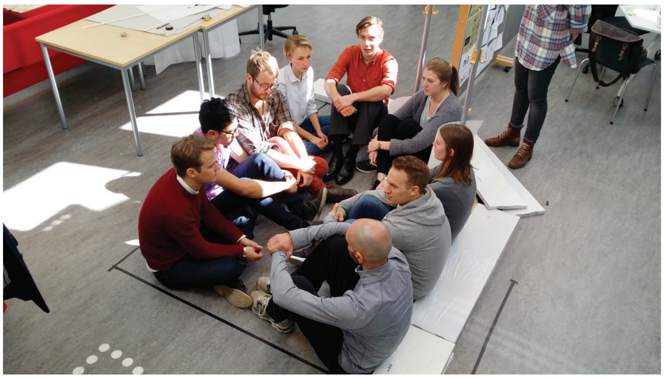

Figure 67. Participants in the marked up liferaft unit section during the "sitting test".

8.2.2. Important aspects

Area
The inside area of the base shape is one factor that will limit the number of passengers allowed in the raft. Higher circumference area per material usage ratio is therefore appreciated (a circle has the highest possible ratio).

Stability
A stable raft is always important, but for liftable rafts it is of even greater importance. The raft has to endure the forces applied on the structure during a lift without deforming too much, otherwise the passengers might come to harm, or worse; the raft could fully collapse. Sharp angles are vulnerable to force caused by the inside air pressure, whilst long straight sections are vulnerable to external force (especially if applied perpendicular to the surface). Shapes closer to a circle are stronger and more stable.

Simple raft pattern
During evacuation, the passengers will have to move from raft to raft through the system to fill it completely. Being able to quickly understand the raft configuration, get a feeling of where you are, and where you are supposed to go, is very important since the evacuation has to be swift.

Production cost
Keeping the price of the product down is crucial since shipping companies first priority often is costs.

8.2.3. Solutions

Square
The first option was a square of 5 x 5 m, placed in a row-based configuration.

Octagonal shape (chamfered square)
Second alternative was the same square but with chamfered comers, creating an octagonal shape with 45° corners instead of 90°. Also placed in a row configuration.

Hexagon
Third option was equilateral hexagonal rafts, placed in a honeycomb pattern.

Oblong octagonal
The last option (added a bit later) was an oblong version of the octagonal shape. Placed in the same row-based patter.

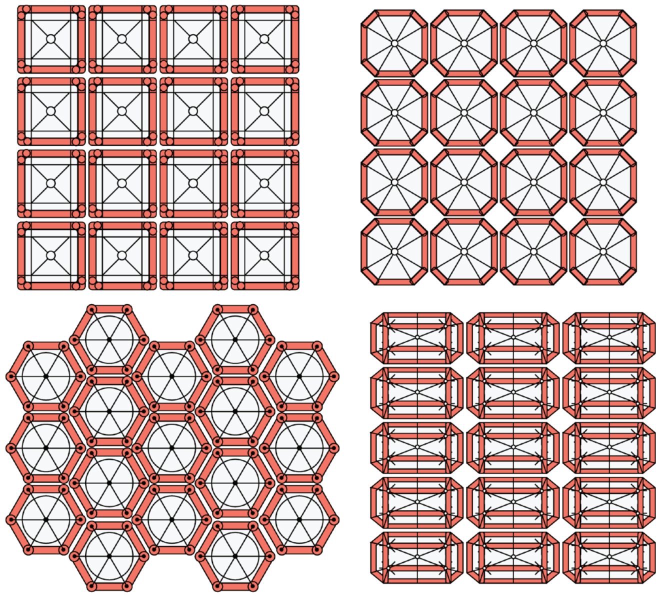

Figure 68. Illustrations of different possible base shapes (the black lines are lifting bands)

8.2.4. Evaluation
The octagonal shape, a square with chamfered corners, came out as the best option. The main reasons are summarized here and the exact result of the matrix is found in the appendix.

- Calculations surprisingly showed that, even though it is not equilateral, the octagonal shape had a higher area per circumference ratio than the hexagonal option, and is thus closer to a circle. This means it has a lower material cost per passenger.

- The shape was deemed very stable due to the chamfered corners and the highest number of sides. When lifting the raft the main buoyancy chamber is exposed to large forces upwards and inwards. Keeping the length of the straight parts down will thus make them less inclined to bend or collapse.

- This solution also had the least sharp corners (45° compared to 60° or 90° in the other options), which allows higher air pressure in the raft without creating too much tension in the material.
(Technical Director at Survitec Group, interview, 2015)

- The octagonal shape can be organized in a simple square pattern, which should be the most simple to identify and understand for people when evacuating.

- It requires crossings between units on four sides (same as square) instead of six for the hexagonal shape.

- The octagonal shape has the highest number of joints, which will add to the manufacturing cost.[1]

Later change

Later on in the project an oblong variant of the octagon, which was dismissed before evaluation due to concerns about lifting stability, was considered again after closer study of several current liftable liferafts and Means of Rescue (MOR). The stability during lifting was deemed sufficient, the proportions are so similar that if it works for the current MOR the oblong octagon should work to.

The possibility of the oblong raft turning with the short side towards the ship was accepted after making sure those openings were wide enough. This also solved concerns about insufficient evacuation routes, which was one of the main reasons, the symmetric base shapes got better scores.

The advantages that made an oblong octagon the preferred shape was:

- Better aero- and hydrodynamic characteristics (less towing resistance and drag).

- Lower lifting height (see also section 8.7 Crane connection).

- Easier to flip for the self-righting concept.

- Wider main evacuation routes.

8.2.5. Refinement

The base shapes exact dimensions are determined by a number of factors. Foremost the area needs to be at least 0,372 m^2 per person. Secondly the volume of the main air compartments needs to provide sufficient buoyancy even if one is not inflated. With capacity for 32 people this means a total area of approximately 11,9 m^2 and with a volume of approximately 2,7 m^3 without any of the air compartment (based on the liferaft weighing 300 kg and 75,2 kg per person).
(IMO, 2015)

Cylinder section length was kept above 0,7 m while minimizing the longest section, enabling manufacturing and maintaining sufficient openings. Total length was kept below six meters and the width larger than the height.

The variants in the sitting test was for 36 people and the conclusions for refinement was:

- It was anticipated that the participants would have difficulty to fit within the marked areas in the user test. However this was not an issue even if it would be uncomfortable after some time.

- A setup with six pillars instead of eight did have a positive effect (relevant for top construction).

- Considering how the participants positioned themselves it was concluded their legs was more likely to end up in one big pile for the symmetric octagon.

The dimension was exactly defined to meet the refined criteria and adapted for 32 people in CATIA based on the tested oblong octagon.

Conclusion

In an initial isolated evaluation for the base shape, a symmetric octagonal shape came out first. When the raft as a whole was considered, an oblong octagonal was the best option; thus it is used in the later concepts of the project.

8.3. Top construction

This section deals with the rest of the raft construction, the top. This is the part mainly used for sheltering the passengers, but this structure also determines if the raft will be reversible, self-righting, rightable or just one-way functioning.

8.3.1. Methods & execution

A decision was made early to stick to existing technical solutions used in liferafts since the main purpose of the project was to show the feasibility of including recovery into the system. Introducing novel and untested technology that could steal focus or make people question the concepts, and it would require extensive testing to be approved by legislators.

1 the visit at the RFD factory however showed that the added cost is insignificant with their new manufacturing technique; hot air welding

During the ideation on this part free brainsketching with continuous group discussions was the main activity. The sketches was then transformed into side and top illustrations to be more suitable for small alterations, and easier to compare and evaluate properly.

The first round of evaluation was a reduction of the self-righting ideas. No evaluation was needed for reversible structures, since they had few variations. In the second round, the two best and one merge, of the self-righting, as well as two reversible (see figure 71), were evaluated in a Kesselring matrix. Varying weighting were made to minimize effects of insufficient knowledge (being early in the project) as well as to find strengths and weaknesses of the solutions.

Scale models in paper were made of the best reversible and self-righting versions. These models was experimented with to locate weak points, how they deformed and to compare minor changes in structure. When refining the merged concept a smaller 3D printed model was created to check exact proportions and to be used as a mediating object, a tool for inspiring discussion, when meeting with stakeholders.

8.3.2. Important aspects

Stability

As for the base construction, stability was the main concern for this part. The same principles; keeping straight parts shorter, and not using too sharp angles applies here.

Enable evacuation

Making sure evacuation could run smoothly was also important. This meant keeping enough space in openings to allow passing easily between units[1], and considering how the units would be possible to attach to each other depending on their top shape. Furthermore, there need to be room for at least one evacuation chute.

Figure 69. Openings for evacuation chutes in the Marin Ark roof

Enable crane connection

Having in mind how the top structure would affect the possibility to attach a crane hook to the raft was also an important aspect.

Production cost

Keeping the price of the product down by minimizing number of parts and avoiding complicated constructions was prioritized.

8.3.3. Solutions

Initially the form was studied based on variations of optimal shapes for lifting (see picture below) and refined into four realistic variants (see picture on following page).

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1 Later on in the project it also became clear that a too large opening could mean it was difficult to pass due to lack of support to hold on to.

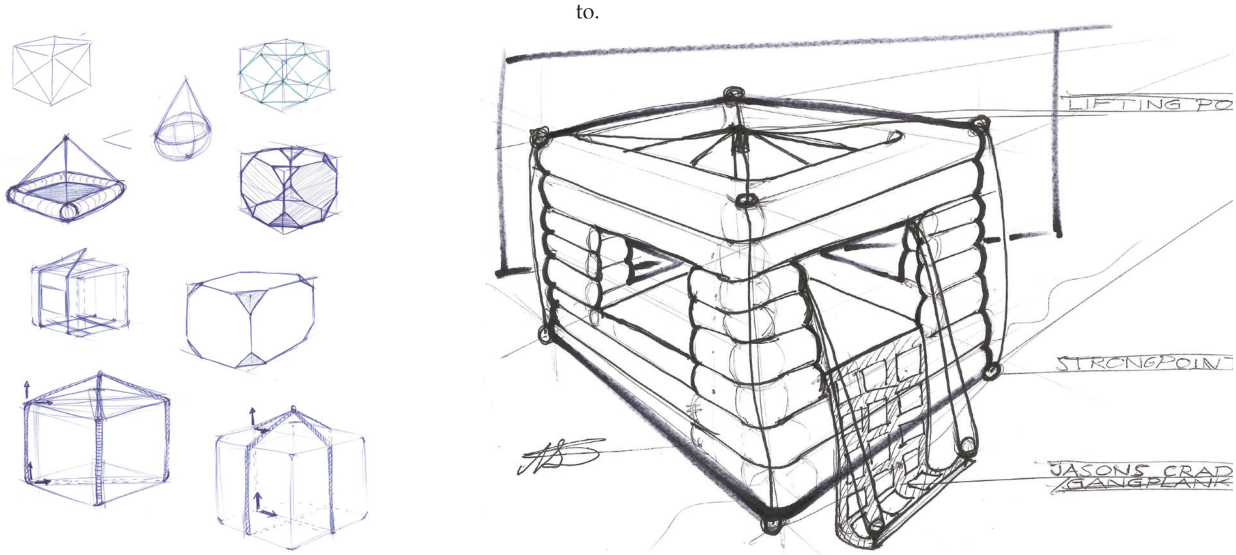


Figure 70. Initially the form was studied based on variations of optimal shapes for lifting and refined into four realistic variants.

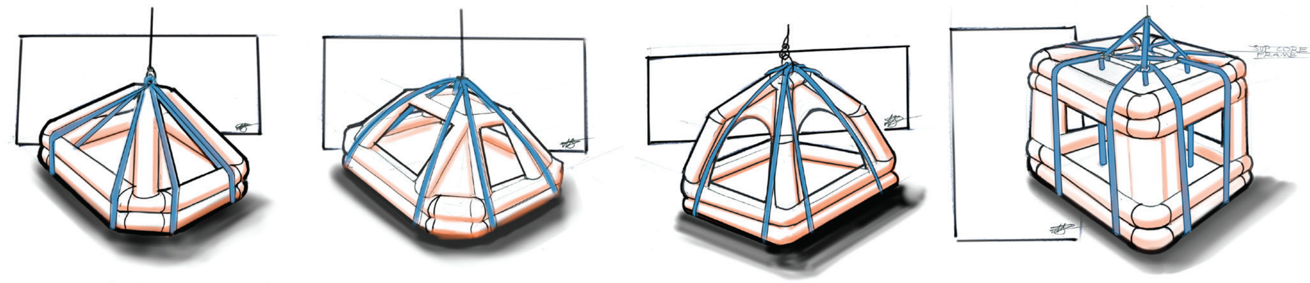


Figure 71. Idea sketches of the first main construction variations with the same base shape

When the base shape had been evaluated multiple variations of these were produced. The self-righting solution allows for greater variety with everything from minimalist (nr 1) to extremely rigid (nr 10). Some of the variants are small variations on how many angles (nr 2 and 7) or possible ways of joining cylinders (nr 9 and 10) using approximate proportions.

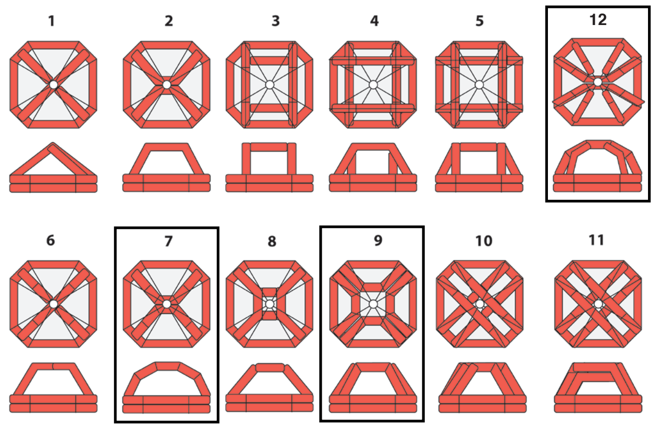


Figure 72. Self-righting construction variations, with chosen ones marked.

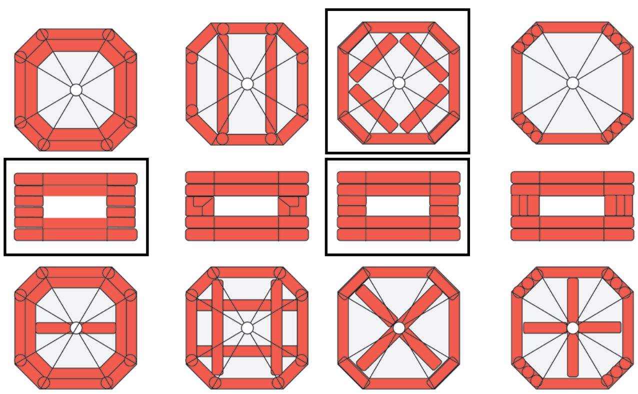


Figure 73. Symmetric construction variations, with chosen features marked.

8.3.4. Evaluation

Self-righting rafts

The first round of evaluation of the self-righting top constructions had one clear winner (nr 7 - Arch) and four alternatives with very close result behind it. The reason was high stability and ease of moving between units, which had the highest weighting in the evaluation. The top two alternatives were brought along to the common evaluation.

Common evaluation

In the common evaluation the Arch solution came out first in a majority of the weighting alterations. This solution also got the highest total score when all rounds were combined. The reversible option with higher openings was the best solution if cost was totally overlooked, if lifting stability was considered not being a problem at all, or if having to turn the raft around (so called self-righting) was seen as a big problem. The full matrix is found in the appendix.

The weighting alterations where the reversible option came out first were all deemed possible depending on how the project would develop so it was kept along with the self-righting Arch.

Models

When building the reversible scale model it became clear that using two vertical pillars in each corner, or using horizontal tubes on top of each other, to support the roof was a lot was best at keeping the bottom and the top stable in relation to each other[1].

Figure 74. Self-righting and symmetric paper models

1 It was unclear if these forces would be an issue for a real raft.

Building the self-righting model was a lot more complicated since the top structure consisted of many bends and were supposed to change angel in several directions. The conclusion was that if it was complicated to model, it could also be complicated to produce. This was difficult to determine without manufacturing expertise but it was not done in any existing rafts, and thus could be an issue.

Change later in the project

When investigating existing self-righting rafts further it was found that all of them were constructed to flip over only in one direction, not from all sides as the concepts were made to do. It was also found that lifting lines are not attached to the top construction, only to the base. This led to a modification of the chosen Arch structure to the common structure used for davit launched rafts of today, practically a combination with self-righting variation nr 3 (see figure 71). This was deemed strong enough, since it is close to current davit launched rafts. This construction was also confirmed sufficient by looking at means of rescue (see figure 74 below). The new solutions were assessed to be equivalent in the other aspects of the evaluation.

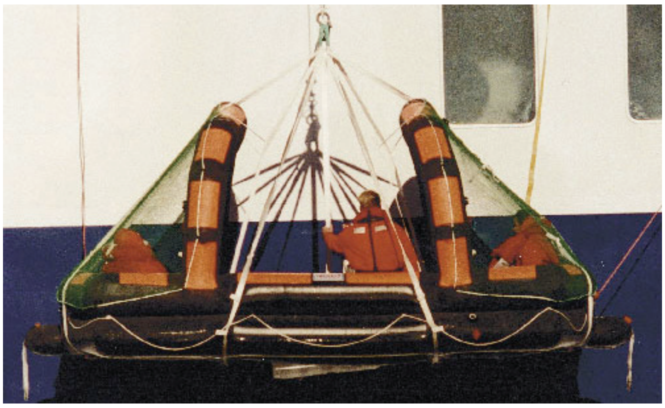


Figure 75. Studying the construction of Zodiac's and Viking's Means of Rescue changed the chosen design (VIKING, 2006)

8.3.5. Refinement

Some final decisions regarding diameters of parts, and number of pillars was left to be taken.

Diameters

The diameter of the top structure pillars was, for the reversible raft, a direct consequence of an optimal positioning of an upper edge cylinder (see section 8.4 Openings & passage between units). The largest fitting diameter, 35 cm, was chosen since the stability they provide for the top structure was deemed necessary.

For the self-righting concept the diameter of the top construction was not restricted by anything else but the diameter of the base (max 50 cm). It was set to 40 cm after comparison to common standards for similar rafts today, and a desire to decrease air volume.

Number of pillars

The number of pillars was based on the results from the sitting test (see section 8.2 Base construction). Six pillars was more appreciated by the participants than eight, and fewer pillars was regarded insufficient for stability.[1]

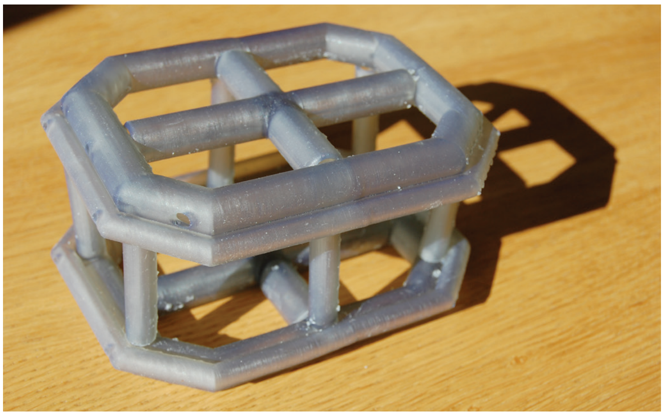


Figure 76. 3D printed scale model, used as mediating object and to evaluate proportions

8.3.6. Conclusion

One reversible option and one self-righting option was seen as realistic alternatives, and kept for further development since they had complementing strengths and weaknesses. The number of pillars on the reversible raft was set to six, with a diameter of 35 cm, while the diameter of top structure for the self- righting concept was set to 40 cm.

8.4. Openings & passage between units

For a concept with many smaller units that people need to move through during evacuation the openings and passage between units is of outmost importance. Today it can be a major issue even with closely connected crafts in moderate sea.

Figure 77. A Canadian test in a wave generator with rugby players going down an evacuation chute to a platform and entering a small liferaft. (Unknown, 2008)

1 Changing amount or dimensions of the pillar could be done without otherwise affecting users.

8.4.1. Methods & execution

The development of this part of the product was divided into three steps; deciding on technical solution, finding out restrictions on that solution, and setting exact measurements.

The ideation on technical solution mainly consisted of brainstorming, sketching while discussing the problem at hand. A number of possible solutions was gathered and evaluated to find the best one. Few and clear requirements means a matrix based method were deemed unnecessary. Several of the requirements were contradicting, why a living discussion, making small changes and compromises to reach a solution.

To sort out the restrictions for the solution and to evaluate how small changes in measurements affected the user's situation, quick mock-ups was built by material at hand. These mock-ups was tested by a few persons and adjusted along the way.

One test investigated what total opening height was comfortable enough to walk through. It was done by using rectangular cardboard boxes of suitable size as substitutes for air cylinders of two rafts lying next to each other, and having participants walk through the mock-up. It was tested on a couple of people of average Swedish height for men and women, and by one person well above average length for Swedish men (193 cm tall, which is the 98th percentile of the Swedish population).

(Hanson et al., cited in Högskolan i Skövde, 2015)

To further validate the chosen measurements, standards from the shipping industry regarding step height was checked, along with anthropometric measures. Exact measurements were set to be within acceptable limits for all important aspects (see below) and evaluating what was best for manufacturing and provided largest usable area inside the raft.

8.4.2. Important aspects

No threshold
For evacuation to proceed smoothly it is of great importance to avoid creating a threshold between the units that is difficult to pass. The Marin Ark has an inflated tube of 40 cm in diameter placed between each opening to climb over, which is creating a bottleneck in evacuation.

Comfortable height
To be able to pass the opening smoothly the height of it needs to be comfortable for everyone to pass through. Crouching makes people move slower, and taking a step while crouched decreases stability.

Barrier
After evacuation, the edge of the raft needs to protect the passengers from the outside. This means the edge should hinder people from falling out, being possible to close off completely to protect from weather and sea. If possible it should work as a backrest for more comfort.

Lookout
When in a liferaft someone should always keep watch to be able to discover help. At the same time it is important to be able to keep the raft closed if the temperature is low (see section 3.5 Physiological aspects & Consequence for equipment). This means it has to be possible to see both the sea and the sky from the inside, even when the openings are closed.

Figure 78. People climbing through the opening of the Marin Ark 2 (CruiseDotCo, 2012)

8.4.3. Solutions: structure

Foldable rib
This technical solution was based on having a foldable part of the edge in all openings. This part would be strapped down to the floor during evacuation, then be folded up and locked in position to form a protection during the rest of the time. The perks of this idea was:

◦ it enables having a higher edge around the raft when closed since it will be folded down when people need to pass it.

Covering rubber sheet
The second alternative was to have rubber sheets stretched over the gap between the units. The idea was to use the same rubber material as for the floor of the raft, and to attach it with rubber straps since they are strong but soft enough to not be a damage risk to people or the raft. The advantage of this solution is:

◦ it completely covers the gap between the rafts providing a "floor" to walk over, which lower the risk of anyone falling down between rafts.

◦ the rubber sheet could also be used to close off the opening with.

Angled, smaller cylinder

Another solution where instead of having two full sized inflated cylinders on top of each other (as most rafts do today), the upper one is made smaller in diameter and is placed, with an angle, on the lower one. This has the following benefits:

- it significantly lowers the threshold users have to pass between each unit.
- it still provides a protecting edge around the raft, although lower, at all times.
- it gives the raft a more hull shaped base, having the sides sloping inwards instead of straight. This makes the raft behave better in waves; the sides are predicted to dig down less when towing the raft since the upper cylinder gets pushed upwards when water hits it from below. The upper cylinder will also directs wave splash away from the raft, just like the top part of the gunwale does on boats.

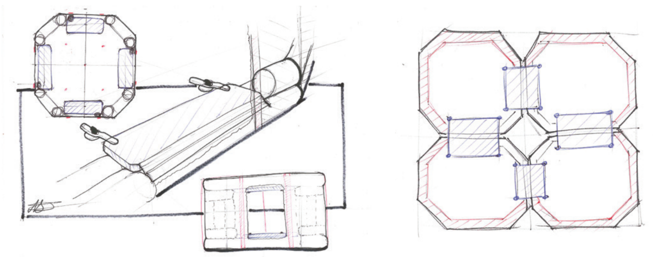


Figure 79. Idea sketches for a foldable rib and rubber sheets covering the openings

8.4.4. Solutions: door

Zipper

The simplest way to close the openings would be using the canopy as a zipped closable door. This is how they solve it today, and it is a well-known solution. Most people are familiar with zippers, which definitely is an advantage. The canopy door would be equipped with a see through part, e.g. translucent plastic, to enable lookout to be kept while the openings is closed.[1]

8.4.5. Evaluation

When discussing the options regarding technical solution the angled smaller cylinder was regarded the best solution because;

- It is a static solution that does not require the users to change anything while in the raft. Both of the other options require actions from the users at some point.
- It was the safest solution. Since the upper cylinder is attached properly it can be used at backrest without risk of moving, in comparison to the foldable solution.
- Simplicity and cost. It would be the cheapest and easiest solution to produce since it does not require moving parts, and is completely built with materials and techniques the industry already uses.
- This structure is a part of the main buoyancy chamber
- It is easy to combine with a zipper door, which also is a good and cheap solutions that is already familiar to the raft industry.

8.4.6. Refinement

Here the steps in the refinement work are presented. To further validate the solution and to decide on more specific measurements some explorative testing on the idea was done. Lastly, final dimensions was set.

Testing - opening width

A full sized drawing of the basic raft shape was marked up on the floor. This mock-up was used for testing available width for openings (along with several purposes during the development). The width was checked against standard doors which, indoors they are generally 70 to 80 cm wide while front doors are a bit wider; 90 to 100 cm. The lowest acceptable width for the openings was set to 70 cm, thus at least as good as the smaller standard doors.

To make sure people reach the sides of the openings for support, Swedish anthropometric measurements on reach was checked. The reach, from fingertip to fingertip, of the 1 percentile of women is 152 cm.[2] The length of the hand is 16 cm. By removing two hand lengths from the full reach one gets a length were gripping both sides are possible, without stretching the arms to an uncomfortable extent. This possible grip reach of approximately 120 cm. Adjusting for a worldwide population using the same calculations, the possible grip reach for the average woman (1 percentile not found) was 116 cm. 116 cm was therefore set to be largest acceptable width for the openings.

(AverageHeight.co., 2015)
(Hanson et al., cited in Högskolan i Skövde, 2015)

1 This solution was difficult to combine with the rubber sheet, since stretching something over the gaps of the raft units will prevent the zipper to be fully closed.

2 Total standing height was taken from the used database, which for humans equals lenght from fingertip to fingertip with arms stretched out horisontally.

Testing - step height

The Swedish passenger ship industry has rules for designing stairs where the step height should be 15 to 20 cm and the step depth has to be at least 30 cm. These were taken as recommendations for what a good step height could be.

The quick tests showed that everything below 25 cm in step height was acceptable considering it is cylinders instead of 90 degree angles. Above that the step began to feel heavy, therefore 25 cm was set as the highest acceptable step height.

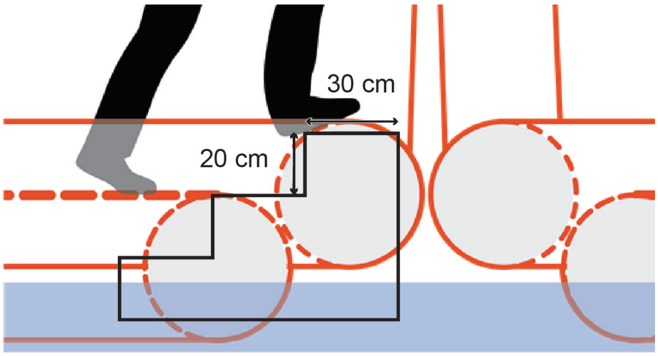


Figure 80. Standard stairs over a cross section of the opening between two final concept budget units

(Sjöfartsverket, 2010)

Testing - opening height

The inside height of the Marin Ark today is 180 cm. This was deemed to be a reasonable height, allowing most people to walk straight inside the raft, and thus kept. The openings would however be lower than this since the threshold cuts into this measurement.

Using the acceptable step height from the step test would make the opening 130 cm high (compared to 100 cm on the Marin Ark 2), and using the maximum recommended step height make it 140 cm. Both were deemed as too small for passing comfortably for a lot of people. Using the lower step height recommendation would however give a 150 cm high opening, which could be enough.

The opening height quick tests showed that a person of 170 to 180 cm quite easily would walk through a 150 cm high opening, although by crouching a fair bit. These persons chose to take one step on the threshold itself before stepping down on the other side.

A persons of 193 cm had a bit more trouble passing the opening because of their height, but since they have longer legs they chose to step over the entire threshold in one stride. Taking this long step made them lower their body position automatically, and thus they did not have to crouch that much more than the shorter persons in the test. However this long stride might be difficult to take when there is relative movement between the rafts.

Other heights were tested briefly and it very quickly became clear that anything below 150 cm started to get really uncomfortable. Thus, 150 cm was set as the smallest acceptable opening height.

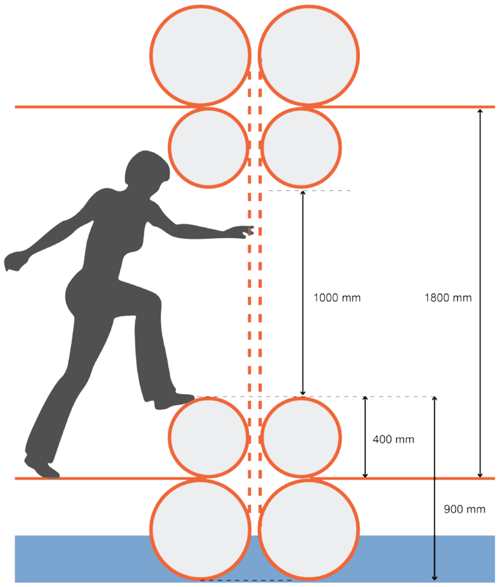


Figure 81. Cross section of the opening between two Marin Ark 2

Dimensions

A number of alternatives with different cylinder diameters for the bottom cylinder, the top cylinder and the pillars, was drawn up.

The decision fell on the marked on in figure 82 on the following page, because it was the best compromise between having:

- a low enough threshold, but still high enough to form a protecting edge which is good from a safety aspect.
- creating a high enough distance from the water level to the opening, which will make less water end up in the raft, but still low enough to make it easier climbing into the raft from the water.
- creating room beneath the smaller cylinder for placing a construction for helping people get up from the water there (see section 8.5 Getting up from the water).

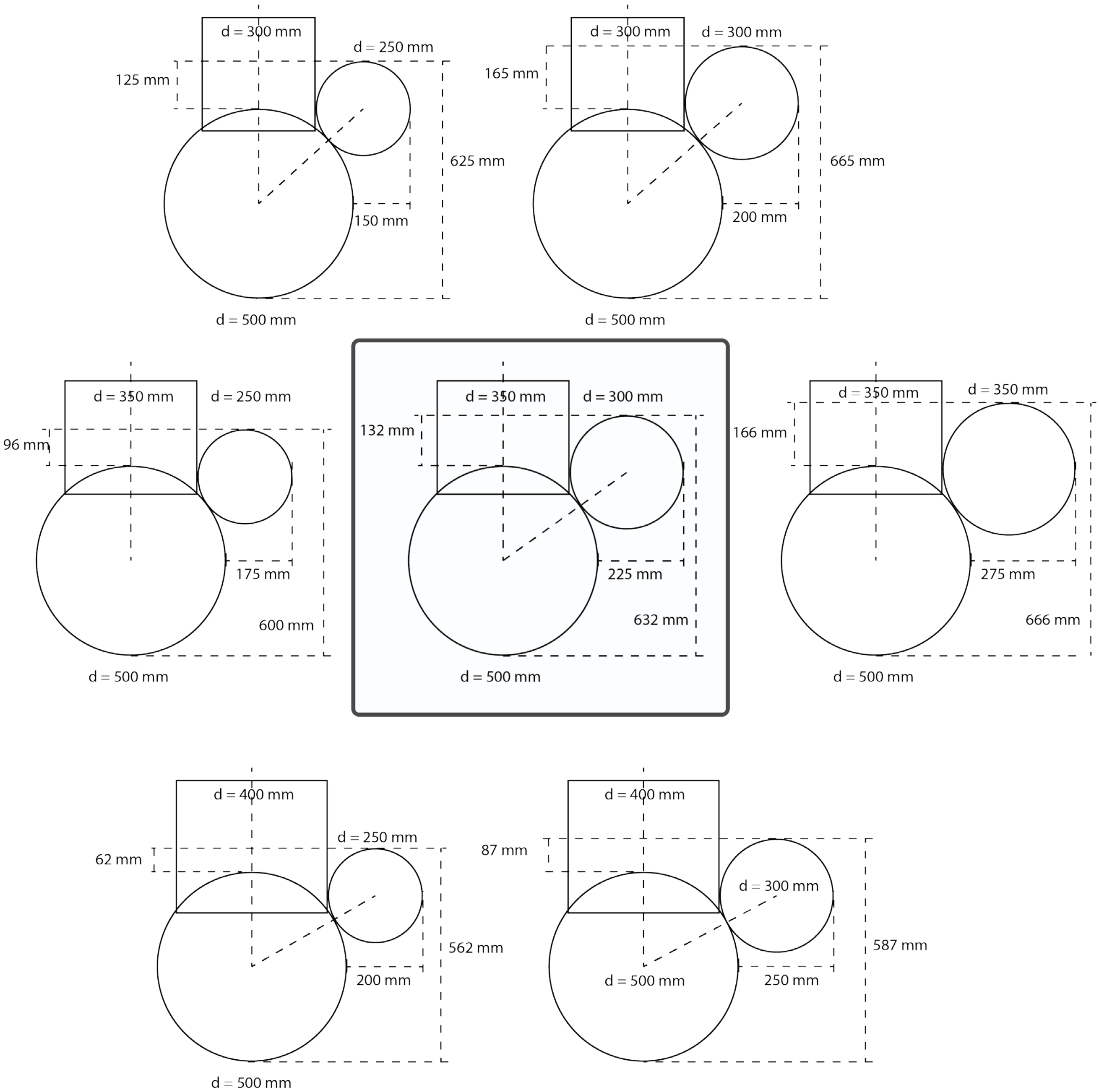


Figure 82. Variations and chosen cylinder dimensions

8.4.7. Conclusion

For the structure of the raft openings on a reversible raft it was settled to use a solution with a smaller cylinder placed at a 35° angle on the top of the bottom one. The diameters was set to 50 cm for the big one and 30 cm for the small one, giving a step height of 13 cm, and a total opening height of 154 cm.
For a self-righting raft it was decided to use the same technique with angled cylinders, the diameter was however set to be 50 cm on both of the base cylinders (at 30° angle). The resulting step height of 25 cm was deemed acceptable since it is open above and the user does not need to crouch.

8.5. Getting up from the water

This section deals with the development of a support to help people get up into the raft from the water. By lowering the edge of the raft openings it has already been made easier, but more support was deemed necessary.

8.5.1. Methods & execution

Developing this part of the raft consisted of three steps after the research; deciding on a technical solution, deciding measurements of that solution, and positioning of it.

Figure 83. One of the authors struggling to get up from the water into a Marine Ark 2 at Öckerö Maritime center

Ideation on technical solution consisted of brainstorming and sketching while discussing the problem at hand. The strategy was to look at existing solutions and improve them. Evaluation of the ideas was done by discussing their perks and problems.

The measurements was dependent on the exact dimensions of the raft base, why it had to wait until those was completely set. The placement and number of aids was set by reaching a compromise between sufficient coverage around a raft unit, a raft group, and a full raft system, and by trying to keep the cost down.

8.5.2. Important aspects

Effect of being in water

People who has been in cold water are quickly affected physically by losing mobility and strength, especially in the hands (see section 3.5 Physiological aspects & Consequence for equipment). This means any support to use for getting up from the water cannot depend on much strength or precision in the extremities of the person using it.

Not hinder connecting the rafts

Any means of support has to consider that the rafts will be attached very tightly to each other. The room between them is very restricted.

Not hinder during evacuation

Getting into the raft will only be possible through the openings, which are also very important to keep clear for the evacuation phase. The means getting up in the raft cannot disturb this phase.

8.5.3. Solutions

Improved ladder

The most used solution for getting up from the water is a simple rope ladder, which is rather difficult to use. An early idea was to improve the ladder by strengthening it in some directions, and make the steps wider, to make it more robust.

(Öckerö Maritime Centre, interview, 2015)

Figure 84. Use of a Jason's cradle. There are versions in fabric that could be better for inflatable products (Platypus Group, 2015)

Jason's cradle

One solution used to get people up from the water is a so called Jason's cradle. This is a big net that is attached directly on the vessel on one side, while the other side can be pulled up onto the vessel. This means it can be used to climb up in while hanging, and to scoop up people with when pulled up.

Integrated step

The last option was integrating an inflatable step below the raft entrance for people to climb up, and step on. This step would be automatically inflated with the raft from the start.

8.5.4. Evaluation

When discussing the options, it became clear that the integrated step was the best solution.

It gives the user the best possibility to push themselves up from the water since it is the most robust solution. It also gives the users enough space to stand on their knees or feet, which makes the last step of getting into the raft significantly easier.

- it does not interfere during evacuation at all since it is situated completely below the raft edges.
- since both the improved ladder and the Jason's cradle requires pulling yourself up, the top of them need to be situated quite high up, near or in the openings, to be able to get into the raft properly. This means they might imply a tripping risk during evacuation.

- when using the angled upper cylinder there is room for placing this step in the space created between the rafts, under the upper cylinder. Meaning this step will not need extra room between the rafts.

- the cylinder solution does not require climbing any rope structures which can be very difficult with cold hands. The other solutions do require this.

Comment

After visiting RFD Beaufort in Belfast and seeing the current step solution on the Marin Ark inflated for the first time, that construction also became an alternative. It was very similar to the integrated step with the difference that, instead of two fully integrated tubes, the air tube was attached to the base. This gives the step the possibility to flex up and down more, it is unclear if rigidity is better or not and which one would cost less to manufacture.

Figure 85. The aid for getting up from the water on RFD Beaufort Marin Ark 2

8.5.5. Refinement

When settling for the integrated step, the next part was deciding on cylinder diameter, length and width of the step, and angle of the attachment to the raft base cylinder. Trying to get all of these measurements as large as possibly could fit was desirable, in order to get a large step, thus deciding them was a natural consequence of the raft base construction.

The measurements of the step ended up being:

- Width: the same measurement as the opening it is placed beneath

- Depth: 2 x the length the top cylinder reaches out from the base cylinder.

- Cylinder size: the biggest size that fits on the base cylinder, below the top cylinder.

The placements of the steps had three things to consider; cost, how to cover all sides of a raft or a full raft system efficiently, and how to not disturb stability when towing since the step will be placed in the water and thus affect drag.

- Since one raft will seldom be on its own in the water (see section 8.1 System size & configuration), fully covering all sides of a single raft was given lower priority. Covering all sides of a raft section (4 units) and a full system was however important.

- Regarding cost it was good to position the steps at the same place for all rafts, e.g. not making them different depending on where in the system they are placed, and also keeping the number of steps down.

- Keeping the raft stable basically meant not placing the steps unsymmetrically in the direction the rafts are supposed to be towed.

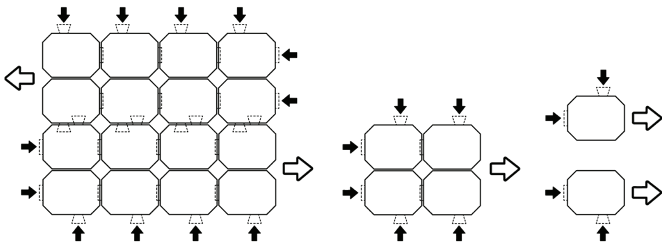


Figure 86. Black arrows indicats steps for getting up from the water into the liferafts, for a system with 16 units, a section of 4 units, and two single units after disconnecting from the others. The white arrows indicates towing directions.

8.5.6. Conclusion

For helping people get up into the raft from the water, one step was placed in the stern and on one of the long sides, of each raft unit. This gives good support of getting up in the raft on all but one short side on a raft group of four rafts, and support on all but two halves of two short sides on the full raft system.

8.6. Lifting structure

This chapter explains the development of the lifting structure of the raft; how lifting lines are places motivated by the way forces are distributed over the structure in a lift.

8.6.1. Methods & execution

For this aspect the process was slightly different since technique and material to use was quite clear from the start, mostly due to the fact that working with inflated constructions have specific constraints. All rough or hard materials should be avoided, and the assembly techniques are limited to gluing, hot air welding and

Figure 87. Studying the layout of a liferaft in full scale marked out

sewing. Therefore the approach was to start with common techniques (currently used for davit launched rafts), and incrementally work out a structure that was deemed sufficient for lifting as well as enabling safe and efficient evacuation.

A full scale layout of a raft was marked up on the floor and used to position lifting points and test how it would be moving between them.

8.6.2. Important aspects

Flexibility

Any lifting structure require extensive testing so the design needs to be flexible. It is extremely difficult to do calculations or simulation on inflated constructions, the behaviour is difficult to predict. Not even manufacturers rely on calculations. If tests shows there is not enough structural stability, more lifting bands needs to be possible to add without having to change the rest of the raft.

Evenly spread load

The weight of the raft needs to be distributed evenly over the construction to avoid too much deformation when lifting. The force cannot be too high in one point due to risks of bending a cylinder section or breaking the attachment points.

Figure 88. A Marin Ark 2 being lifted at the training facility (ÖMC). The long side sections are bending down, but since the raft is empty it is not critical.

Avoid raft deformation

If the raft bottom part deforms too much, the floor will collapse into a bowl like shape. This means the passengers inside would end up in a big bundle on top of each other and risk being seriously injured. Deformation in the top part of the raft is however not as problematic and does not put the passengers at risk in the same way, but should of course also be avoided if possible.

Not affecting evacuation

Any construction for lifting the raft has to consider that people need to have enough space to pass through the rafts quickly, it cannot hinder the evacuation. In the davit launched rafts a large amount of lines go from the raft floor to the lifting point to make sure the floor does not collapse. This solution spreads the load well but makes it difficult to move around in the raft.

Figure 89. VIKING 39 person davit launch liferaft with a "forest" of lines inside (VIKING, 2006)

Simplicity

In order to fail proof the raft, complicated constructions should be avoided. Using already used techniques also means manufacturing does not need to be set up and reduces the amount of testing needed.

8.6.3. Understanding the forces

Lifting in an elevated centred point is preferred since connecting to several points increase risk of errors. The resulting forces will all be pointing towards this point, both upwards and inwards to the centre of the construction. How the forces are divided between upwards and inwards depend on the position of the lifting point. If it is higher up the resultant force is angled more upwards.

The longer the cylinder sections are the more sensitive they are to bending, especially with forces perpendicular to the direction of section.

8.6.4. Material

When lifting heavy loads in the construction industry, and in general, synthetic lifting straps in plastic (e.g. polyester or polypropylene) or metallic chains are most commonly used. For this project's purpose lifting straps is the best choice since they are lighter in weight and will not risk damaging the raft. There are straps for lifting loads considerably heavier than this raft will be, finding one with the right capacity will not be an issue.

8.6.5. Solution

Important elements of the full solution will be explain one at a time here.

Vertical lines inside the raft

To avoid a spider web of lines inside the reversible raft angled lines were to be avoided since they needed to have doublets to maintain the reversibility (creating a cross). The best choice was to use completely vertical lines inside the raft for holding up base and floor.

For a self-righting raft this will not be an issue. Since it is only supposed to be used with the same side up, lines can be angled. Too small angle makes a line take up more space in the raft however, and may block evacuation routes.

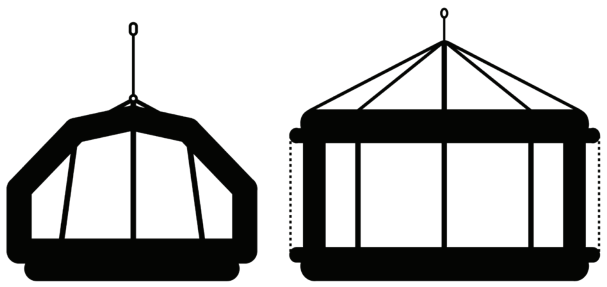


Figure 90. Side views showing the vertical lines inside the symmetric concept and angled inside the self-righting

Structured line matrix

In order to spread the lifting load the lines was spread out in a pattern that covers the entire floor equally but at the same time leaves free passage through the raft in all directions (see drawing below). These lines have the primary function to lift the bottom but they can also be used as support to hold on to when moving through the raft.

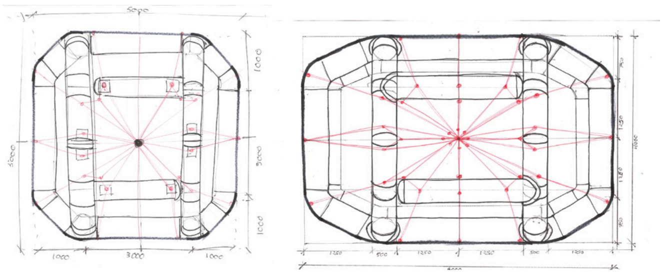


Figure 91. Planning sketches for positioning of lifting lines (dots representing attachment points)

Converging lines on the top

To gather all the lifting straps in one lifting point they are converged at the top of the raft. The angle of these top lines was kept between 35° (for far corners, all other have better angles) and vertical which gives an acceptable resultant force vector, and at the same time does not add too much height to the total construction.

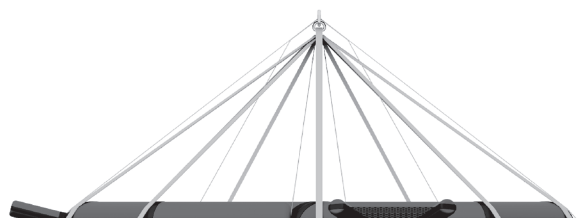


Figure 92. Side view of lifting lines on the top of the final symmetric concept (there is an identical setup on the bottom as well).

No piercing lines

No lines in the lifting construction are actually passing through the floor. This was done deliberately to avoid having to make sure these passages were completely watertight. All lines holding the floor up are instead attached directly on the floor, or on the air tubes beneath the floor or on top of the roof.

For the self-righting raft the lines will run from the inside of the floor, up to a lifting point, passing through the canopy. The canopy is not load bearing and thus easier to waterproof than the floor.

8.6.6. Conclusion

To be able to lift the raft a structure of lifting straps was placed out around the outside of the raft, spread in a pattern inside the raft, and converging from the top of the raft to one lifting point. This pattern distributes the load over the raft and the rafts floor, but still allows people to move through the raft in all directions.

8.7. Crane connection

This section deals with the parts and procedure developed for the actual lift of the raft units.

8.7.1. Methods & execution

The process of finding a solution for the connection point had three steps; ideating on technical solutions, evaluating them, and working out the details for the best solution.

The ideation was done by sketching on ideas and discussing them. Inspiration was sought by researching lifting tools from the construction industry and products from the climbing community. Evaluation was done by discussing the alternatives based on criteria and requirements relevant for this part of the raft, and choosing thereafter.

The chosen solutions was refined, but setting the last details of the lifting construction, such as deciding size and capacity of the bearing parts, was not deemed necessary to do within the project. The construction needs to withstand four times the workload (LSA Code). However there is no point setting dimensions and exact components before a decision to build a prototype has been made.

8.7.2. Important aspects

Simplicity

Throughout the whole evacuation and recovery process, simplicity is very important due to the extreme use situation. Simplicity here meaning error prevention by using simple and reliable technical solutions, as well as eliminating as many actions (and possible mistakes) required by users to perform.

Possible without SAR help

Since the idea of the entire project is to make use of ships of opportunity in mass rescue operations, it is very important that every step when using the raft can be performed without help from SAR personnel, and preferably without experienced users at all.

Total height

As the raft is to be lifted onto a ship's deck, the total height from the raft bottom to the lifting point has to be kept as low as possible, otherwise the raft might have problems getting over the gunwale of some ships.

8.7.3. Solutions

Sling

The simplest solution is adding a lifting sling to the lifting point and attaching the end close to one of the raft openings. Then a lifting hook can be attached easily to the sling, preferably by someone standing in the raft, but also by someone on a vessel close to the raft. This is the solution used during the tests with SSRS and Stena Line and it has worked very well.

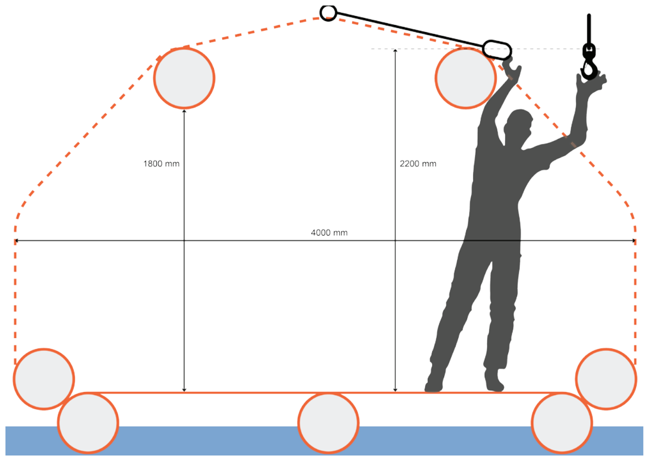


Figure 93. Cross-sections illustrations of connecting the crane hook from inside the liferaft, directly to a sling on a self- righting concept

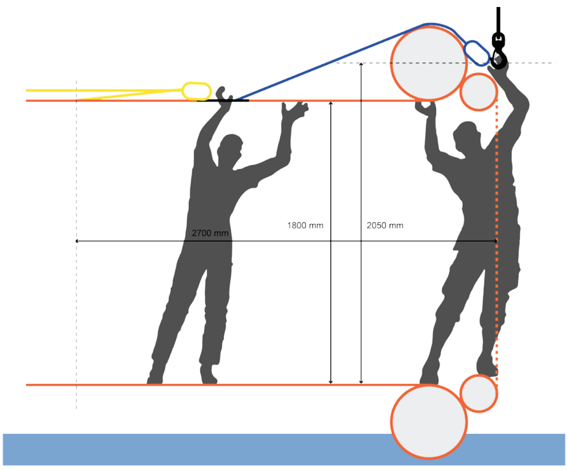


Figure 94. Cross-sections illustrations of connecting the crane hook from inside the liferaft, through an opening in the roof, for a symmetric concept.

Roof opening

Includes adding a place close to the lifting point where the raft roof can be opened, and the hook can be attached manually to the lifting point. This solution requires a user to pull in the hook from the side to the centre top of the raft. This could e.g. be done by using a one way rope lock (common when climbing).

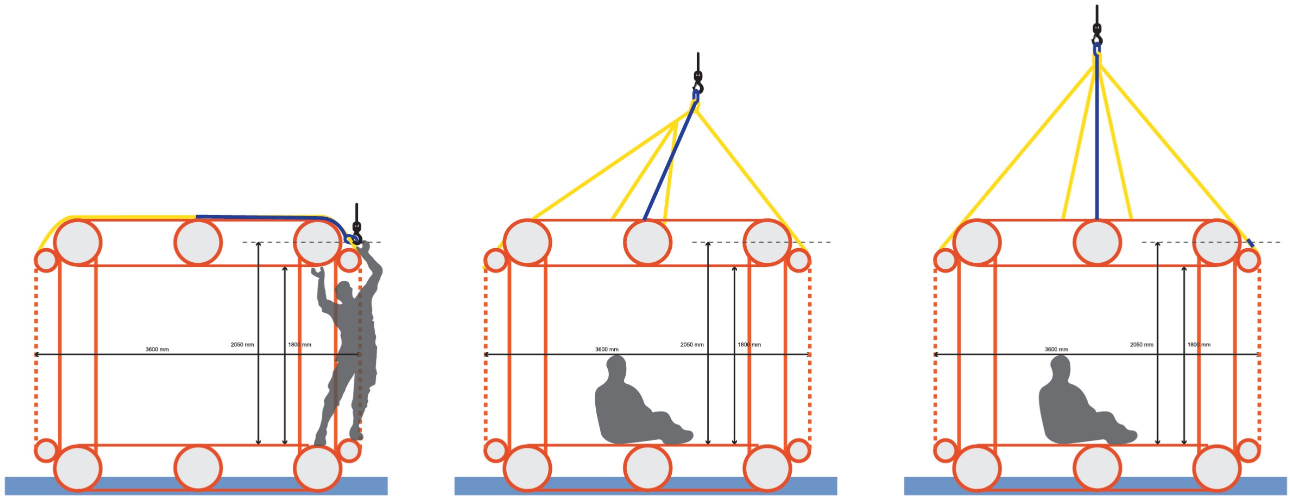


Figure 95. Cross-section illustration of the final concept for connecting the crane hook on a symmetric concept. Left: User connects crane hook to lifting eye. Middle: the blue lifting lines centre the hook as it is being raised. Right: There is tension in all lifting lines and the hook is centered.

Sliding connection point

A solution where the connection point can slide on one of the lifting lines strained over the short end of the raft. This means the connection point can be folded down to one of the raft openings, where the hook is attached, and the connection point (with the hook attached) is then released and free to slide up to the centre of the lifting construction when the lift is initiated.

8.7.4. Evaluation

Sling

- This solution will not add much to the total height for a self-righting raft since those openings go quite far up the top of the raft. On a reversible raft the sling adds the distance from the centre of the raft to the opening (approximately 2 - 2,5 m depending on raft construction) which makes the total height more than 6 m which is deemed to be too much.
- It is a simple and reliable technical solution.
- It does not require any complicated actions from the users. It is difficult to imagine what can be done incorrectly.

Roof opening

- This solution would not add much height at all to the total height.
- It requires a very water tight and carefully constructed opening in the roof and floor of the raft.
- It requires a two-step procedure from the users, which might be difficult to understand in a stressful situation. If the users tries to pull the hook to the lifting point from the inside and through the opening it will cause big problems.

Sliding connection point

- This solution will not add much to the total height since the connection point is folded down. Just a short additional sling (approximately 0,5 m) might be needed for reaching over the edge of the raft.
- Is a technically more advanced solution than the simple sling. It is important to test it enough to make absolutely certain nothing can get jammed to avoid the raft being lifted at an angle.
- Does not require anything difficult or complicated from the passengers.

When comparing the options, the sling is the best alternative since it is the most reliable solution. This solution is applicable with the self-righting raft, but it causes a height problem for the reversible one. It was therefore decided to use the sling for the self-righting raft, and the sliding connection point for the reversible raft as the second best solution.

Possible automatic connection with magnetic hook

There is a magnetic crane hook operated by remote on the market that could be used to automatically connect the crane to the raft from the rescuing ship. Either of the solutions would work with this and while this should be tested, it was not deemed realistic that all ships will have this in the future.

Figure 96. Remote operated magnetic crane hook from elebia, up to 20 tons available (ELEBIA AUTOHOOKS, S.L.U., 2015)

8.7.5. Conclusion

For the self-righting raft a simple sling will be added to the lifting point where a crane hook can be attached when the raft unit is to be lifted. For the reversible one a solution with a connection point that slides on one of the lifting lines is used instead, to keep the total height down.

8.8. Disconnection of units

This section describes the development of the connecting and disconnecting mechanisms of the raft system. Both how the full system will be divided into raft groups, and how those groups will be divided into single raft units.

8.8.1. Methods & execution

The strategy for the connecting the rafts was to make a solution similar to that for the Marin Ark. However, without the need to cut lines since this has proven troublesome in training. Furthermore, the risk of cutting a lifting lines would now be added.
(Hinnerson & Falkman, interview, 2015)

The connection development was done with incremental improvements with informal evaluation along the way.

8.8.2. Important aspects

Stability

Keeping the raft units stable and tightly connected to each other is very important for the evacuation phase since it minimizes the relative movement.

Reliability

The technical solution used for connecting and disconnecting the raft units has to be reliable since malfunctioning parts or other problems can have fatal consequences in this context.

Simple disconnection

The raft units will be connected from the start when the system is launched, so users will not have to meddle in that. When raft sections or raft units are to be disconnected, during evacuation and before a lift, the amount of actions and the difficulty of them has to be kept to a minimum (see 4.4 User Mapping).

Unavailable for unauthorized

Conflicting with the need of simplicity and clarity, there is a need to discourage unauthorized persons from handling the disconnection system. If units are disconnected before intended, the evacuation process can be disrupted, and units can end up floating around alone.

Possible from other vessel

Being able to perform any necessary action to disconnect units from a vessel (e.g. FRB or Rescuerunner) is important, since e.g. SAR personnel has to be able to execute all steps if passengers are incapacitated.

8.8.3. Solutions: construction

Strong points, shackles & straps

The Marin Arks four units are kept together by rope or straps attached with shackles to strong points on the rafts. These strong points are situated at each corner of those units, and lines go between the strong points on the opposite raft unit to hold them together. This was the most simple and logical way to do it. For the reversible raft the strong points will be placed both top and bottom, adding up to 16 in total.

On the self-righting raft the connection points on the long sides need to be placed a bit lower since the top is rounded. However on the short sides they can only be placed on the bottom part of the raft. Due to the distance high up the straps would slack and jerk as the units moved relative to each other, with a risk of injuring someone.

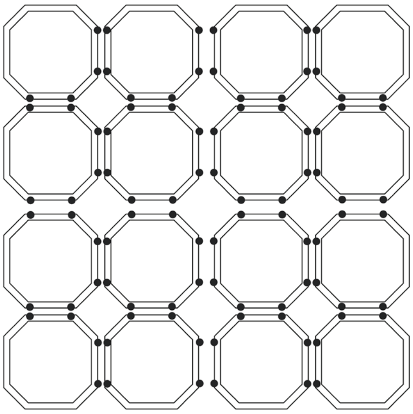


Figure 97. Top view of 16 units, black dots representing strong points where straps and shackles are attached.

Quick release shackles

To be able to disconnect the units smoothly quick release shackles are to be placed on the lines between the units, on the connection both up and down. These shackles are opened by pulling a release sprint that easily can be attached to a release line.

8.8.4. Solutions: procedure

Manual disconnection points for raft sections

The raft sections will with this solution be disconnected manually from two points on the outside of the raft corners. These points are reached by leaning out ventilation openings placed on the corners of the raft.

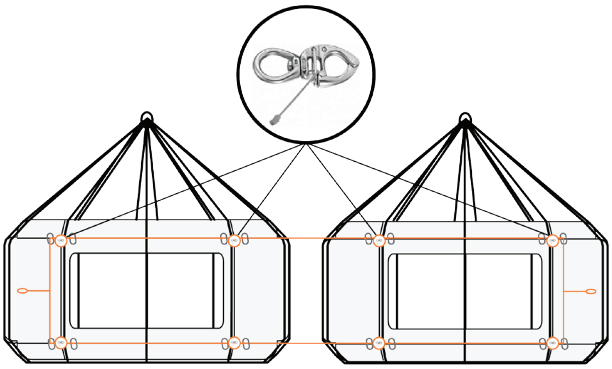


Figure 98. Positions on one side of shackles and the manual release lines

The disconnecting will be done by pulling a combined release line for all quick release shackles on one raft section side, eight connection can be disconnected with one line. This can be done from either corner of the group side.

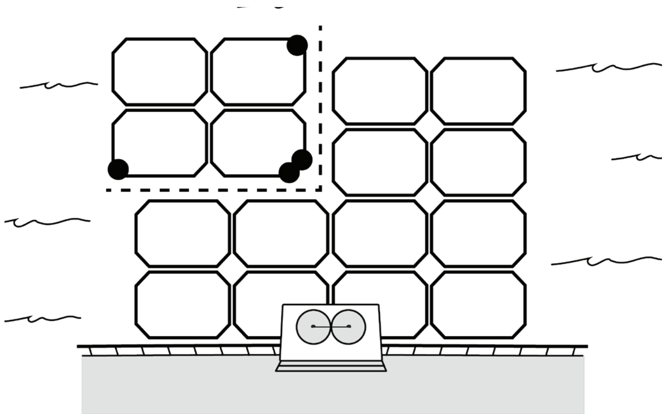


Figure 99. One of the symbols inside the rafts displaying where units can be disconnected. More illustrations explaining how and where actions are performed can be found in 8.10 Signs, symbols, & instructions.

The possibility to connect the raft sections from any corner and not just the middle one (which would be more effective), was added because the outer corners are the only ones reachable from another vessel.

Automatic disconnection of units

The disconnection of a single raft unit will here be automatically done when a lift of that unit is initiated, release lines run from all connections of every unit to its lifting point. The release lines will be made shorter than the lifting lines, and the quick release shackles will thus be opened before the unit start to leave the surface. This way units will be disconnected before a lift without any action required from the user.

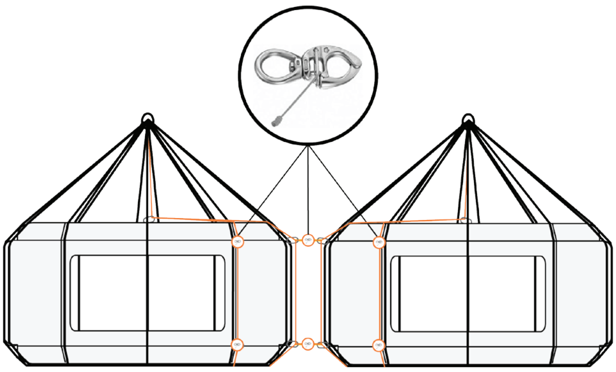


Figure 100. Positions in one corner of shackles and release lines for automatic release during lifting

8.8.5. Evaluation

The technical solution with lines, shackles and strong points have been used before and is therefore deemed as reliable and good enough. Since the self-righting concept cannot be connected in the top on the short sides, due to its shape, passages in that direction will be less stable which could be a risk.

Regarding the disconnection of the raft sections;

- The disconnection only requires one action (repeated two times)

- The action, pulling a line, is not complicated but requires guidance to make sure the right lines are pulled, which will be added by colour coding (see section 8.9 Colour coding).

- By placing the detachment mechanism on the outside of the raft, the risk of the action being engaged at an incorrect time, by an unauthorized person, is decreased.

- The risk of persons who are supposed to perform the action not finding the mechanism is however increased. Therefor there will be signs and instruction added in the raft to point out the place to interact with (see section 8.10 Signs, Symbols & Instructions). These instruction will also have to make it clear that this is an action only to be performed by someone who knows it.

Regarding the automatic disconnection of a single unit;

- The solution is very good from a user perspective since they do not have to interfere at all, meaning they cannot make any mistakes.
- The technical solution a bit more complicated, but if the lines jam, it is always possible to cut them loose as a last solution.

All in all, this package solution for connecting and disconnecting the rafts was judged sufficient for the concepts. To be sure the line construction will not malfunction or get jammed, it has to be tested properly on prototypes with all lines present.

8.8.6. Conclusion

The raft units will be connected with lines and shackles. The raft sections will be possible to disconnect manually by quick release shackles, and combined release lines to pull, making them easy to reach and handle. Raft units will be automatically released when they are about to be lifted, by connecting the release shackles to the lifting point.

8.9. Colour coding

This section describes the development of the colour coding used on parts of the raft. The Marin Ark system has a lot of lines, ropes, straps and parts that comes in all kinds of colours. This can create confusion and makes it difficult to sort out what components do, the colour coding aims to improve this.

8.9.1. Methods & execution

The first step in this process was to list different parts and elements into different categories to sort out what should be coloured the same.

The next part was setting the colour for each group. The choices was based on common rules of what colours mean to people, which colours gives high contrast with each other, and some quick research of what colours are available for parts used in the raft, such as ropes and lines.

Quick comparisons of colour combinations was made in early CAD models to make the final decision.

8.9.2. Important aspects

High visibility in sea

The products visibility at sea affects search and rescue time, thus it is the highest priority.

Differentiate parts with different function

The aim for the colour coding is to help users tell the difference between lines that are for lifting, connecting, and for helping them since these are to be treated differently. Some of the lines can for example be cut if something should jam up, while this never applies to lifting lines. Lastly, the users need to locate and understand what parts they are to interact with to handle the raft system.

Cost

Manufacturing cost is a major concern for the products, and it is not realistic to believe that money will be spent on getting special parts in the correct colour. Colours that are common for the corresponding materials should therefore be used as much as possible, and small differences in colour has to be accepted. Because of this exact colours are not defined in the project and no samples are provided.

The meaning of colours

That some colours mean or implies things to most people should be utilized. For example red and green are highly connected with right/wrong or on/off, or red alone is used for warnings.

8.9.3. Solutions

The division of the raft parts will be listed here together with their assigned colour and a motivation.

Raft construction: Orange

All air compartments and the canopy.

Since the superior goal for the colour choice of this part is to have high visibility in sea.

Raft floor: Black
The raft floor (and the roof for the reversible raft).

The floor is only visible from the inside why high visibility is not prioritized here. Having the entire inside of the raft orange can create an intense lighting effect that would be reduced by using black for the floor. The floor will also have painted instructions on them, which are easier to make clear on a high contrasting background.

Connecting construction: White
All lines etc. that are holding the raft system together.

A common colour on rope and straps. White is neutral, does not draw the eye and does not necessarily mean anything to people (like e.g. red or green does), which is good since users should not interact with or pay attention to these lines.

Lifting construction: Yellow
All lines that are bearing for the lifting function.

This is an existing colour for construction straps that is quite neutral. The users should not really interact with these lines, but the lines inside the raft can be used for support as a secondary function, why the colour should not be discouraging interaction.

Static supports & helping equipment: Flourescent Yellow
All added ropes and straps that are supposed to support the passengers e.g. handles around the openings, ropes around the outsides for people in the water to hold onto, handles around the steps etc.

These parts are made for the user to hold on to, but not the perform actions with. Fluorescent yellow is similar to the yellow lifting straps, which is good since they are similar in function for the user. This colour is however easier to spot. It is also an existing colour on thinner straps or lines, and have been used for this purpose on rafts before.

Interaction points: Blue
All parts that are to be interacted with by users, e.g. lifting hook or sling, disconnecting points and disconnecting lines, water drains, zippers, ventilation opening, knife, mooring lines, drogue, survival pack, and towing point.

Blue has high contrast against the orange raft, which is important for parts that should be easily discovered but not have a distinct meaning in itself. It is also available for most materials and parts.

Figure 101. Pictures showing example parts in the colours that are to be used in the product concept

8.9.4. Evaluation

For the rafts inflated construction and the canopy there was not really another choice for colour, neither for the floor. There was some uncertainty whether to use white on the lifting lines and yellow on the support lines or vice versa. This was compared quickly in the CAD model, and the choice fell on yellow lines since the orange raft (a quite red orange) combined with many white lines gave it an unwanted resemblance of an ambulance or a fire truck.

8.9.5. Conclusion

The raft is to be colour coded with white, yellow and blue parts in addition to the orange and black base construction. The white and yellow is to be used for telling the difference of lifting-, supporting- and connection lines, and the blue is to be used to signal interaction points.

8.10. Signs, Symbols & Instructions

This section describes the development of all graphic material used in and on the rafts. This includes graphic material for the following purposes.

◦ Explain the evacuation and recovery process with the system

◦ Guide the users through the raft system during evacuation

◦ Point out where parts in the raft are located

◦ Instruct how to use interactive parts of the raft

◦ Warn users of hazard risks

◦ Overview of raft and provided tools

8.10.1. Methods & execution

The process of producing the graphic material was divided into the following steps; stating what parts of the raft and the process that needed graphical material, brief research on what instructional graphics of similar purpose looked like (mostly road marks and evacuation plans in buildings). Then material was produced, some with a lot of alternatives, some with few. An initial evaluation was done to come up with an amount of alternatives suitable for a short formative evaluation sessions in a focus group.[1]

This session was conducted with three participants with some prior knowledge of the project, and extensive knowledge in graphical design. They were presented with a few graphics at a time, and explained which situation they were in when seeing them. First was a free discussion about how they interpreted the material. When that discussion felt sufficient, the material was explained and they were encouraged to share more thoughts. The results from this session was used to make final refinements on the material.

8.10.2. Important aspects

Cognitive load

The use context is stressful and many users might be panicking. This means decreased cognitive skills that all provided instructions need to consider and adapt to.

Language barriers

Users in the raft system will be speaking different languages and there will often not be one language that everyone understands. Text should therefore be used sparsely, and never without complementing pictures.

Placement of graphics material

When designing graphic material one should consider where it will be placed from the start. Things that are to be printed directly onto the inflated construction cannot be done in the same way as things to be printed on signs or paper. Material printed onto the raft needs to be able to do with stencils, and take the background colour into account. Material printed on signs and paper can be done more freely.

8.10.3. Material

The material will be presented divided into the groups they were listed in earlier in the section introduction along with short additions to what was important for that specific graphical material.

Explain the evacuation and recovery process

The two following illustrations describe the two main phases (evacuation, and recovery) of the MERS system. These are to be placed in the printed manual (in the survival pack) and the first one, explaining the evacuation phase, will also be included on a sign at the assembly point on the ship. When passengers are waiting to go down the chute they have time to look at instructions, and getting information about what is going to happen can have a calming effect.

1 A focus group is a form of group interview or workshop (Bligård, 2011)

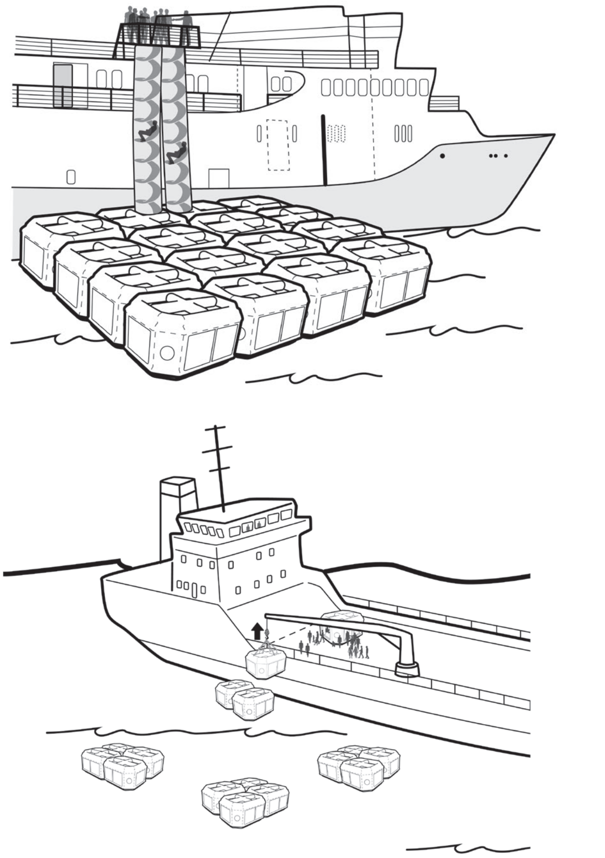


Figure 102. Illustrations of the evacuation with a system deployed next to a ship and the recovery with liferaft units being lifted onto a ship of opportunity

Guide the users through the raft system during evacuation

Material to guide the users through the raft system was produced in two complementing parts. One evacuation guide, including two illustrations, to be placed at the assembly point, complemented by prints on the raft floor to guide the passengers in the actual rafts.

The first illustration show an overview of the system and point out how to walk to fill the system correctly, and the second illustration will instruct the passengers to fill the raft units from the far edge and inwards.

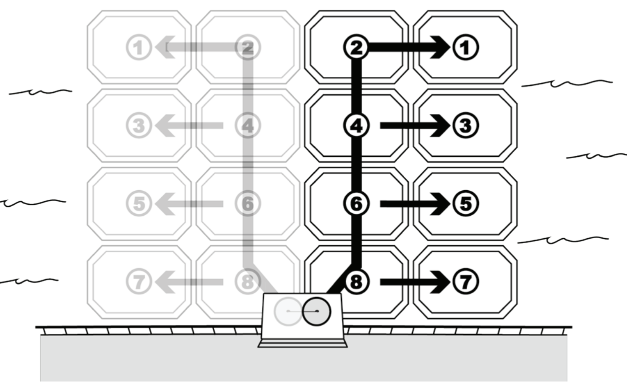


Figure 103. Illustrations showing the system evacuation route

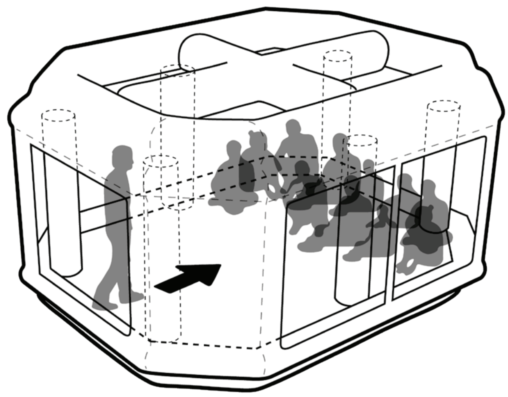


Figure 104. Illustration showing how to fill up the raft units.

The printed material on the floor includes arrows pointing out which openings to go through, and a division of the floor area into four parts with instructions to fill them with eight passengers each. The arrows was provided to discourage people to walk around randomly in the raft system. The area division was added to support passengers to fill up the raft completely. Keeping count of 32 people placed out randomly in a raft is difficult, even more so under stress. By giving smaller areas to fill with a smaller number of people, it will get easier to keep count and people are more inclined to sit as close as needed to be able to fill the raft.

(SSRS, exercise, 2015)

For the floor graphics a large number of alternatives with minor changes was produced from the start. These alternatives was reduced to five before they were brought to the evaluation session.

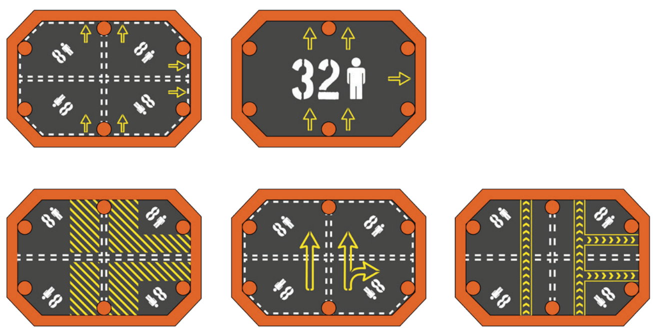


Figure 105. Evaluated variations of floor graphics

Point out where parts in the raft are located

To help people locate parts of the raft where they need to perform actions some signs were designed. Signs were made for the following parts; the zippers, crane hook, disconnection points, and water drains. The strategy for these signs were to be able to express what part it dealt with in one icon, combined with an arrow to point out direction, and a short text line for redundancy. These icons were to be printed directly on the raft or the canopy, and thus cannot be too complicated, and need to be highly visible.

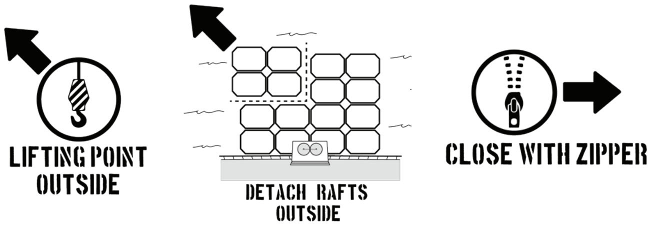


Figure 106. Signs indicating where to perform certain actions

Instruct how to use interactive parts of the raft

For people to be able to perform the actual actions of connecting a crane hook, and disconnecting the raft sections, it was deemed that more thorough instructions was needed for support. These actions are however not to be encouraged for any random passenger. It has to be clear that they should be performed by ship crew members, SAR personnel, or a raft leader, firstly if available. The more detailed instructions cannot be printed directly on the raft and will need to be attached as decals or similar.

The thought behind the illustrations was to convey what type of action needed to be done (e.g. pulling or pushing), where exactly it needed to be done, and what consequences it would have. It was also decided that showing quite a lot of the context in the illustration was good, since that clarifies the main task better. Too zoomed in illustrations are difficult to put in a bigger picture.

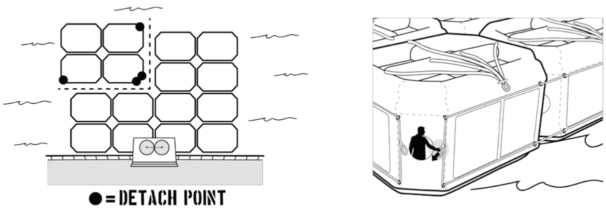


Figure 107. Overview and user action illustrations for disconnecting a raft section.

The steps included when disconnecting the raft section is firstly to identify the disconnection points and understand which ones to use in combination, and secondly to pull the correct release lines.

The steps included for connecting a crane hook is to locate the connection point outside and attach the hook, close the zipper doors, and wait for the lift. Thus this illustration series includes three pictures showing these step.

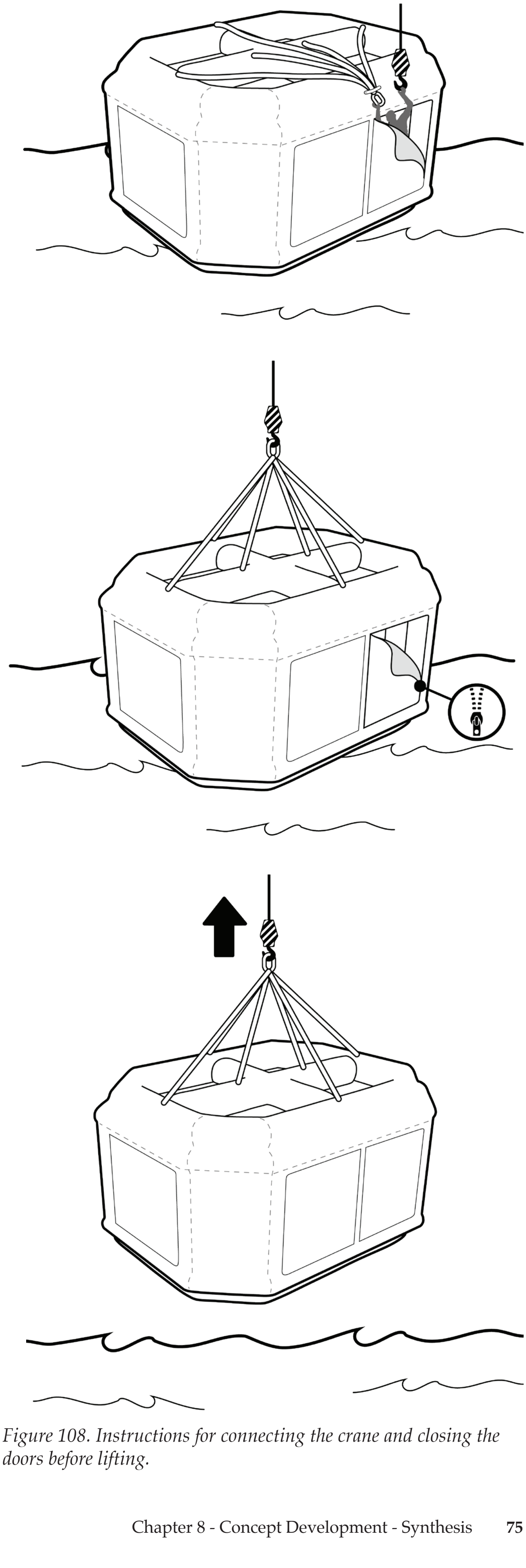


Figure 108. Instructions for connecting the crane and closing the doors before lifting.

Warn users of hazard risks
Passing between the units includes passing over a gap where there is a small risk of tripping or falling down if the users does not pay attention. Therefore it was decided to add a warning sign for this part to make the users aware of the gap.

Most people connect triangular shape to warning due to e.g. traffic signs. This shape was therefore deemed most suitable for this purpose along with the well know term "mind the gap", and an illustration showing the step between the units. See the illustration below.

Figure 109. Warning sign for the gap between units, inspired by similar train signs

Overview of raft and provided tools
To make sure all tools in the rafts are found and used an overview pointing them out was designed.

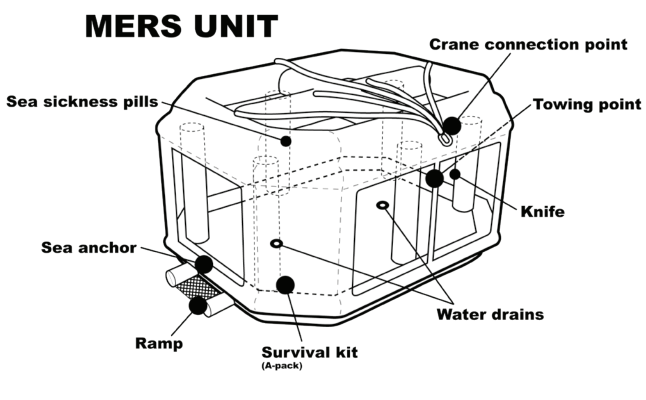


Figure 110. Sign indicating where to find various items and features on a unit, to be printed on a wall of the unit

8.10.4. Evaluation
Some of the illustrations were very clear to the participants and did not get much critique at all, why they lack feedback here. The others are however listed below.

Floor graphics
During the evaluation session the participants agreed on which floor graphic alternative they preferred. They also quickly grasped the division of using white for marking area and yellow for showing direction.

> *"You can tell the white is connected to area and yellow to direction" - Participant 1*

The preferred alternative was chosen to use and only minor changes was done later to adapt it to a stencil.

Process overview
The illustrations got small remarks on how to place the persons in them to clarify what is happening, otherwise they were clear to the participants.

The participants all thought that showing only the first one when waiting for evacuation was enough, since they users should not think about more than they have to do in the moment. By seeing the evacuation chute and the rafts being lifted simultaneously there was some confusion for a short while about how the evacuation was to be conducted. Also some worried about the ship of opportunity not being correctly equipped (see quotes). The participants therefore thought the later steps should only be included in the printed manual.

> *"Will I be lifted down instead?" - Participant 3*

> *"My first thought: well, what if the ship does not have a crane?" - Participant 2*

The small adjustments was done, and the advice on where to show what inform

Evacuation guide
The evacuation guide that was showed to the participants got critique for showing too much information. The participants wanted to remove the people to make it clearer, and to divide the guide into two version, one for each chute line since there is a difference in which direction to walk.

This critique was deemed very useful and the evacuation guide was stripped down of details and split up into two. The first version can be seen in the appendix.

Raft fill up guide

This illustration was a bit confusing due to the usage of the arrows in the picture. Before, the arrows showed where to walk, and in this illustration it showed in which direction to fill the raft. This was corrected after the evaluation.

Crane attachment process

The series for showing how to connect the hook was considered to look a bit dangerous since the doors was completely open in the first illustration. The participants also wanted clarification on which part to attach to which one, since both the connection point and the hook looked movable.

The refinement of these illustrations meant adding half opened zipper doors on the first one, and making sure the connection point looked (temporarily) fixed to the raft, and the hook was placed in the hand of the person attaching it. The old version showed to the participants can be seen in the appendix.

Disconnection process

Regarding these illustrations the participants understood how the action was to be performed (see quote), but they missed an indication that this was something only crew members should do (if possible). They definitely though a driven passenger could take initiative to perform this task when the instruction were provided.

> *"you are supposed to pull down in a loop to disconnect when you are supposed to go" - Participant 1*

Because of this the text "raft leader only" was added below.

Mind the gap

The participants immediately interpreted this illustration as a warning, and did not have much to say other than that the warning should be placed at eye height in the raft by the opening to alert people who are not already watching their step (see quote).

> *"It would be better if it's on the wall so you look down in case you are not already doing that" - Participant 1*

Overview of raft

The participants thought the overview was a bit too crowded with information. They thought the disconnection points could be left out of the overview since it is not for everyone and described elsewhere. The disconnection points was left out of the updated version of the overview, and the level of detail reduced to make it easier to interpret.

09. Final Concept - MERS

This chapter is divided into three parts. Firstly the main idea of the concept is presented, followed by the procedure step by step. Secondly two raft unit concepts and their features are presented. Lastly some conclusions regarding the entire MERS concepts value for its stakeholders are presented.

Reading guide
The chapter provides a presentation of the final concept. The process of reaching this final result is described in the previous chapters.

Figure 111. The MERS concept. Here being presented as a single raft unit, a raft section and an overview of the full system.

9.1. MERS - Marine Evacuation & Recovery System

The final concept of this project is called MERS, short for Marine Evacuation and Recovery System. The system is based on a modular solution where small, liftable liferaft units are combined into a large system. By using this solution the perks from having a large system during evacuation is kept, while the flexibility in having small units during recovery is obtained.

The MERS system has three major advantages to other liferafts and MES solutions available on the market today; it is multifunctional, efficient and safe.

Multi-functionality

Its multi-functionality is expressed by the MERS system being both an evacuation and a recovery system, not just one of them as current systems.

Efficiency

The efficiency lies in being able to evacuate continuously. By allowing for up to 832 people to evacuate into one systems (with 26 units) within 30 minutes through two of the same chutes or slides used today.

At the same time recovery can be efficient for either a large system or in small scale with just one or a few units. Especially if there is room on the deck for one unit to be emptied while the next is being lifted, and a third is being prepared.

The testing done by SSRS in realistic conditions showed that up to one unit per five minutes can potentially be recovered (see 3.10 FIRST project). This would mean 384 persons per hour for just one ship of opportunity, and even if only half of that is reached it is still a tremendous improvement compared to today.

Safety

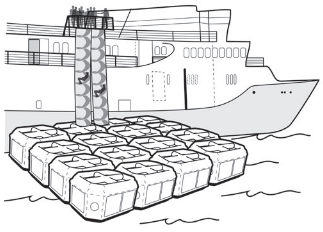
By providing a system that is used for the entire rescue operation, the hazardous task of moving people in distress between vessels on the water is eliminated.
By staying inside the liferaft the people are protected during the entire process.

Figure 112. Raft section of four units floating in the water.

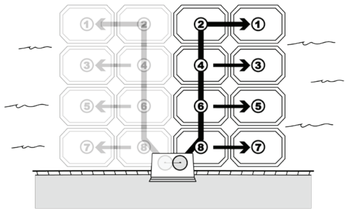
9.1.1. Evacuation & recovery procedure

The entire process of evacuating and recovering a MERS system will be gone through step by step here in order to clarify how the concept will work.

1. Launch system
This first step is performed by crew on the evacuating ship. The system is deployed by pulling a rope at the installation point on the ship. It takes two minutes for the system to inflate completely.

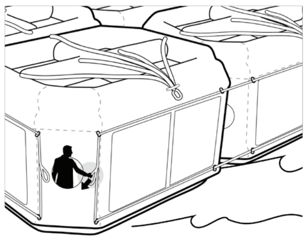


2. Evacuate passengers
Passengers are gathered at an assembly point, this step is to be finished within 30 minutes of its initiation according to regulation. After that the passengers are sent down evacuation chutes or slides, one person at a time, controlled by two crew members at the top of the chute, and two crew members at the bottom

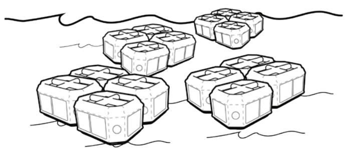


This step should also be finished within 30 minutes of its initiation according to regulation. When arrived in the raft system the passengers should proceed through the system to the raft furthest away that is not full. They will be guided by crew members placed out in the system, and by instructions in the rafts.

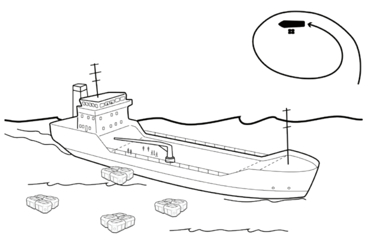
3. Disconnect into raft sections
When a raft section of four rafts is completely filled with passengers it should be disconnected and, if possible and necessary, towed away from the sinking ship. The disconnection is to be carried out by the assigned raft leader. It is done by pulling two release lines in one corner of the raft section.



4. Wait for ”ships of opportunity” or SAR groups
The raft sections of four rafts will stay together floating in sea until help arrives. During this time the passengers have a couple of functions in the raft to tend to, which are found in the provided manual. They include e.g. distributing seasickness pills, launching the drogue, and making sure the raft is kept dry inside.



5. Position ship for lift
When a ship that can lift raft units arrives, either a ship of opportunity or a SAR vessel, the ship will position itself close to the raft to prepare for lifting it. The best way to do this is making a big turn around the raft to flatten the sea, then placing the ship on the wind side of the raft to provide lee (this turn is developed and tested by SSRS and Stena Line). If there are two ships present one can provide lee while the other performs recovery.



6. Attach crane hook
The next step is to attach the crane hook to the connection point on the outside of one of the units in the raft section. This can be done in several ways, but recommended for now is to launch a fast rescue craft (FRC) from the ship to bring out the hook and attach it. The main alternative is to send a line connected to the cran-hook directly to the liferaft, and the raft leader can attach it. If an automated solution were developed in the future, it would be to prefer.

7. Lift the raft unit
When the crane is attached to the raft unit, it should start lifting it. The initiation of the lift will automatically disconnect the unit if it is still connected to others. The raft units should be lifted and put down on deck if possible (otherwise it will have to be lifted and emptied alongside the freeboard).

8. Empty the raft unit
When placed on deck, the raft should be emptied and the passengers should be brought to safety on board.

Repeat step 5 - 8.
The last steps should be repeated until all raft units are recovered. It can be done by one ship alone, or preferably by several if available. The more ships that are involved, the faster the operation will be competed.

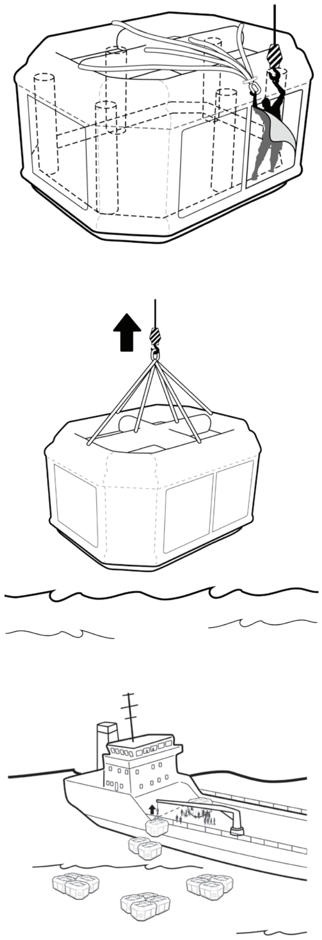


Figure 113. Illustrations of all the steps in the use process

9.2. Unit concepts

Here the two final concepts for the design of the raft units are presented in detail. The first concept called “Symmetric Unit” is the primary user focused solution, featuring the best performance the project developed. The second unit concept called “Budget Unit” is a budget solution that will be a lot cheaper, mainly due to changes in the inflated structure. It was created since price was an extremely important requirement from many of the stakeholders.

The final concepts are first presented as a whole followed by a brief explanation of how the various areas have been implemented:

- Symmetric unit overview
- Budget unit overview
- Size & configuration
- Construction
- Openings & passage between units
- Getting out of the water
- Lifting structure
- Crane connection
- Connection between units
- Colour coding & expression
- Signs, symbols, & instructions

This chapter provides short summaries of the motivation for how different features are designed. For a detailed description of the different aspects and how they were developed, see chapter 8. Concept Development - Synthesis.

9.2.1. Symmetric unit overview

The symmetric unit is what the project has concluded to be the best solution for a Marine Evacuation and Recovery System (MERS). It is adapted for manufacturing to make it economical up to the point where it fully meets all the requirements the research have shown a MERS should.

9.2.2. Budget unit overview

The budget unit does meet the requirements but in many areas substantial compromises have been made to make it more economical. It is meant to show how recovery can be included without costing much more than the currently used Marine Evacuation Systems (MES).

Figure 114. Structure and lifting lines of the symmetric and the budget unit. Note that the lines are also attached to the bottom of the symmetric units.

9.2.3. Size & configuration

Each liftable raft unit have capacity for 32 persons and should be combined into sections with four units, but can also be in sections of six.

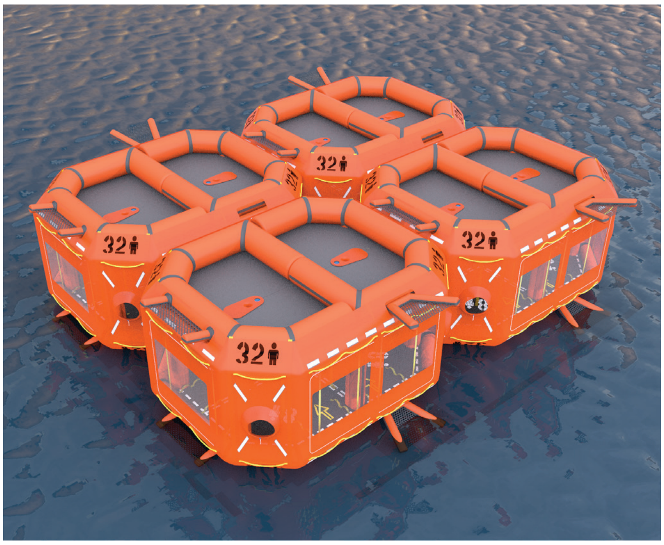


Figure 115. Section of four symmetric units

Figure 116. Each unit has a capacity for 32 people

The sections are combined into systems symmetrically placed around evacuation chutes or slides. Each system could consist of up to 26 units (maximum with two chutes) but a 16, 20, or 24 unit configuration is recommended.

The unit capacity is set to keep the total lifting weight lower than the four ton capacity of many cranes (see section 3.7 Cranes and winches) with substantial margin, partially due to possible water on the floor.

SOLAS regulation sets the average weight of each person to 75, 2 kg and additionally the water bags needs to contain 20 litres per person. Including the liferaft itself (about 300 kg for similar rafts) 32 person capacity means the total lifting weight will be approximately 3 350 kg.

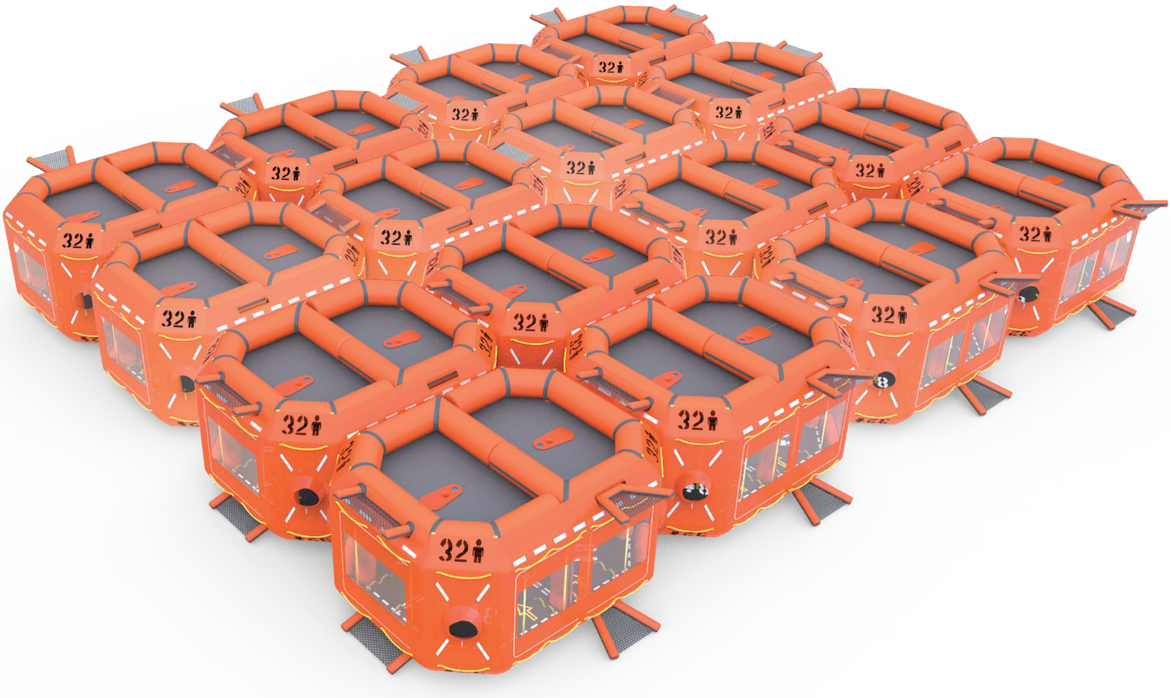


Figure 117. Top view of a system with 16 symmetric units

9.2.4. Construction

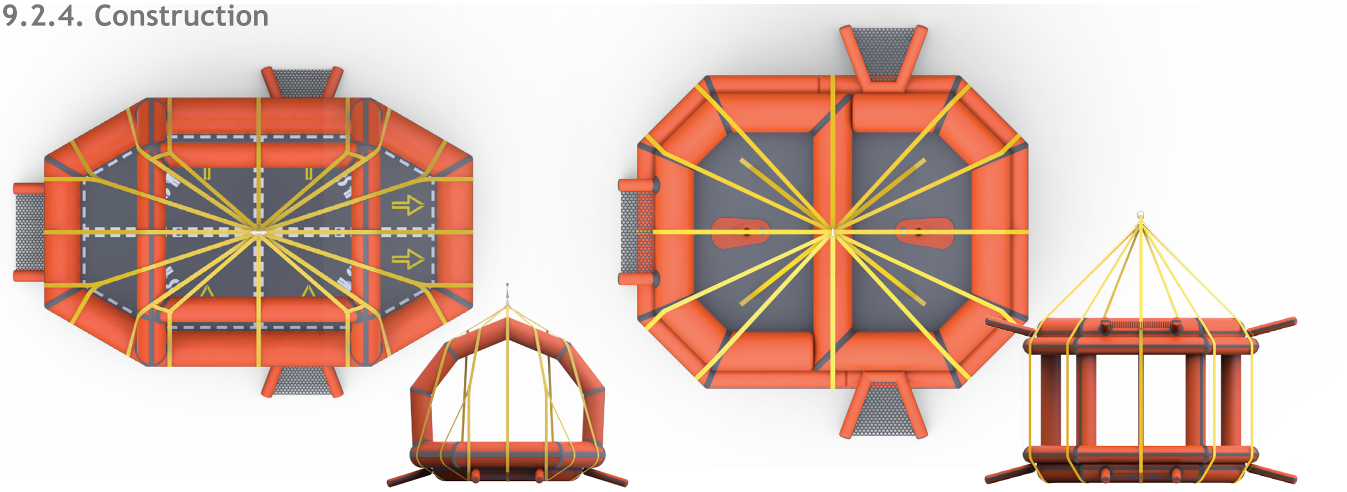


Figure 118. Structure of both the budget and the symmetric unit.

Buoyancy and air compartments

The base construction of both concepts consists of two air compartments. Their volume is each 2,7 m^3 to provide sufficient buoyancy even if one of the compartments is not inflated.

The symmetric unit is initially manufactured into four air compartments. Two inner compartment where the cylinders are 50 cm in diameter, and two with 30 cm diameter at an angle. One inner cylinder is connected with the smaller, outer on the opposite side. This way the entire raft floats without either compartment. By permanently combining the two cylinders into one compartment, maintenance cost can be reduced since fewer tests need to be made.

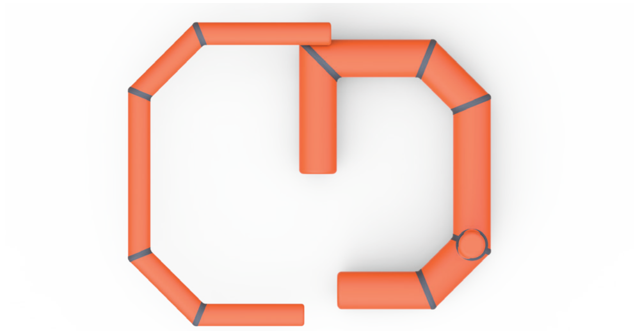


Figure 119. One isolated air compartment of the symmetric unit, seen from above

For the budget concept the inner and outer cylinder form one air compartment each. The outer compartment is 2,7 m^3 without including the top construction.

The cylinder crossing the middle of the units provides both needed buoyancy and supports the longest sections of the main buoyancy chambers, which could otherwise be most prone to bend during lifting.

The angle between the cylinders of the air compartments significantly improves the aero- and hydrodynamics, and if floating by themselves dragging is reduced. The main advantage is much easier towing, the raft will not tend to dig down since the water resistance creates forces upwards instead of down.

Base shape

The seating area is just over 11,9 m^2 based on regulations that require 0,372 m^2 per person. The shape is an oblong octagon, for the symmetrical unit all angles are 45° and for the budget unit 30° or 60°.

The octagonal shape provides:

- Simple and straight evacuation routes with the four crossings to other units (compared to six of a hexagon).
- Lifting stability with short cylinder sections, thus reducing risk of bending.
- Good aero- and hydrodynamic properties, which makes towing easier and reduces dragging.
- The angles enable higher air pressure (and thus strength) needed for lifting.
- High amount of area per circumference, which means less material and cost per passenger.

Pillars and top construction

The symmetric concept is fully vertically symmetric, as it functions upside down as well. There are six pillars with a diameter of 35 cm, which was deemed to provide sufficient rigidity without being excessive. The dimension is maximized for the main buoyancy cylinder setup. If a smaller diameter or fewer pillars are enough for stability there is no reason found in the research why it should not be changed.
The height inside the unit is 180 cm, which enables most people to walk upright or at least close to it.

9.2.5. Openings & passages between units

The step height in the symmetric concept is 13 cm, with 180 cm height inside the raft this means an opening height of 154 cm. Research suggests even a slightly smaller opening makes it substantially more difficult to pass through, but testing in realistic conditions is needed for this to be conclusive.

For the budget concept the step height is 25 cm based on stairway recommendations. The bigger step is acceptable since it is open above and the user does not need to crouch.

The openings on the long sides, that are part of the main evacuation routes, are 1100 mm wide. Narrow enough to enable the average sized woman (in a worldwide population) to reach both sides of the opening. But still wide enough to allow people to go past each other, or a child to walk next to a parent.

The short side openings are set to 750 mm, larger than the set minimum based on standard doors (700 mm).

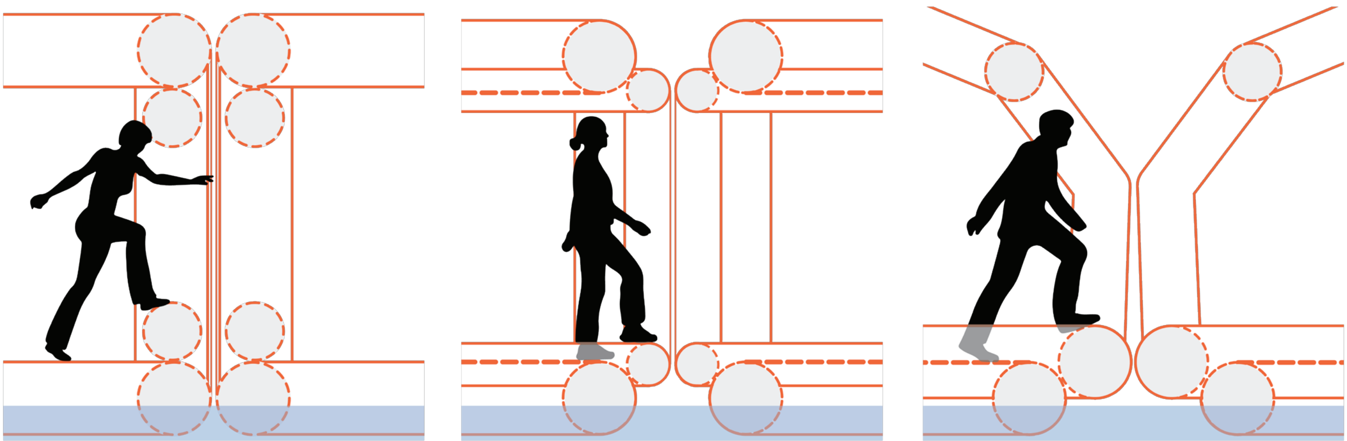


Figure 120. Cross section of passage between units for the current Marin Ark 2, symmetric concept, and budget concept

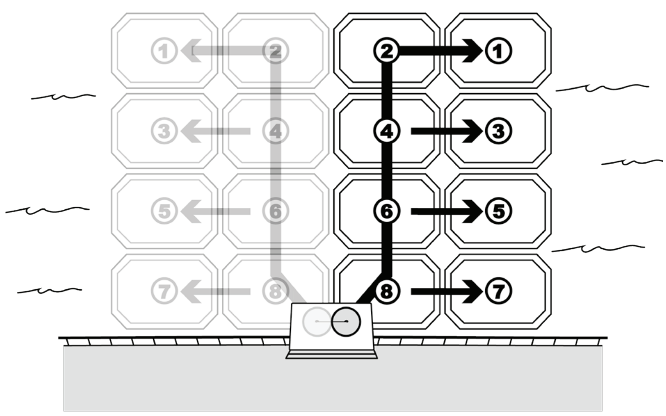


Figure 121. View through the corridors in a unit and top view illustration of the evacuation route

9.2.6. Getting out of the water

There are steps of rubber mesh at an 11° angle, making them almost a ramp, to enable getting up from the water placed in the stern and on one side of each unit. This means all sides of a system with 16 units will have these aids with a maximum gap of 7,1 m (the width of two symmetric units) between them. These can be inflated when the system is deployed due to the angle of cylinders in the base.

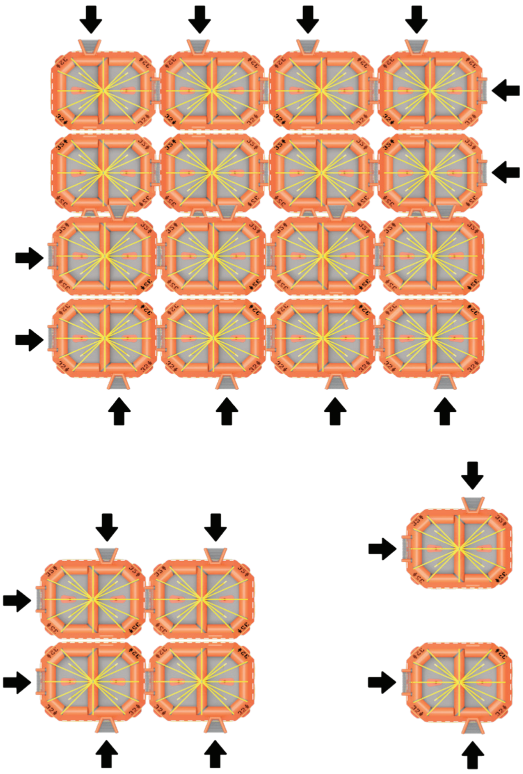


Figure 122. Black arrows indicating steps for getting up from the water into the liferafts, for a system, a section and two single units.

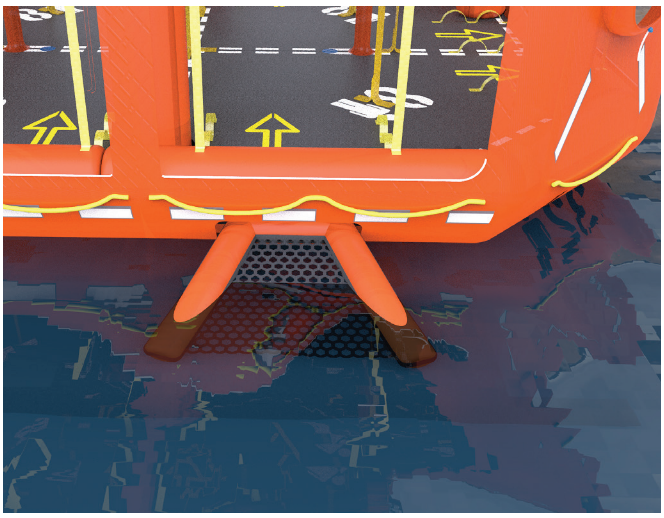


Figure 123. Ramp to help users get up from the water.

9.2.7. Lifting structure

The lifting lines are positioned to spread the forces over different parts of the unit construction. On the outside there are lines both in corners and the middle of long sections to minimize risk of cylinder sections bending. Inside the lines are positioned in the centre and along an ellipse to evenly spread forces over the floor. This is to prevent the floor from bending into a bowl that would be hazardous for the people in the unit.

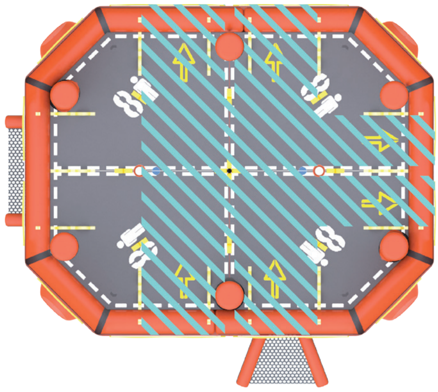


Figure 124. Illustration showing area of evacuation routes and where lines can be added

More lifting lines can be placed in the corners inside both units and as many as wanted on top of the symmetric. However, not inside in the area shape like a cross-centred in the raft since that would obstruct evacuation. The lines are positioned to allow people to easily pass and reach between them, the distances are the same as the opening widths.

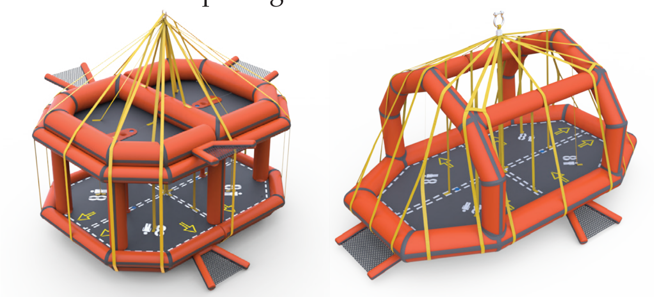


Figure 125. Perspective view of structure and lifting lines (the symmetric unit has lifting lines on the bottom as well)

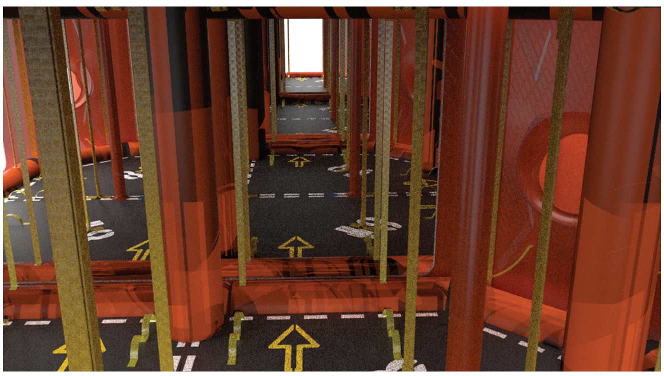


Figure 126. User view when entering a system of 16 units with the main evacuation route straight ahead.

9.2.8. Crane connection

On the budget units a 1,5 m sling connected to the lifting point is attached to the crane hook. This means the total lifting height will be approximately 4,5 m.

- For the symmetric concept a short sling is connected to a shackle on an extra strong lifting line in the middle of the long side.
- When the lift is initiated the shackle slides along the line, simultaneously the other lines that are attached in the middle of the line are lifted.
- The lines from the short side are attached to the shackle, centring it and thus making sure the forces are spread to all lifting lines.

On both concept the crane can be connected either by someone inside the raft or from a rescue craft on the outside.

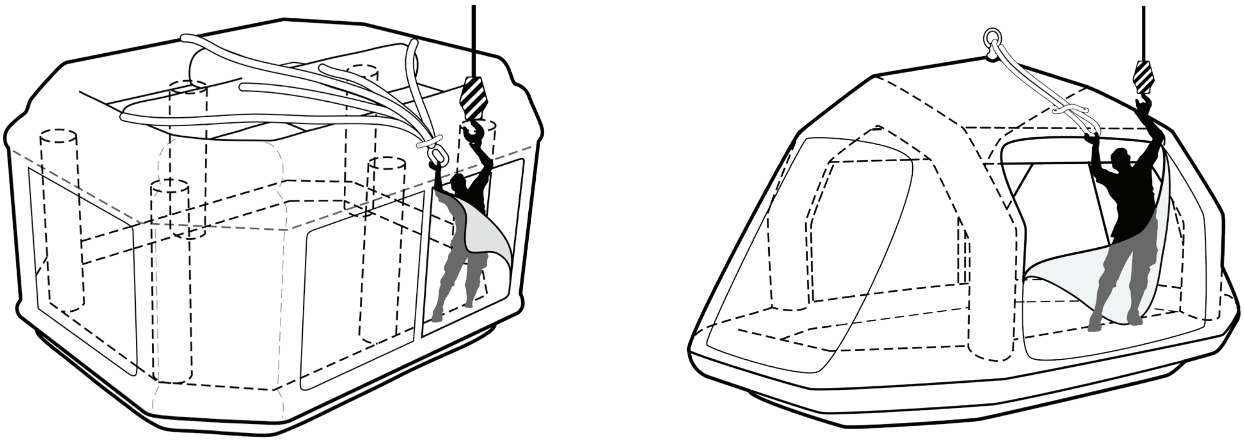


Figure 127. Illustrations of how to connect the crane hook for the concept units

Figure 128. SSRS personnel connecting the crane hook to a liferaft from Rescuerunners (Swedish Sea Rescue Society, 2012)

9.2.9. Connection between units

The units are connected with lines and quick release shackles. Release lines connected to the sprints of the shackles allows for the units to be disconnected easily.

There are lines positioned so that in the corners between raft sections of four units, by pulling a loop, one side is disconnected. This can be done from inside the unit through the ventilation openings or from a rescue craft alongside.

Release lines are also connected to the lifting point so that the units is disconnected from all others when lifting is initiated, but before there is tension in the lifting lines.

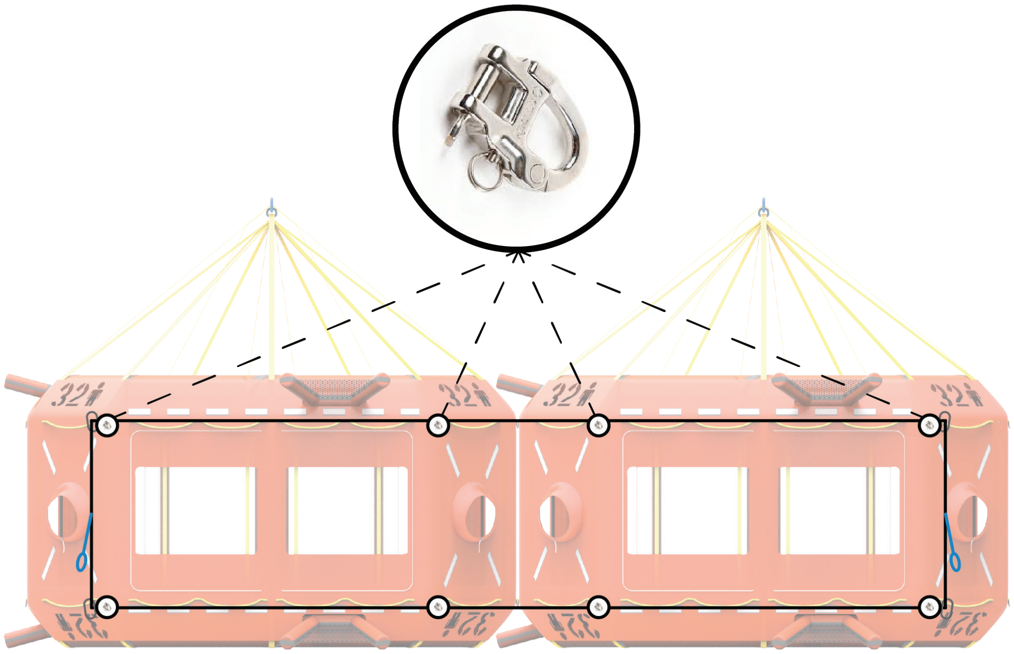


Figure 129. Shackles and release lines for manually disconnecting one side of a section of four raft units

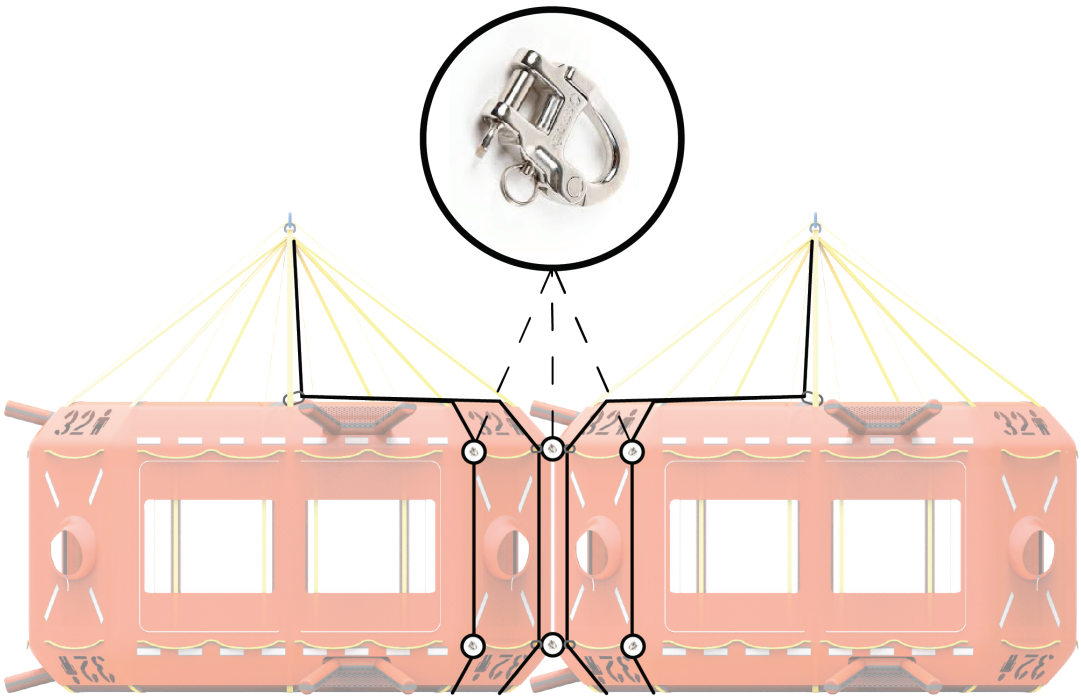


Figure 130. Shackles and release lines for automatic disconnection of a units when they are lifted

9.2.10. Colour coding & expression

The main parts of the liferaft are orange to provide good visibility at sea.

The floor is black to provide high contrast to graphics painted on it, and to avoid the slightly psychedelic effect produced by orange floors (as with the Marin Ark).

Connection lines are white because it is a common line colour and thus inexpensive, it also clearly sets them apart from other lines.

The lifting lines are yellow since it is a common colour for bands made for lifting. Since people are also to hold on to some of them the high visibility is another advantage.

Parts made specifically to provide support, such as rope ladders, are fluorescent yellow. This provides even more visibility, especially with weak lighting (night etc.), which is important since they need to be seen from the water. The colour is commonly used for these parts on other liferafts so standard products can often be used. The colour is also linked to the lifting lines but at the same time separated.

Interaction areas such as drains, crane connections etc. are blue.

Figure 131. Pictures showing the unit concept.

9.2.11. Signs, symbols & instructions

Clearly indicating evacuation routes, how many people are supposed to fit in each unit, and when it is filled to capacity is of great importance and is therefore painted on the floor (and inner roof for the symmetric unit). The evacuation routes are marked with large yellow arrows indicating direction. Each unit is divided into four areas bounded by a white dashed line. In the centre of each is a symbol showing that area is to be filled by eight people. The unit is split into smaller areas since it is very difficult to overview and count 32 people, especially inside a liferaft in a crisis. A group of eight is small enough to be one group (without subgroups) and large enough to contain for example an entire family.

Some important warnings and simple instructions are indicated by large symbols painted directly on the raft. More detailed information is printed on decals attached to canopy and pillars.

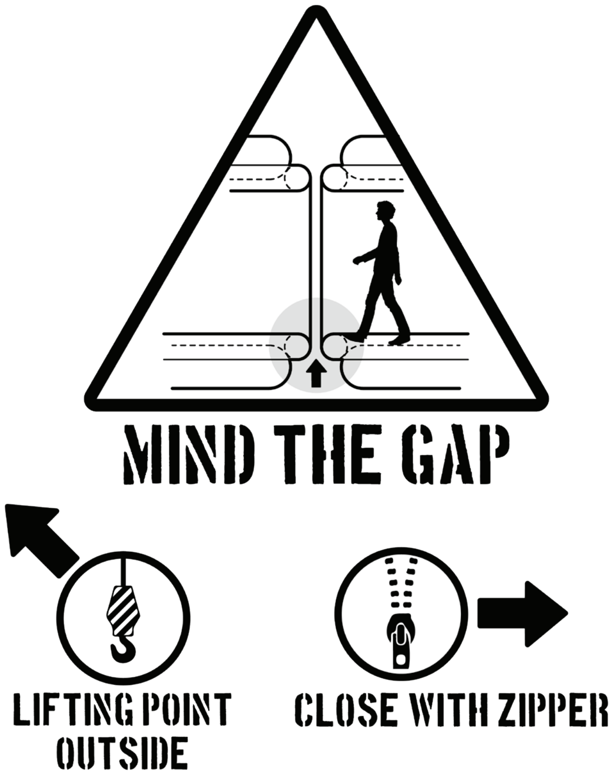


Figure 133. Selection of symbols inside the rafts

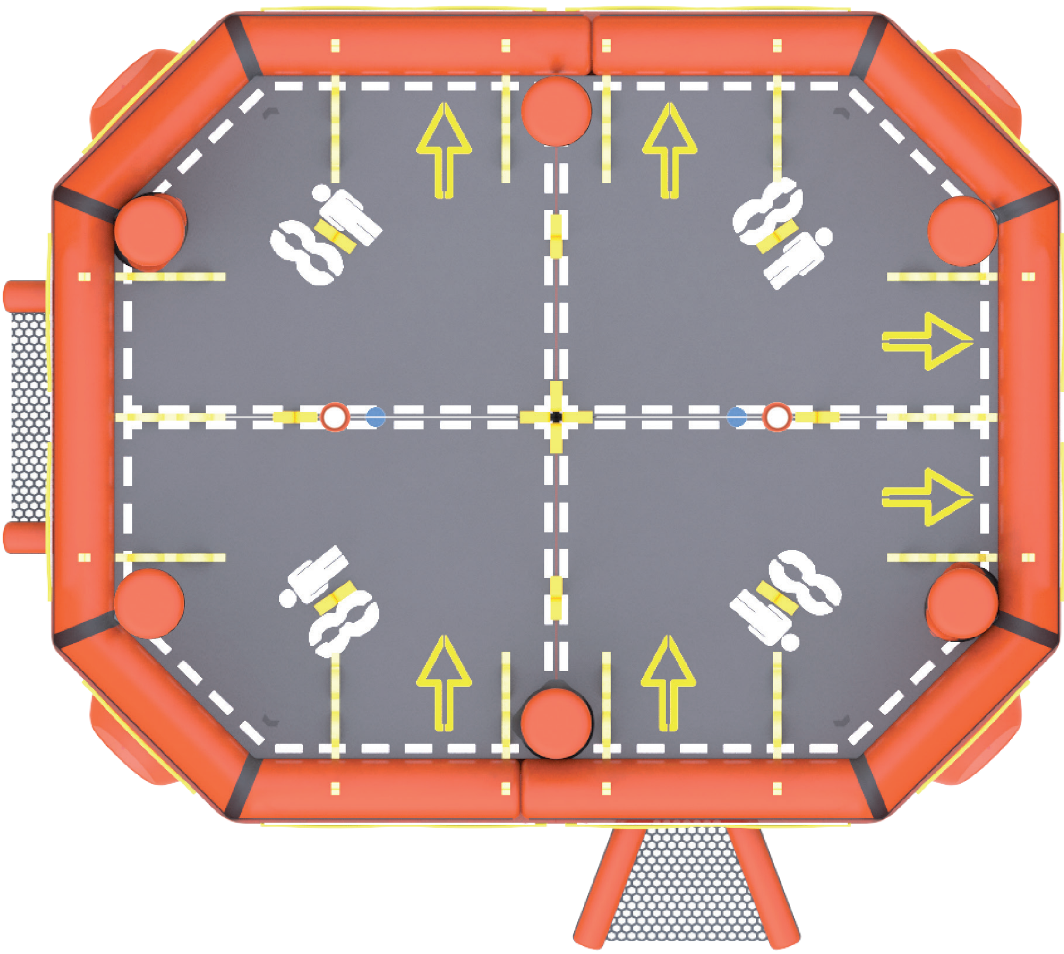


Figure 132. The floor graphics indicating escape route and capacity of areas in a unit

9.3. What the concept will do for stakeholders

Live up to passenger expectations

For passengers that need to be evacuated this MERS concept means that there will be a thought out procedure for the entire rescue process. When large passenger ships are evacuated today passengers often end having to climb up pilot ladders or being lifted one at a time by helicopters. The consequence is extremely slow and potentially dangerous rescue operations. These problematic solutions are not what an average passenger expects when an accident occurs. They expect to be taken care of properly, and brought to safety in reasonable time, which the MERS concept has a good potential of doing.

Facilitate for SAR personnel

A mass rescue operation is defined as a situation where the SAR resources are overwhelmed. It is not realistic to have sufficient SAR resources on standby to handle the amount of people many ships carry today. The popular MES systems of today are very difficult to handle from a SAR perspective due to their large size, their immobility and their bad suitability for helicopter operations. The Mass Evacuation and Recovery system in combination with cranes on ships of opportunity would mean they have tools that give them a chance of doing their job, keeping people safe.

Prevent disasters & protect reputation

For a passenger shipping company, a system that makes mass rescue operations more efficient and less dangerous would be a possibility for damage control if an accident occurs. Making sure an accident turns into a successful rescue operation, instead of a tragedy, should be of interest for any company that cares for their customers and brand value.

Give crews tools to handle situations they face

For a shipping company, a system like this would rather be a way to give their captains and crewmembers means to actually help when facing a scene of an accident. According to sea law, every ship in range needs to help if a distress call is sent (if it is possible without putting their own crew or ship at risk). But when they arrive they often stand powerless due to lack of proper equipment.

Save money for shipping companies

Being able to aid efficiently in mass rescue would also save shipping companies' a large amount of money. A freight ship can costs approximately 60 000 - 100 000 USD per hour it is off schedule. Having a ship in your fleet occupied by picking up survivors one at a time for several hours will thus cost the company huge sums.

10. Discussion

This chapter includes a number of areas regarding the project, discussed separately.

Reading guide
This final chapter should be read for getting the project groups view on the final result, the process and future recommendations.

10.1. Final concept - fulfilment of aim & goal

The final concept absolutely fulfil the criteria as "a scalable solution that enables all suitable ships to efficiently aid in mass rescue operations at sea, by recovering people in distress from survival crafts to safety on board". If everything works as intended, and if the solution actually fulfils the purpose of "decreasing the number of casualties in severe passenger ship accidents at sea", can only be answered when implemented, or after being a part in inspiring new regulation.

In our view the Marine Evacuation & Recovery System concept is much better than any existing products. It does fill a large part of the capability gap in the rescue process, because right now no acceptable solutions for recovery exist. So even if it is building on already used technology the innovation level is high. We believe the graphics alone are a major improvement.

That there are motivations for every part of the design is a strength, even if a lot still needs to be verified with manufacturers and through prototype testing. We have no major doubts about the symmetric concept. However we are sceptical about self-righting in general, and the issue is even greater with connected units as would be the case with the budget concept.

The concept as a whole is in many ways proven through the FIRST project. Furthermore the great feedback we have received from both shipping companies and SAR organisations shows that people believe in it, and so do we.

10.2. Answering the research questions

- Is it possible to utilize existing life rafts, possibly with minor adjustments, or is a completely new liferaft design necessary?
The conclusion was that a new life raft design is needed, even if the final concept turned out to be possible to use in combination with current rafts as re-liftable units[1].

- Can a solution work with existing cranes such as those for rescue boats?
Yes the research suggests it can, but it does require field-testing before a definitive answer can be given.

1 For an explanation of re-liftable units see chapter 5.2 Principle concepts.

- Is it possible to create a solution that works without the aid of rescue services and without anyone having to get into the water?
The final concept could potentially be used without aid, but that would not be anywhere near as efficient. Current projects at SSRS are trying to come up with a solution for this to work efficiently. Potentially the self-driving Rescuerunner that is being developed could be part of the answer.

- Can a new solution both improve the situation and fulfil the strict demands on cost and space efficiency of shipping companies, so that some are motivated to implement it without being forced by legislation?
Some companies such as Wallenius and Stena Line are very interested in implementing it without legislation change, but without exact specifications or price the answer is still not clear.

- Can this project together with FIRST inspire to new international legislation?
Time will tell, but convincing a manufacturer would have been a shortcut to this. The project was presented at the IMRF conference in Bremerhaven and hopefully things are in motion, but a change in legislation unfortunately seems to be far into the future.

- Can the project create a product or system that in a first stage could be implemented on a few ships of Swedish shipping companies?
As mentioned there is serious interest in the concept, but the project is not at a stage where a definitive answer can be given (first prototypes need to be built).

10.3. Limitations & focuses

Aiming for known solutions
For the project it was stated that an important attribute for the final concept was being realisable and reasonable. To achieve this, decisions throughout the entire project often fell on well-known, reliable solutions rather than testing new experimental ones that could raise questions about feasibility. If impressing with more novel solutions would have been a better way of reaching the goal and if good solutions have been missed due to this is very hard to say. What we do know is that the shipping companies, and the manufacturer, we have presented for so far have received the project very well.

Focus on ships in need of evacuation
When the project was initiated and explained by SSRS focus was on mass rescue operations where a large ship with many passengers was in need of evacuation. It was only in a late stage of the project that it became clear how much freight-shipping companies (e.g. Wallenius Marine AB) have to win from a concept like this. While not in need of the evacuation capabilities they are often involved as ”ships of opportunities”. Also the problems with sinking refugee ships in the Mediterranean has become even worse during the time the project was carried out, and had most likely been deemed more acute if the project started today.

If these insights had come earlier, these issues and stakeholders had been a higher priority. Maybe the problem should have been stated with freight companies as the main stakeholder. This would probably have affected the end result. But the real question is if the purpose of saving lives at sea would have been fulfilled to a greater extent? Either way meetings about sending a recovery system to the Mediterranean, for freight ships that have no need of more evacuation systems, are planned.

10.4. Methods, execution & process

Few user tests
Systematic and well-organized user testing of solutions with larger test groups were planned for but not carried out due to lack of time. We have been critical towards the fact that rescue and survival equipment is not tested in more realistic conditions. Unfortunately there was not sufficiently rough conditions to warrant new testing with existing products for us either during the time period of the project. Without a prototype it was thus not prioritised, but perhaps more testing should have been done since the absence makes the final concept in part open to questioning.

Lack of first-hand experience
It has been difficult to reach people who have been in this type of accidents since they are rare, especially in Sweden. Thus, the research has been forced to rely on secondary sources in many areas. Furthermore, people in different areas with extensive experience have been interviewed and observed. Observations of more novice users in non-training situations would have provided more reliability to the results. On the other hand the needs of lots of different stakeholders were studied through primary research and considered in the design, which adds reliability and might not have been possible if other studies had been conducted.

Early decisions & late research

Some of the early decisions taken as a result from early evaluations have changed during the project when more knowledge was acquired. This was due to the visit to the raft manufacturer ending up quite far down the road in the project. This was partly intentional since the group wanted to present concepts during the visit, but also a consequence of problems coordinating the trip. Since a raft manufacturer was not on board the project from the start, the strategy was to find one and catch their interest by presenting interesting and well thought through concepts. This became somewhat of a paradox during the project since good concepts was depending on knowledge of the manufacturing techniques.

The evaluation that had to take place before the Belfast visit was, because of this, lacking in reliability on some points. It could perhaps have been compensated by more extensive research, but the group prioritized getting the project further before performing flawless evaluations, and deemed the assumptions made reasonable and sufficient for the evaluation purpose. When now looking back at those assumptions, they were mostly correct, and the changes made later on were not extensive. Neither was it in our view a problem for the project process or the quality of the end result.

High amount of iterations

Since the project goal was to create a highly realisable final concept, the strategy at several stages in the process has been to settle for a solution that is good enough early, to be able to take that solution further, rather than finding the best solution ever possible. This strategy resulted in time for a high amount of iterations and refinements of selected solutions, which in our opinion is great from the aspect of this projects (as well as SSRS and FIRST's) long-term goal.

10.5. Sustainability

The assumption that the prioritised aspects are among the most important regarding sustainability could be questioned considering no life cycle analysis or similar were conducted. It was still deemed to be excessive with any such evaluations since problematic areas were already known and it would be more effective to focus on working with those aspects.

It could be argued that trying to save more lives in itself is working with social aspects of sustainability. Especially by also focusing on refugees and not only the western markets.

10.6. Accessibility

Is the final concept an inclusive design? On one hand it could be argued that more extensive studies on the effect of disabilities in this context should have been conducted. For example while physical effects of cold water is similar to many disabilities, what is the effect with both? Perhaps testing with these user groups should also have been done. On the other hand it is inclusive since focus have been on several aspects that are not serious issues for fully functional people, such as passing between units. By making it easier for everyone it also helps make it possible for more people. The accessibility aspect have however not been studied separately. Elderly, children, people with disabilities, basically anyone with difficulty to go through the chute are supposed to be sorted out at the assembly point for evacuation with lifeboats instead, and since the evacuation system was not to be changed it has been considered somewhat out of the scope.

10.7. Further recommendations

Conduct validating user tests

The one most important recommendation for future work with the project is to conduct validating user tests for several of the part solutions. If this should be done by testing one part at a time with a partial mock-up, or if a full scale mock-up for testing part and overall function is difficult to say. This type of testing is however needed to confirm the concepts quality and usability.

Prototype and test in realistic conditions

The next step would be building a prototype to test in realistic circumstances on sea, also with real users further on. This is also a very important step since the use context is rather special, and the need for testing the reliability of a safety product is extensive.

Adapt to manufacturing

The last recommendation for this specific concept would be to make it production ready in close collaboration with a manufacturer, since they will have a more detailed knowledge on manufacturing optimization.

Adapt to changes on market

Since a new type of survival craft, such as the VIKING LifeCraft, which is a hybrid between liferaft and lifeboat, is about to be introduced the market change needs to be analysed. Maybe the concept should be inspired by this solution and try to include propulsion? Maybe it should try to distance itself from it to become a clearer other alternative?

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Unknown (2015) *Pat on the back* [Photograph] Available at: *https://s-media-cache-ak0.pinimg.com/236x/f6/e9/42/f6e9428966fcc479c795c3232116b514.jpg* (Accessed on 2015-02-19)

AwesomePlacesOnEarth (2013) *General Sherman Looking Up* [Photograph] Available at: *http://awesomeplacesonearth.com/sequoia-national-park-california/* (Accessed on 2015-02-19)

Unknown (2015) *Square reef knot photo* [Photograph] Available at: *http://pixshark.com/rope-knots.htm* (Accessed on 2015-02-19)

Unknown (2015) *Compass direct* [Photograph] Available at: *http://imgarcade.com/1/true-north-compass/* (Accessed on 2015-02-19)

Fig . 63 - Falkman, F. (2014) *Mass rescue* [photograph] Powerpoint Presentation, Swedish Sea Rescue Society, Gothenburg, October 2014.

Fig . 75 - VIKING LIFE-SAVING EQUIPMENT (2006) *VIKING Liferaft, means of rescue, 12 persons, MOR* [Photograph] Available at: *http://www.viking-life.com/viking.nsf/public/products-fetchtradeingitemdata.html?opendocument&product=L012MOR0* (Accessed on 2015-03-05)

Fig . 77 - Unknown (2008) *Chute evacuation* [Film still] Ottawa, Canada

Fig . 78 - CruiseDotCo (2012) *MSC – Marine Evacuation Systems* [Film still] Available at: *https://www.youtube.com/watch?v=hujElVB5MKo* (Accessed on 2015-03-18)

Fig . 84 - PLATYPUS GROUP (2015) *Jason's cradle* [Photograph] Available at: *http://www.platatac.com/jason-s-cradle.html* (Accessed on 2015-03-05)

Fig . 89 - VIKING LIFE-SAVING EQUIPMENT (2006) *VIKING Liferaft, davit launchable (self-righting), 25 Persons, type DKFS* [Photograph] Available at: *http://www.viking-life.com/viking.nsf/public/products-fetchtradeingitemdata.html?opendocument&product=L025DFS0* (Accessed on 2015-03-05)

Fig . 96 - ELEBIA AUTOHOOKS, S.L.U. (2015) *elebia®, the crane hook of the future* [Photograph] Available at: *http://elebia.com/* (Accessed on 2015-04-08)

Fig . 128 - Swedish Sea Rescue Society (2012) *Rescuerunners connecting crane hook* [Photograph] Available at: *http://www.first-rescue.org/favorite-photos-and-videos.html* (Accessed on 2015-03-05)

Appendix I - VIII

This chapter includes a number of areas regarding the project, discussed separately.

Reading guide
This final chapter should be read for getting the project groups view on the final result, the process and future recommendations.

Appendix I. Stakeholder Analysis
Appendix II. HCA
Appendix III. Scenario Details
Appendix IV. Mid Concept Features & Evaluation
Appendix V. Base Shape Evaluation
Appendix VI. Top Structure Evaluation
Appendix VII. Early illustration versions

Appendix I. Stakeholder Analysis

Examples of the needs and expectations of stakeholders, an analysis made early in the project.

Passengers

Needs
- Weather protection
- Safety
- Comfort
- Clear information

Expectations
- Expects that in an emergency shipping companies, in combination with SAR resources, have made adequate preparations and that the rescue process is handled in a competent way.

Crew

Needs
- Weather protection
- Safety
- Minimum time and focus required to launch liferafts
- Confidence in and ability to effectively perform evacuation procedures
- Information / Communication

Expectations
- Working equipment
- Reasonable workload and responsibility

Family to people in distress

Needs
- Information

Expectations
- Same as passengers

SAR

SSRS (in other countries coast guard, navy)
Helicopter crew (pilot, winchman, rescue man)

Needs
- Safety (no parts to get injured on, possible to perform tasks without increased exposure)
- Sufficient input to make informed decisions
- Sufficient aids / equipment for them to perform their task (rescue and evacuate)
- Easy to locate liferaft (High visibility, radar reflector? location beacon?)
- Possibility to identify liferaft (and if it there is people in it)
- Easy to move people in / out of life raft (including unconscious / injured)

Small vessel operators:
- Clearly marked and easily accessible interaction areas
  - Towing points
  - Lifting points
  - Parts to separate
- Minimum obstacles in the water (ropes etc)

Helicopter crew:
- Accessibility to liferaft (sufficient opening / surface to recover person in distress)

Expectations
- Working SAR equipment (their own)
- Clear chain of command

Survival Craft Manufacturers

For example Survitec, Zodiak, RFD, VIKING, and LSAA

Needs
- Possibility to sell the life rafts
  - Low cost
  - Fulfilling regulation
  - Selling points
- Predictable behaviour of materials / components
- Possibility to test

Expectations
- Equipment used and maintained as described
- No risk of legal accountability

Liferaft maintenance

Needs
- Clear as well as consistent procedures and instructions
- Clearly marked units
- Ability to note / see what maintenance has been done and when

Shipping companies

Passenger, freight, fishing

Needs
- Low investment cost
- Low maintenance cost
- Minimum staff required (with minimum training)
- Clear that regulations are fulfilled
- Minimum space usage
- Reliable equipment

Maritime Rescue Co-ordination Centre (MRCC)

Sjöfartsverket

Needs

- Knowledge of what equipment is available
- Information on progress of rescue operation

On-scene Coordinator

Needs

- Knowledge of what equipment is available
- Information on progress of rescue operation

International Maritime Organization

Needs

- Possible to set clear regulation
- Easy to evaluate if regulations are met

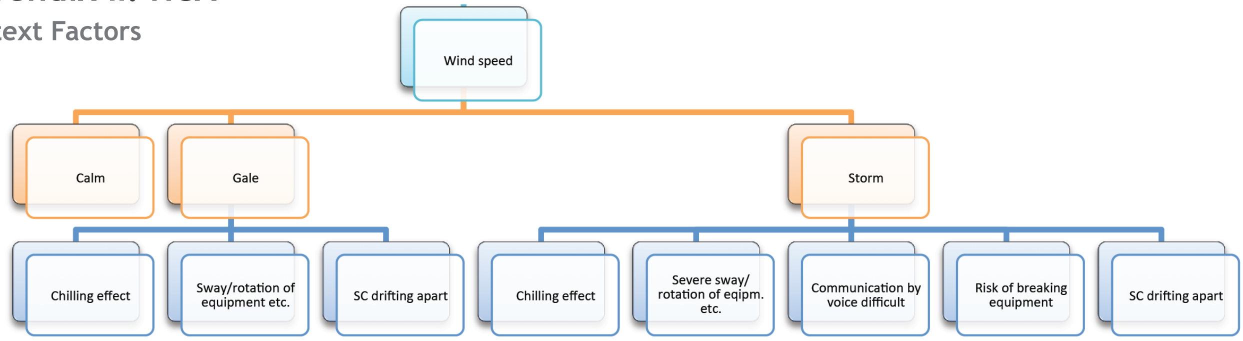
IMRF

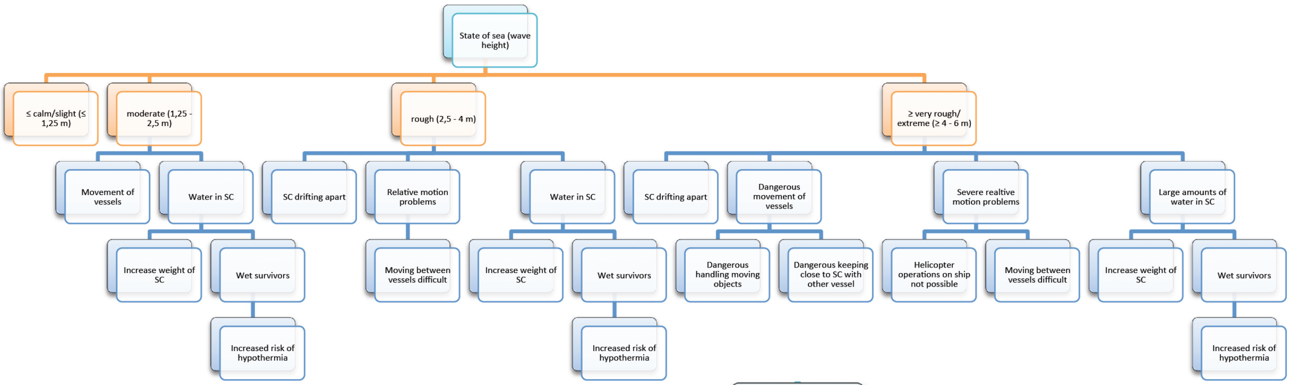
Needs

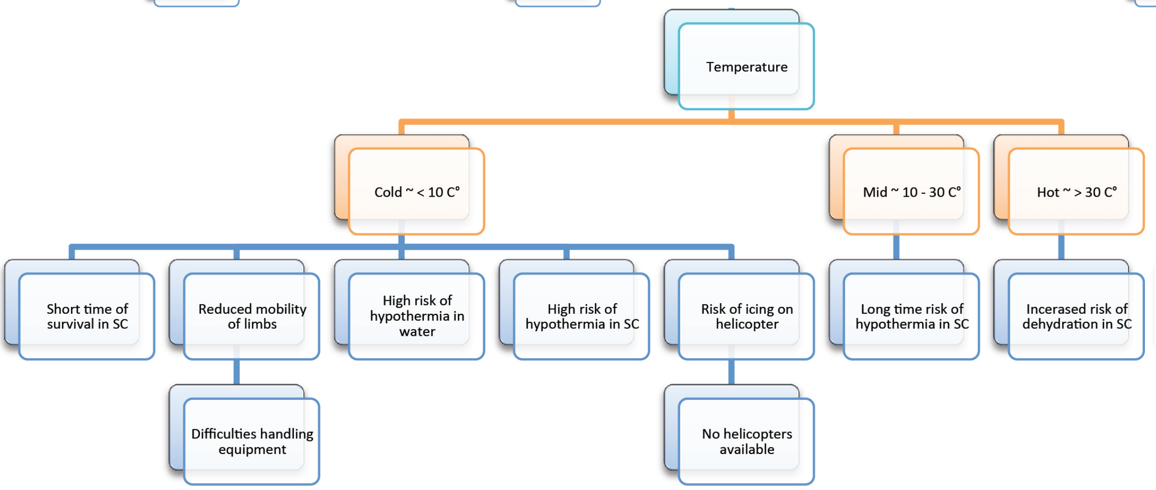
- Information to further develop marine SAR

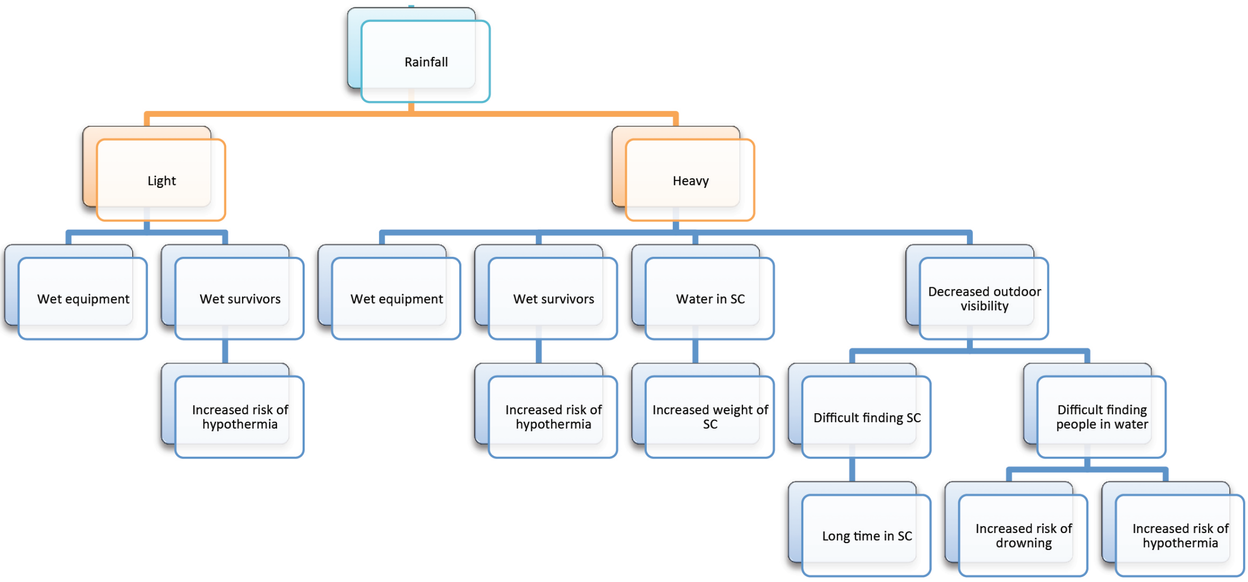
Appendix II. HCA

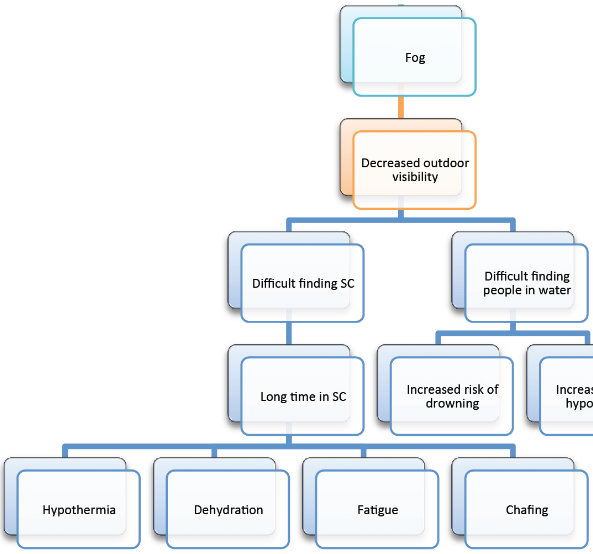
Context Factors

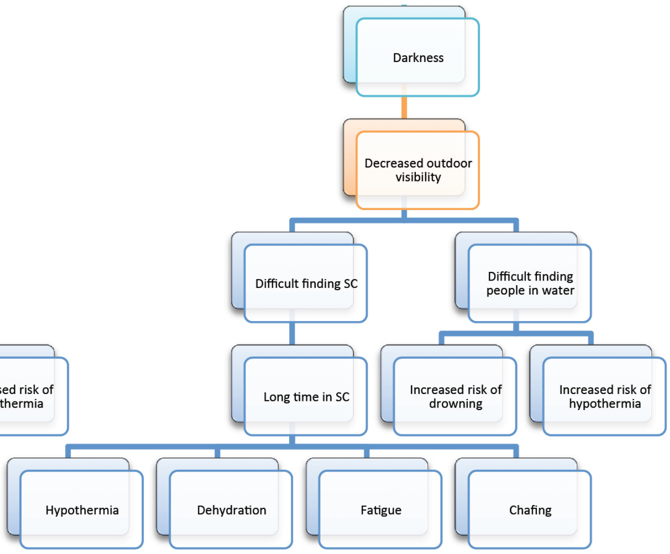


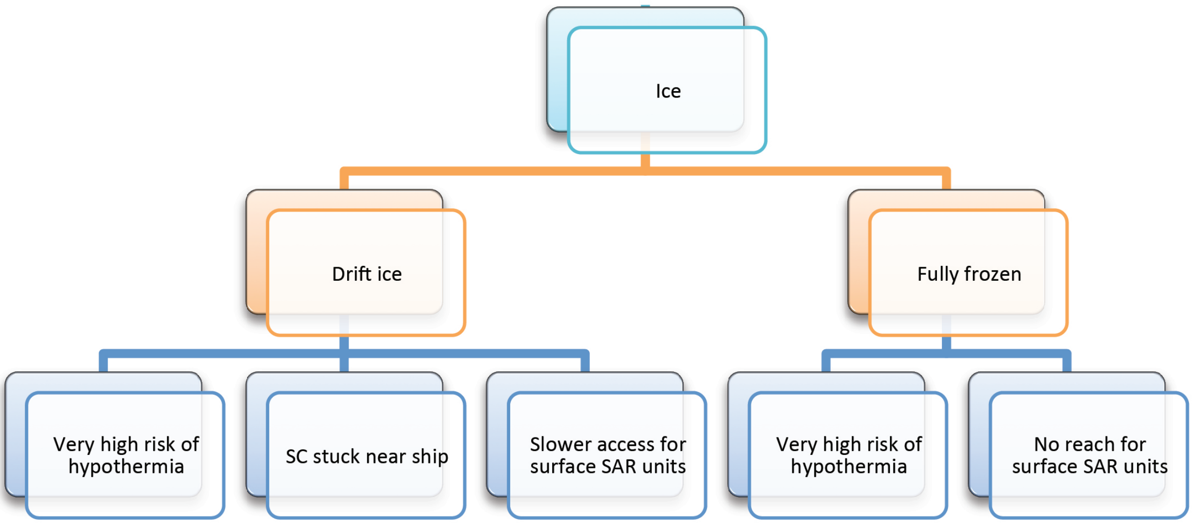


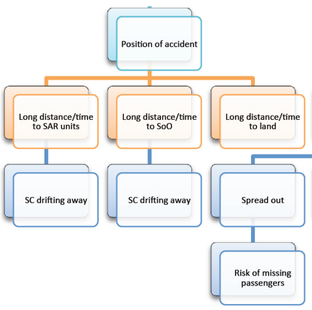


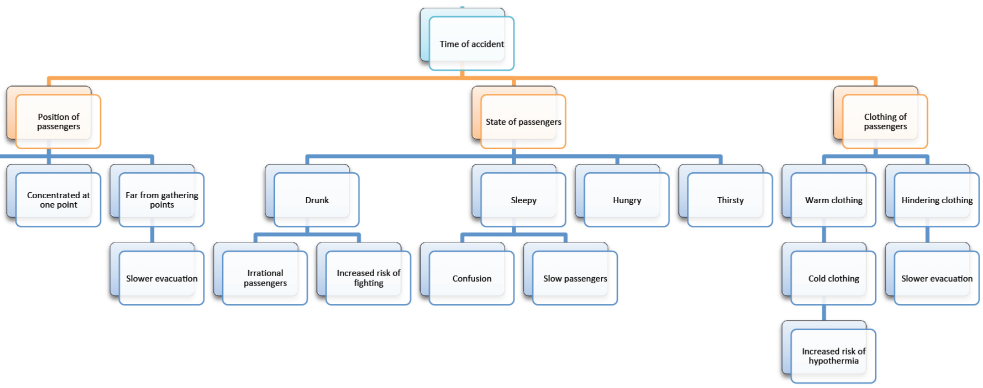



Fog
Decreased outdoor visibility
Difficult finding SC
Difficult finding people in water
Long time in SC
Increased risk of drowning
Increased risk of hypothermia
Hypothermia
Dehydration
Fatigue
Chafing


Darkness
Decreased outdoor visibility
Difficult finding SC
Difficult finding people in water
Long time in SC
Increased risk of drowning
Increased risk of hypothermia
Hypothermia
Dehydration
Fatigue
Chafing

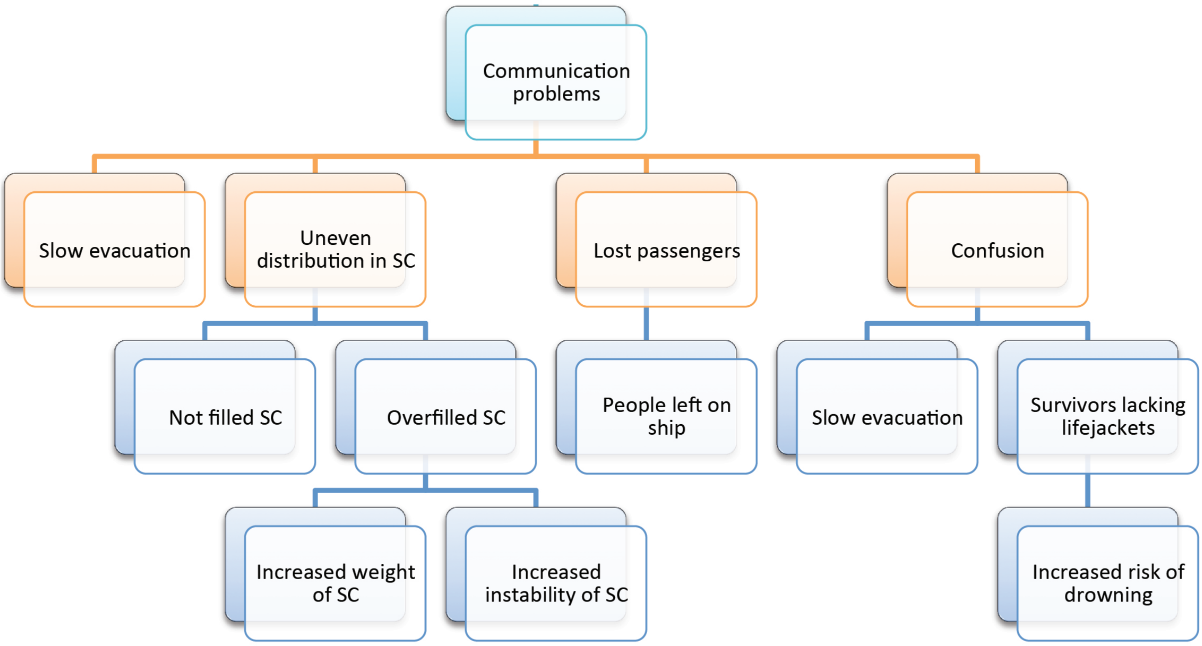

Ice
Drift ice
Fully frozen
Very high risk of hypothermia
SC stuck near ship
Slower access for surface SAR units
Very high risk of hypothermia
No reach for surface SAR units

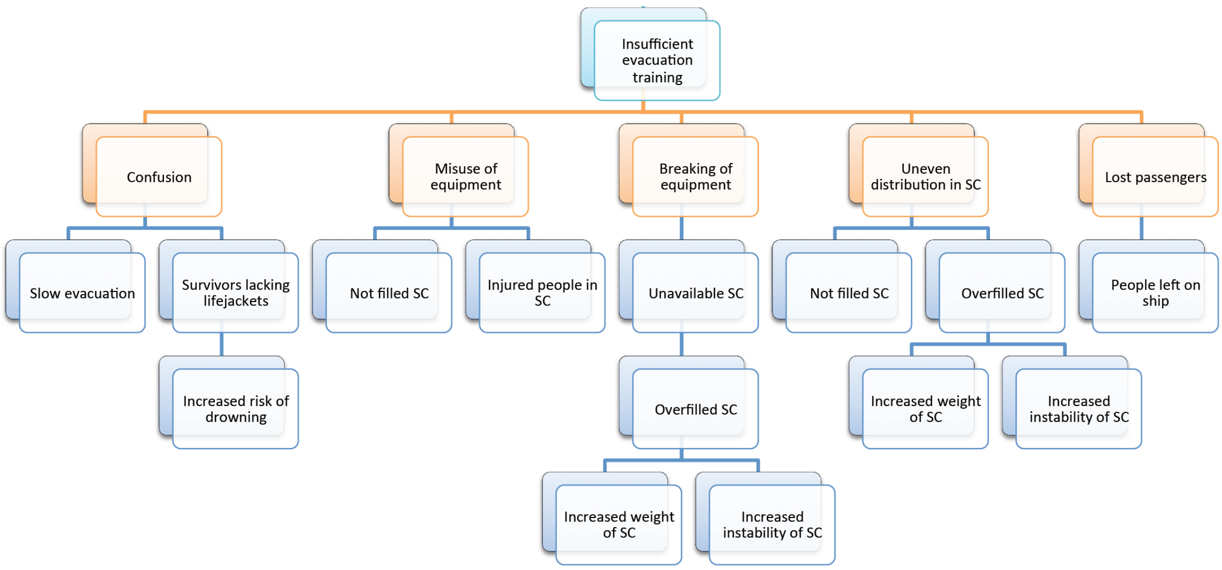

Position of accident
Long distance/time to SAR units
Long distance/time to SoO
Long distance/time to land
SC drifting away
SC drifting away
Spread out
Risk of missing passengers

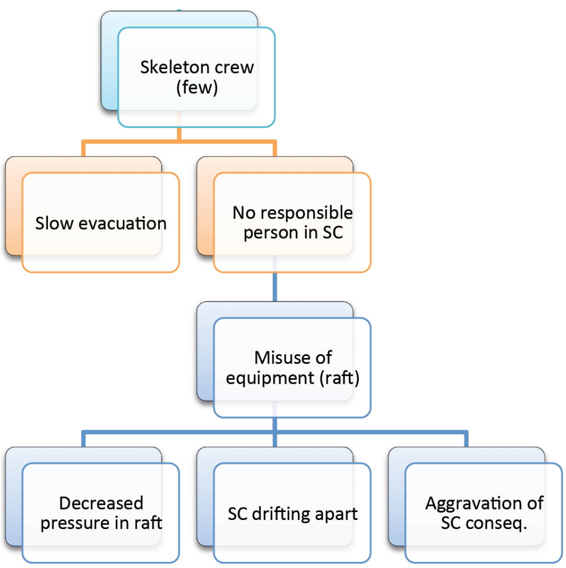

Time of accident
Position of passengers
State of passengers
Clothing of passengers
Concentrated at one point
Far from gathering points
Slower evacuation
Drunk
Irrational passengers
Increased risk of fighting
Sleepy
Confusion
Slow passengers
Hungry
Thirsty
Warm clothing
Cold clothing
Increased risk of hypothermia
Hindering clothing
Slower evacuation

Appendix II

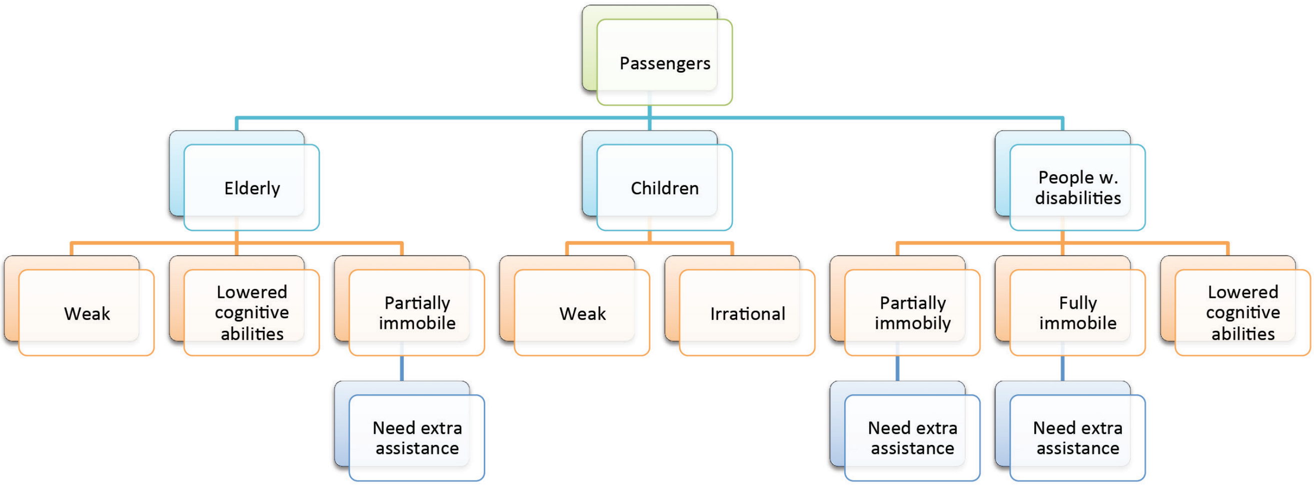
Crew


Communication problems
Slow evacuation
Uneven distribution in SC
Lost passengers
Confusion
Not filled SC
Overfilled SC
People left on ship
Slow evacuation
Survivors lacking lifejackets
Increased weight of SC
Increased instability of SC
Increased risk of drowning

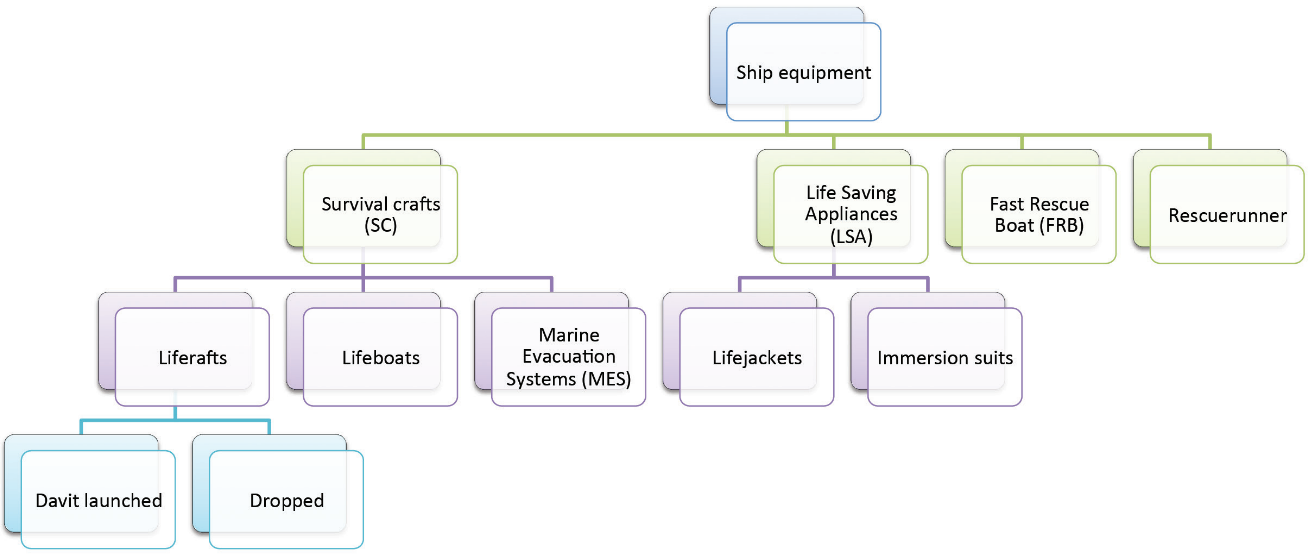

Insufficient evacuation training
Confusion
Misuse of equipment
Breaking of equipment
Uneven distribution in SC
Lost passengers
Slow evacuation
Survivors lacking lifejackets
Not filled SC
Injured people in SC
Unavailable SC
Not filled SC
Overfilled SC
People left on ship
Increased risk of drowning
Overfilled SC
Increased weight of SC
Increased instability of SC
Increased weight of SC
Increased instability of SC


Skeleton crew (few)
Slow evacuation
No responsible person in SC
Misuse of equipment (raft)
Decreased pressure in raft
SC drifting apart
Aggravation of SC conseq.

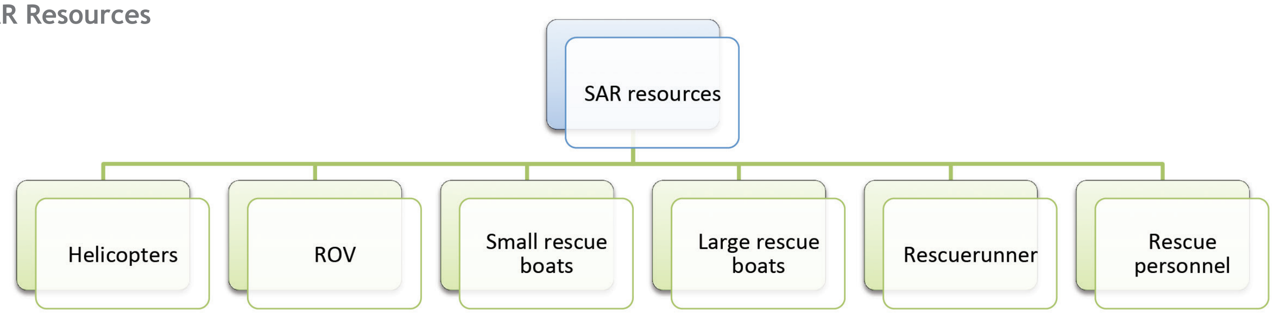
Passengers



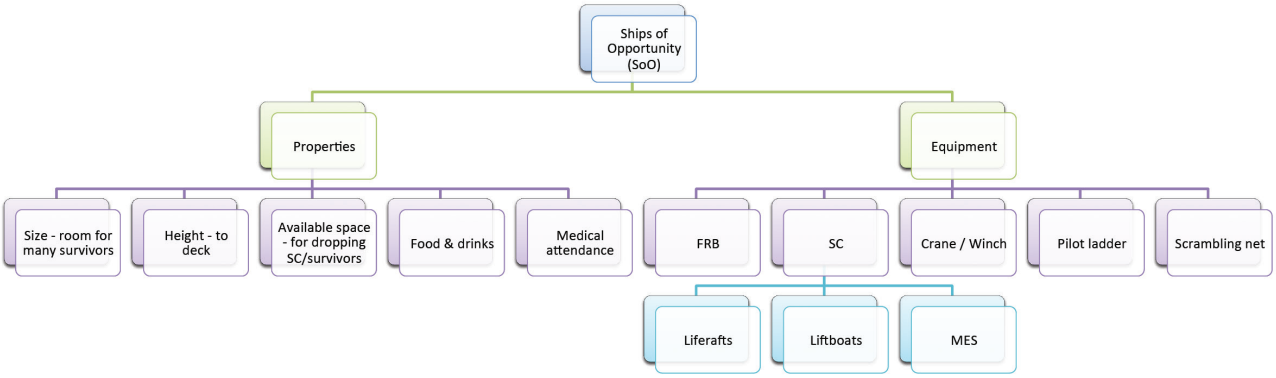
Ship Equipment



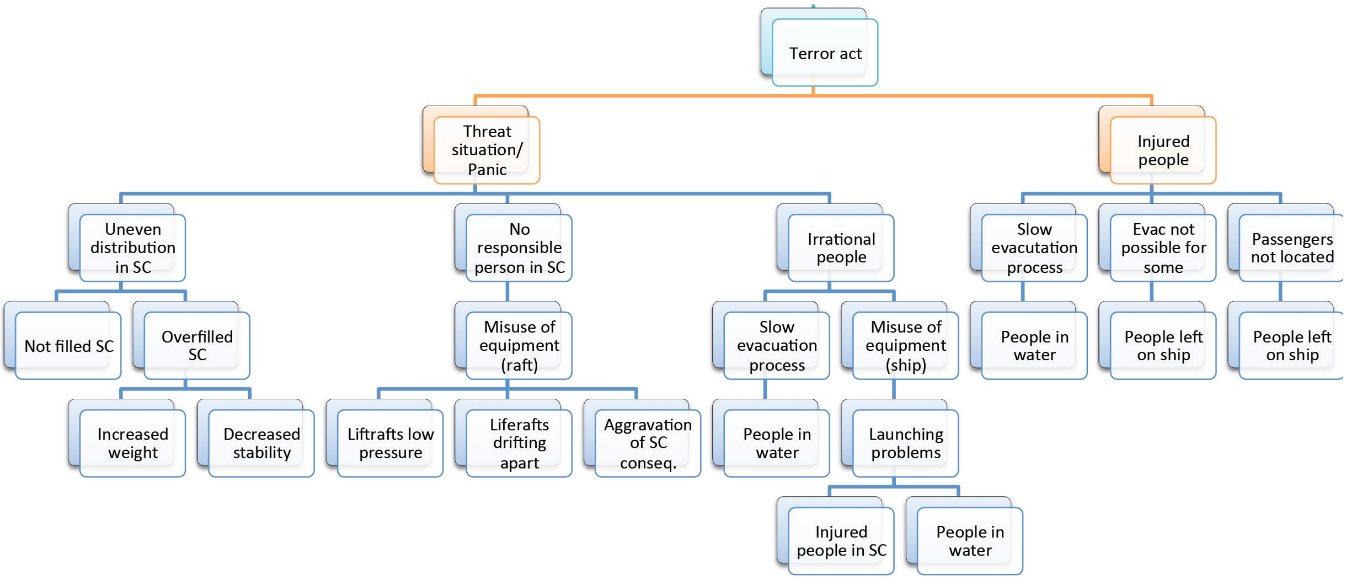
SAR Resources

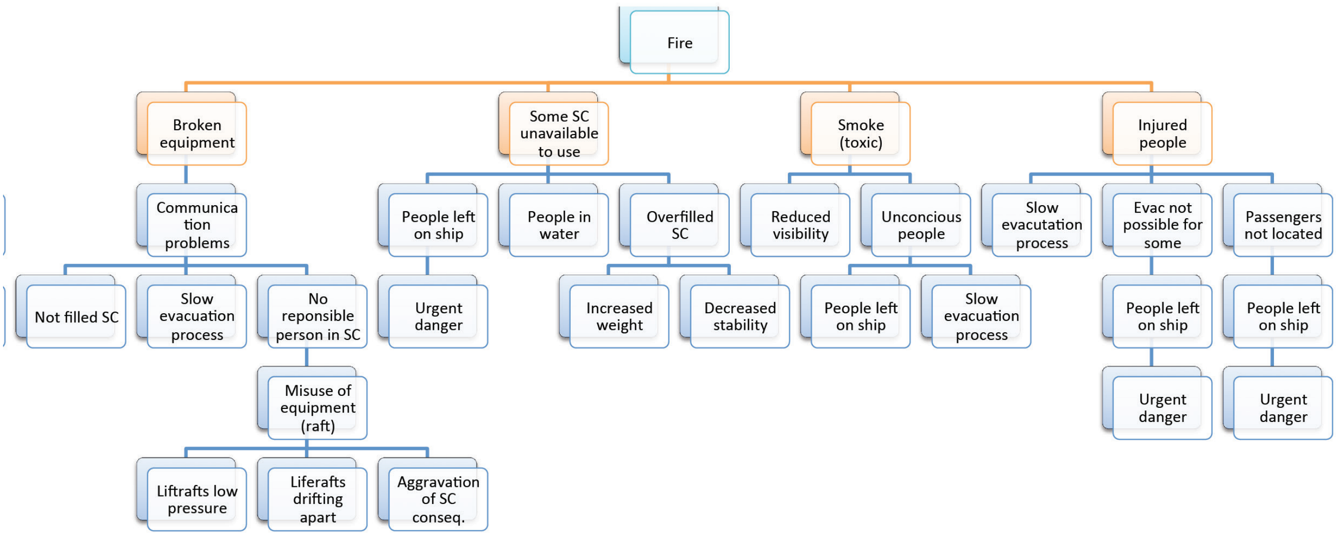


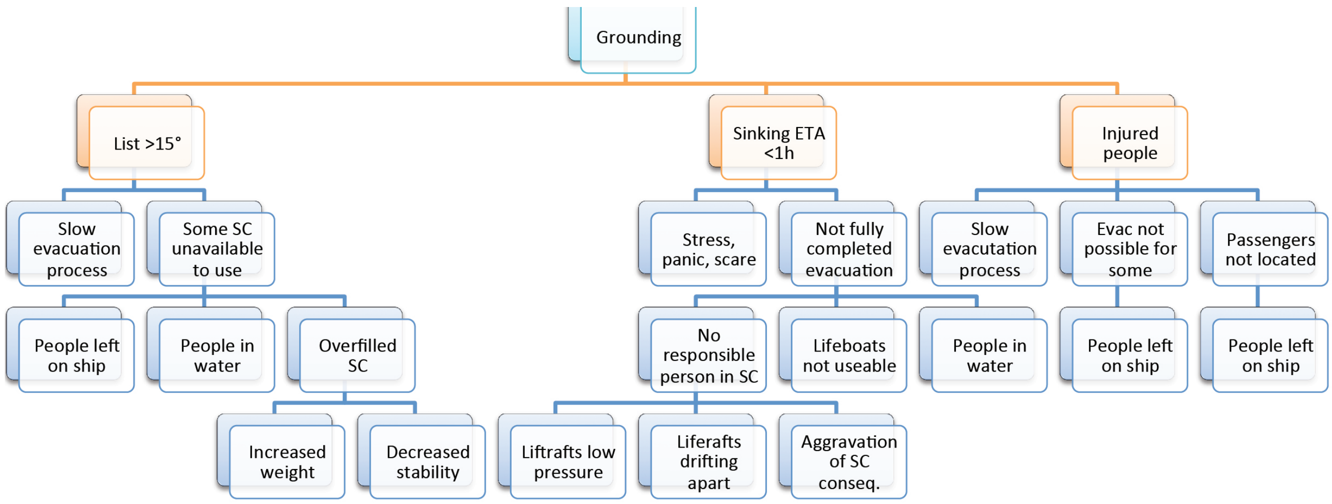
Ships of Opportunity

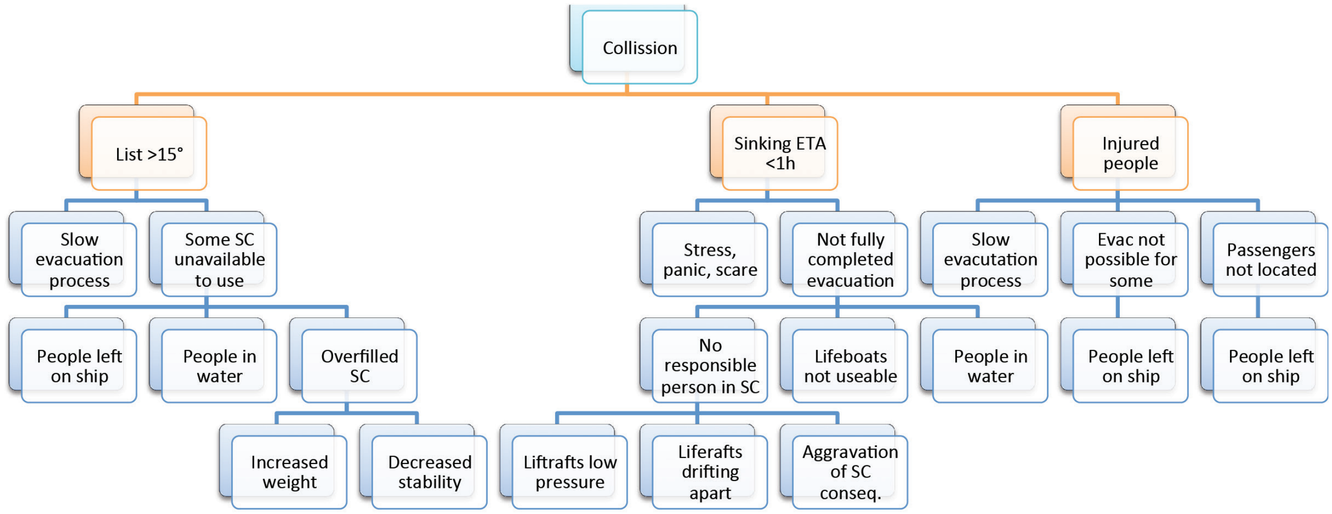


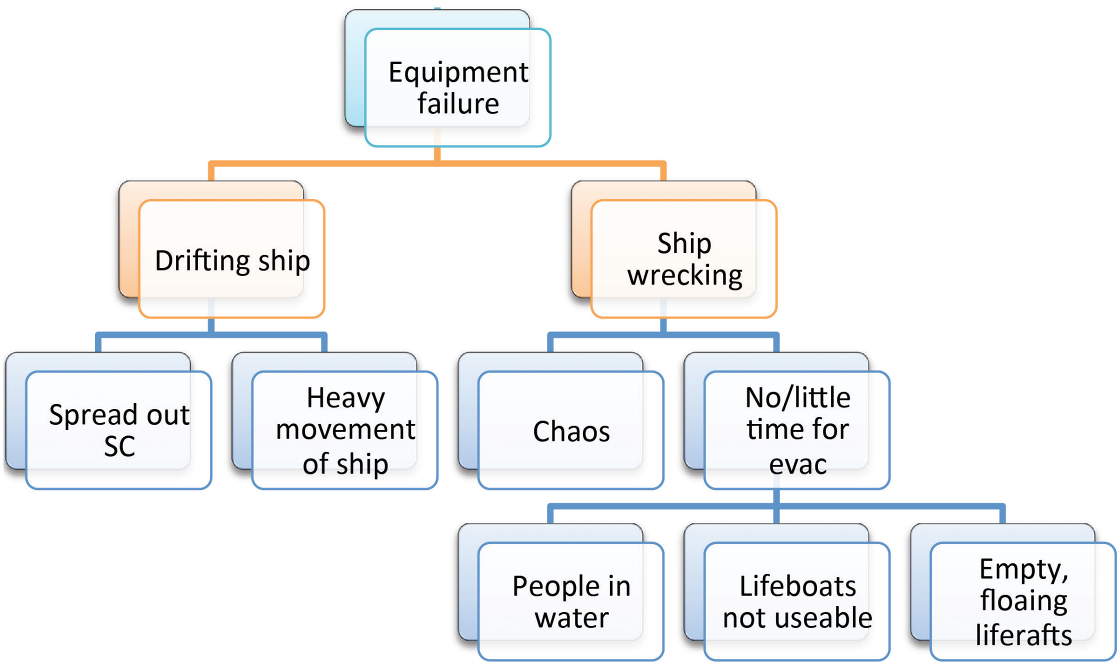
Type of Accident






Grounding
List >15°
Sinking ETA <1h
Injured people
Slow evacuation process
Some SC unavailable to use
Stress, panic, scare
Not fully completed evacuation
Slow evacutation process
Evac not possible for some
Passengers not located
People left on ship
People in water
Overfilled SC
No responsible person in SC
Lifeboats not useable
People in water
People left on ship
People left on ship
Increased weight
Decreased stability
Liftrafts low pressure
Liferafts drifting apart
Aggravation of SC conseq.


Collission
List >15°
Sinking ETA <1h
Injured people
Slow evacuation process
Some SC unavailable to use
Stress, panic, scare
Not fully completed evacuation
Slow evacutation process
Evac not possible for some
Passengers not located
People left on ship
People in water
Overfilled SC
No responsible person in SC
Lifeboats not useable
People in water
People left on ship
People left on ship
Increased weight
Decreased stability
Liftrafts low pressure
Liferafts drifting apart
Aggravation of SC conseq.


Equipment failure
Drifting ship
Ship wrecking
Spread out SC
Heavy movement of ship
Chaos
No/little time for evac
People in water
Lifeboats not useable
Empty, floaing liferafts

Appendix III. Scenario Details

Indirect source
Made up
Changed

Name	Estonia Today	Norman Atlantic evacuated	Costa concordia off-shore	High traffic area collision	Refugee ship	Concordia
Type	Faulty equipment	Fire	Grounding	Collision	Faulty equipment	Overwealmed by sea
						Capzise (90° immidietly)
Conditions	Severe	Moderate	Easy	Extreme	Moderate	Moderate
Temp (°C)	10	12	20	3	15	5
Sea state	Very rough	Moderate	Calm	Rough	Moderate	Moderate
Waves (m)	4,0 - 5,4	1,25 - 2	0 - 1,25	2,5 - 4	1,25 - 2	1,5 - 2
Wind (m/s)	12 - 20	13 - 20	Fresh breeze (~8-10)	10 - 20	13 - 17	8 - 16
Beaufort	6 - 8	7 - 8	5	6 - 8	7	5 - 7
Rainfall	-	-	-	-	Heavy	Moderate
Other	-	-	-	Costal Ice	-	-
Location	Baltic sea	South Adriatic Sea	Tyrrhenian Sea	Kattegatt	Mediterranean	Norwegian Sea
People in distress	989	499	4252	1500	700	64
Of which crew	149	55	1023	250	0	15
Time (mayday sent)	01:22	06:00	21:45	11:00	17:00	14:22
Ship type	Ro-pax	Ro-pax	Pax	Ro-pax	Fishing vessel	Sailing yacht
Available helicopters	4 (+13 later)	5	5	0	2	0
Time before first heli arrival	1 h 43 min	1 h	15 min	-	2 h	-
Avr. round-trip time (incl. pick up)	2 h	1,5 h	1 h	-	2 h	-
Other SAR resources		2 large rescue boats	2 large rescue boats	0	1 large boat	1 large boat
			2 small rescue boats			(36 hours)
Ships of opportunity (SoO)						
First on scene	2 x Ro-pax (1 Dest. Gotland)	2 Ro-pax + 1 cruise	1 Ro-pax + 1 cargo	1 Ro-pax + 1 cargo	1 Ro-pax + 1 cargo	2 trading
Length (m)	202 / 195	180 / 220 / 315	180 / 220	180 / 220	200 / 175	
~Lowest open deck height (m)	15 / ?	15 / 21 / 30	20 / 30	20 / 30	20 / 12	
Time to location						30 hours
Later	3 x Ro-pax + 3 x cargo	2 cargo	1 Ro-pax + cargo	-	-	-
Exact position	59.22 N; 21.40 W	?	42°21'55"N 10°55'17"E	57°32'28.3"N 11°19'19.7"E	34°57'36.2"N 14°02'11.6"E	24°45'00.0"S 39°32'17.0"W
Closest distance to land	55 km	25-30 km	50 m	25 km	100 km	320 km
						(found 265 nM)
Distance to land downwind	~80 - 90 km	50 km	50 m	25 km	600 km	5500 km
unfavorable distance to land			30 km			
SC nr / people	/ 890	299	4052	1500	100	64
Lifeboat	300	100	2000	700	-	-
Ark	500	199	1200	600	-	-
Liftable	90	-	852	200	-	-
Standard	-	-	-	-	100	64
People in water	99	70	50	0	500	-
People stuck on ship	0	130	150	0	100	-
Crane on SoO	Yes	Yes	Yes	Yes	Yes	

Appendix IV. Mid Concept Features & Evaluation

Concepts

Reversible	Symmetric rightable	Oblong rightable

If inflated upside down or capsized

<table>
<tr><td>Is equally functional 'upside down' (like the Marin Ark system)</td><td colspan="2">The top-construction makes it self-righting</td></tr>
</table>

Construction

Smaller cylinder (30 cm in diameter) placed at an angle on the bottom cylinder, as the second part of the main buoyancy chamber	The two parts of the main buoyancy chamber are positioned vertically on top of each other (as is the standard solution for current rafts)	Has two cylinders of the same size (40 cm in diameter) placed at a 45° angle as the main buoyancy chamber, creating a bottom shape resembling a boat hull.

Water drains

<table>
<tr><td>Four nylon fabric tubes between roof and floor (to lead water away from the roof)

Four in the roof plus four in the floor (to drain water from the inside, can be tied off).</td><td colspan="2">Four nylon fabric tubes through the floor that can be tied into a knot to be closed</td></tr>
</table>

Towing

<table>
<tr><td colspan="2">Corner first</td><td>Short side first</td></tr>
</table>

Crane connection

<table>
<tr><td>Multiple possible solutions that would reduce the lifting height (from approximately six meters with a sling solution).

It was not decided which one to use at the time of the presentation</td><td colspan="2">A sling from the lifting point, which gives a total lifting height of approximately four and a half meters.</td></tr>
</table>

Aids for getting up from the water

Steps of rubber mesh both up and down (since it is reversible) on two sides of one corner.	A single, narrow, and long step for getting out of the water placed at one corner (filling the square shaped cavities created between rafts when connecting the octagonal shapes).	One wide rubber mesh step for getting out of the water in the stern

Comment: It is possible to add more lifting lines to all three concepts without affecting the evacuation routes.

Evaluation

	Reversible	Sym. rightable	Oblong rightable
Economics	**2.7**	**3.7**	**3.7**
Investment	2	4	4
Deck space	**2**	**5**	**5**
Crew	**4**	**2**	**2**
Tot	*8*	*11*	*11*
Evacuation	**4.6**	**3.4**	**3.6**
Crossing	**5**	**3**	**4**
Connection Stability	**5**	**4**	**3**
Up from water	5	3	4
Wave protection	3	5	4
Hydro release	5	2	3
Tot	*23*	*17*	*18*
Mid	**4.0**	**4.1**	**4.4**
Hydrodynamics	**4**	**3**	**5**
Aerodynamics	3	5	5
Stability / righting	**5**	**3.5**	**3.5**
Comfort	4	5	4
Tot	*16*	*16.5*	*17.5*
Recovery	**3.8**	**4.2**	**4.6**
Towing	**4**	**3**	**5**
Height	**3**	**5**	**5**
Crane connection	**2**	**5**	**5**
Lifting stability	5	5	4
Exit	5	3	4
Tot	*19*	*21*	*23*
Total	66	65.5	69.5
Total average	**15.1**	**15.4**	**16.2**

Explanation of considered aspects

Economics

Investment
The rightable concepts get a better score since they require less material and labour to manufacture. Furthermore, a reversible raft requires double sets of some equipment. The rightable still do not get a full score since they are still liftable and thus require more cost for lifting straps, cylinders and components for higher pressure etc. than e.g. a throw overboard raft.

Deck space
The score is simply based on amount of material needed, thus the reversible gets a lower score.[1]

1 Liftable rafts require higher pressure and thus more gas cylinders, which would take space and lower the rightable concepts score to a 4.

Crew
The reversible concept does not require crew to be trained in righting the rafts, making their education less complicated by removing a step that educators often feels the participants struggle with.

Evacuation phase

Crossing
Based on the height and width of the barrier between raft units.

Connection Stability
The reversible concept can have connections both up and down with equal spacing on all sides which gives it a higher score.

Up from water
This score is based on the height of the entrance, how supportive the step is, and number of instances (the symmetric rightable concept only has one per unit).

Wave protection
Based on height from the waterline to the opening, and shape (better score given for angled cylinders, due to outward direction of splashing water).

Hydro Release (if the ship sinks before evacuation can be initiated)
Lower scores based on consequence if the rafts inflate upside down. The oblong get a better score since it is less wide and thus expected to be easier to flip back over.

Mid phase

Hydrodynamics
The projected area and shape towards waves determines this score.

Aerodynamics
The shape of the rightable concepts would provide a lower drag coefficient.
Stability & need for re-righting: Based on risk of capsizing and consequence if it happens.

Comfort
Based on back support provided by the inflated structure (leaning against the canopy would have a chilling effect and increases risk of hypothermia).

Recovery phase

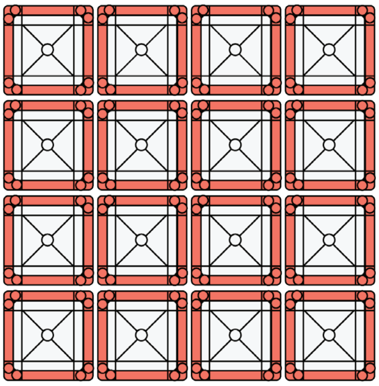
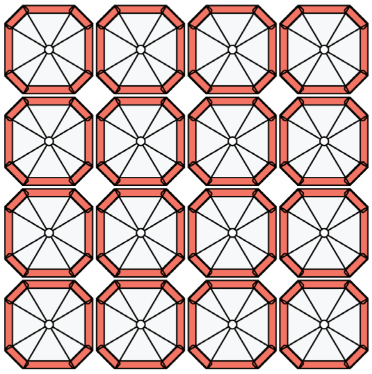
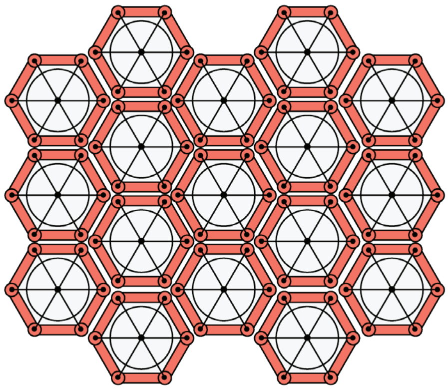
Towing
The projected area and shape (estimated drag coefficient) in the towing direction
Height: From the bottom of the raft to the lifting point where the crane hook is connected.

Crane connection
Based on how easy it is to connect the crane hook, technically as well as from the user's perspective.

Lifting stability
The concepts with symmetric base shape get a higher score

Exit
Based on the height of the step, when leaving the raft, once it has been put down on the deck of a ship of opportunity (for the symmetric rightable concept it is one meter). This affects the time it takes to evacuate a raft unit, which on some ships will need to be moved to make room for the next raft unit.

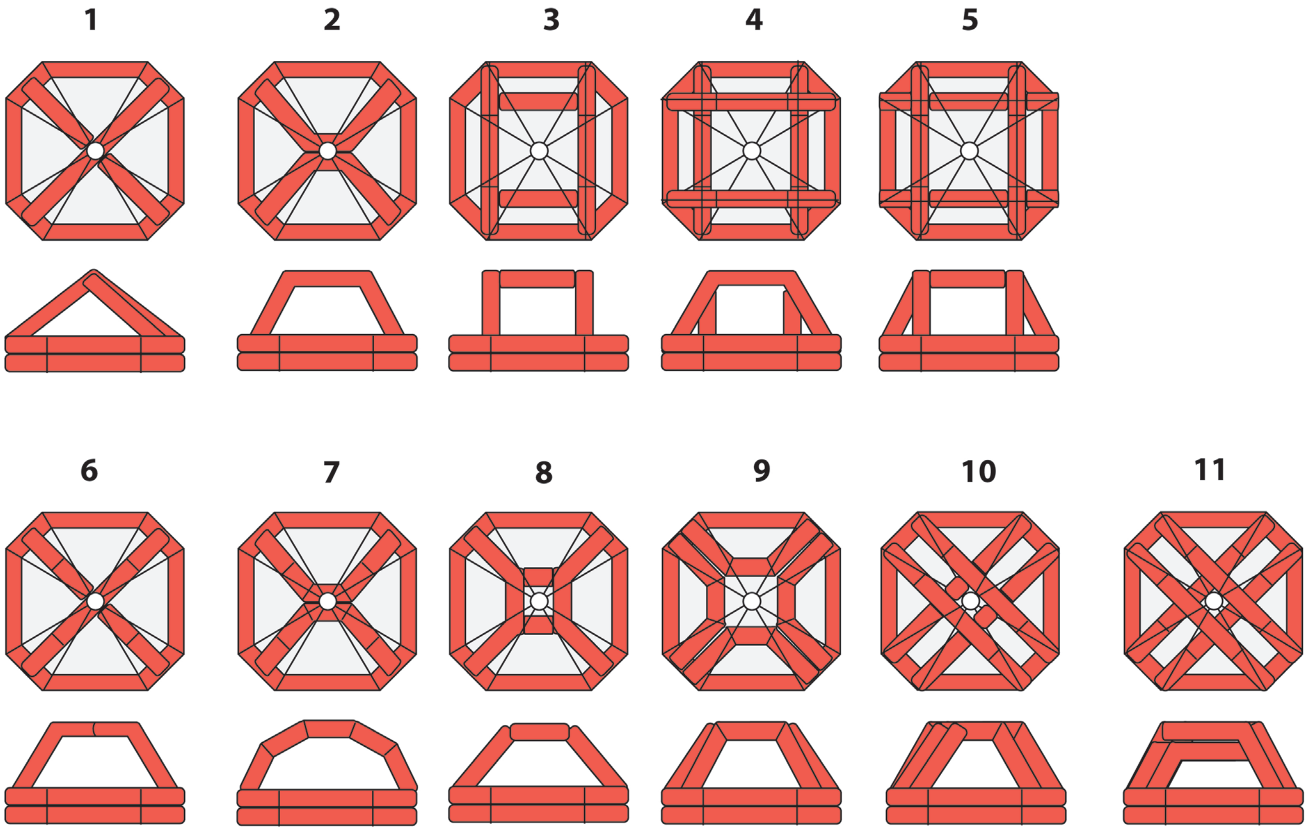
Appendix V. Base Shape Evaluation

Criteria	k	Square	Octasquare	Hexagon
Stability	1	3	4	5
Lifting stability	3	2	3	4
Area / Material	1	3	5	4
Evacuation				
Width Openings	1	5	4	3
Flow / logic	1	5	5	3
Packing	1	5	4	3
Amount of joints	2	5	5	3
Nr componenents	1	5	3	4
		33	33	29
		42	45	42

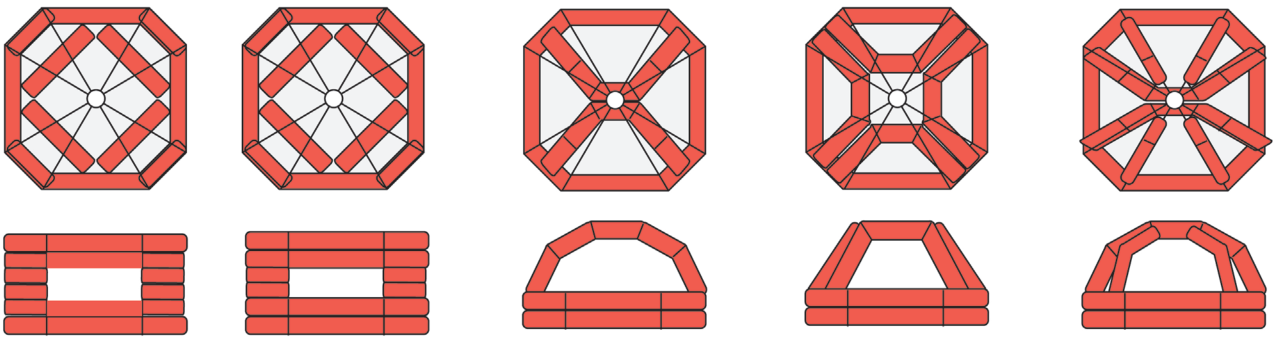
Appendix VI. Top Structure Evaluation

Self-righting evaluation



Criteria	k	1	2	3	4	5	6	7	8	9	10
Lifting stability	5	4	4	1	3	3	4	4	4	5	5
Material	0,5	5	5	4	2	2	5	5	4	1	1
Evacuation:											
Size Openings	1	1	3	5	4	5	3	4	3	2	2
Crossover	2	1	3	2	3	3	3	5	3	3	3
Amount of angles	0,5	5	4	4	2	4	4	2	4	2	4
Nr componponents	1	4	5	3	3	1	4	5	3	3	1
Volume	0,5	1	3	3	3	3	3	5	3	3	3
		33	40	23	32	32	39	45	38	39	38

Common evaluation



Criteria	k	Sym. 1	Sym. 2	Arc	Pod	ArcPod
Connecting units	3	4	4	2	2	2
Lifting stability	5	1	2	4	5	5
Aerodynamics	2	2	2	4	4	4
Evacuation						
Size Openings	3	5	2	5	4	5
Crossing fallout risk	2	5	5	4	3	4
Crane connection	4	2	2	4	3	4
Stability (empty)	0,5	2	2	4	4	4
Helicopter evac	0,5	3	1	4	3	4
Material	2	2	2	5	4	4
Nr componponents	2	2	2	5	4	4
Inside Volume	1	5	5	3	2	3
Rightening required	5	5	5	1	1	1
slide / chute connect	4	4	4	4	2	3
		110,5	105,5	121	103,5	118

First	113	107	125	107
Re-eval	110,5	105,5	121	103,5
Cost-	102,5	97,5	101	87,5
Evac+	139,5	128,5	145	122,5
Lift OK	105	95,5	101	78,5
Crane OK	102,5	97,5	105	91,5
Cost +	122,5	117,5	151	127,5
Evac OK	81,5	85,5	112	101,5
Lift +	115,5	115,5	141	125,5
Rightening +	135,5	130,5	126	108,5
Total	1128	1080,5	1228	1053,5
	2	3	1	4
	Second best		Best	Worst

Appendix VII. Early illustration versions

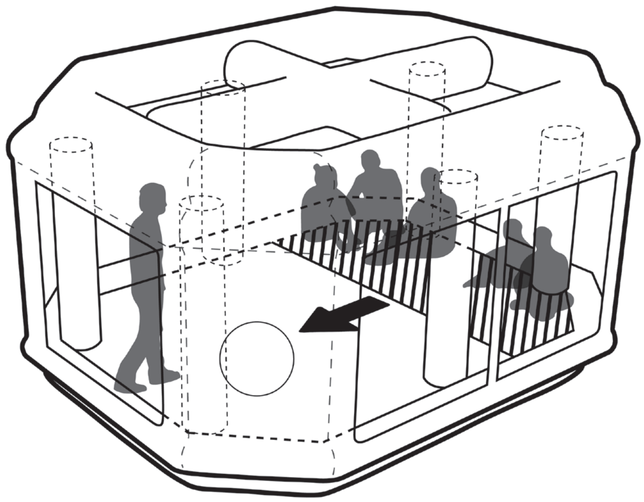


Illustration on how to fill up the raft units during evacuation. This was shown during the focus group session.

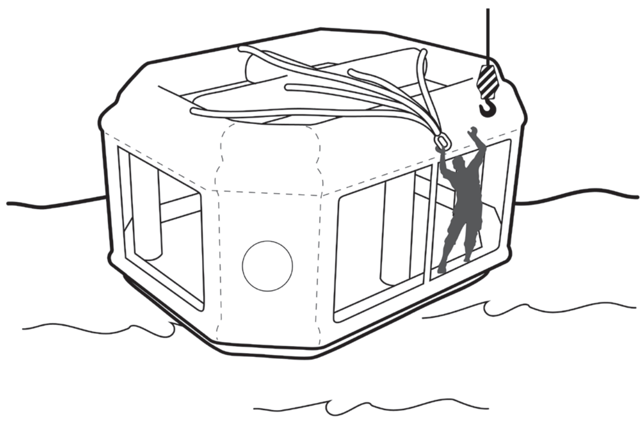


Illustration on how to attach the crane hook before a lift. This was shown during the focus group session.

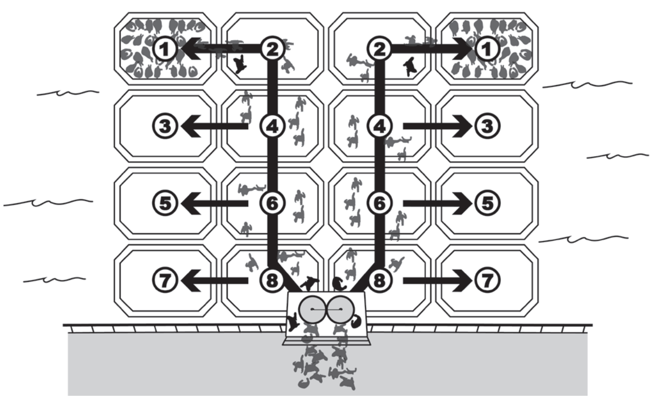


Illustration on how to fill up the raft system during evacuation. This was shown during the focus group session.

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