FLOODSTAND-deliverable:

Benchmark data: Introduction to the Mustering, Abandonment and Rescue models

Authors C.N., N.M., Y.H.
Organisation BMT, BV, SSRC

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Abstract:
This report presents the main results achieved through the Task 5.1 of the FLOODSTAND project, entitled "Benchmark Data". Data were collected from different sources in order to address the different aspects of evacuation in case of a flooding event. The deliverable also presents the core concepts underpinning the development of the mustering, abandonment and rescue (MAR) models.

CONTENTS

1. EXECUTIVE SUMMARY

This report presents the main results achieved through the Task 5.1 of the FLOODSTAND project, entitled “Benchmark Data”.

In this task, the partners have collaborated in order to gather a significant amount of relevant inputs for defining the scope of scenarios and the models to be developed in WP5, and developing and feeding the models for mustering, abandonment and rescue.

Data were collected from different sources in order to address the different aspects of evacuation in case of a flooding event. Amongst these aspects are the detection of flooding, the assessment of damage by the crew, the assessment of the situation by the master, the decision to stay onboard or abandon the ship, the effects of flooding on evacuation, the launching of life-saving appliances (LSA) while the vessel is listing because of flooding or the recovery of LSA by the Search and Rescue (SAR) services.

We interviewed several passenger ships’ masters and SAR personnel, and sent questionnaires to some of them in order to have feedback on the decision making process in case of flooding as well as the practical needs faced by them when it comes to real massive evacuations of cruise and passenger ferry ships. Accident and evacuation drill reports were analysed. A regulatory review was also performed.

Moreover, we present the core concepts underpinning the development of the mustering, abandonment and rescue (MAR) models, adapted from a combination of the SAFECRAFTS FP6 EC funded project’s results and the current state-of-the art practice for ship evacuation simulation. These concepts are in accordance with the work performed in WP4 and WP6 of FLOODSTAND project whose output need to be integrated in WP7.

2. BENCHMARK DATA

2.1 Regulatory analysis

It is important to carry out first a regulatory analysis first in order to know the basic mandatory requirements that every large passenger ship, every company operating large passenger ships and every SAR organisation need to fulfil.

The summary of the regulations with their references is attached in Annex I of this report. Section 2.1 of this report highlights the main important regulatory requirements related to the emergency preparedness and the management of emergency situations onboard passenger ships.

2.1.1 Before the event – Emergency preparedness

Drills/Exercises

- There should be abandon ship drills every week.
- Every crewmember participates in at least one abandon ship drill every month.
- For voyages lasting more than 24 hours, passengers should do a muster exercise within the first 24 hours and have a familiarisation with life jackets.
- An announcement providing safety instructions to passengers (on the public address system) should be made before departure in cases where there was no muster exercise: actions to be performed when hearing the emergency signal, actions on arrival in muster station, means of drawing passengers' attention etc. These announcements (or safety briefings) should be conducted each time passengers embark.

Emergency/evacuation procedures/plans

- **The muster list** shall explain:
  - The abandon ship signal.
  - The General Emergency Alarm and public address systems.
  - The crew's actions and duties when the alarms are sounded.
  - The passenger's actions when the alarms are sounded.

- There should be **contingency plans:**
  - A contingency plan should indicate which authorities and organisations to contact in an emergency.
  - The **contingency plan** should contain an example of **emergency preparedness plan.**
  - There should be procedures for ensuring that all personnel are trained and aware of the **emergency plans**.

- There should be **co-operation plans** between SAR and passenger ships
  - These plans should contain provisions for periodic exercises to test effectiveness: there should be different scenarios, SAR and company personnel should be involved.

- There are performance standards for evacuation simulations in order to validate the design of passenger ships (**evacuation times**).
- A flooding detection system for watertight spaces below the bulkhead deck shall be provided for all passenger ships carrying 36 or more passengers constructed after July 2010.
- According to Safe Return to Port, the systems should remain operational when the ship is subject to flooding of any single watertight compartment.

- All passengers onboard should be identified and their exact number known by the master and the shore-based company management.
- Ships should report their position to a coast radio station.
- Each RCC (Rescue Co-ordination Centre) and RSC (Rescue Sub-Centre) should have up-to-date information on SAR facilities and communications in the area and have detailed plans for conduct of SAR operations.

Ships operating in polar or remote areas

- Ships operating in polar waters should:
  - Carry LSA and survival equipment (like personal and group survival kits) according to the environmental conditions of operation.
  - Regularly remove ice accretion from lifeboats, liferafts and their launching equipment.

- **Enhanced contingency plan for passengers operating in areas remote from SAR facilities**:
  - The ship informs the Rescue Coordination Centres of the arrival date/time in the remote area.
  - Company should exchange directly with SAR the **SAR co-operation plan.**
  - SAR may ask for **the Company's emergency plan.**
  - The ship should report positions and intentions to RCC while in the remote area.
  - Voyage pairing should be considered (exchange of information so that another passenger ship in the area can be used as a SAR facility).
  - Enhanced life-saving appliances should be carried onboard.

2.1.2 During the event – Crisis management

Mustering, Abandonment & Rescue

- **Trim and stability booklet**: contains information to enable the master to operate the ship in compliance with statutory and class requirements: enable the master to quickly and simply obtain accurate guidance as to the stability of the ship under varying conditions of service.

- **Damage control plan and damage control booklet:** help prevent progressive flooding. The DCB includes general instructions for controlling the effects of damage. They should be in printed form. They can include damage consequence diagrams.

- **Damage control plans**: there should be plans showing watertight compartments, openings, and means of closure and the position of controls for correcting list due to flooding. They should be exhibited on the navigation bridge as well as the ship's control station. In addition to the plan, the use of stability software programs can be very beneficial for effective damage control.

- **Contingency plans: emergency plans** should distinguish initial actions to be taken immediately and subsequent response depending on the ship and event's characteristics. There should be detailed response action showing the steps to limit consequences and escalation of damage in case of an accident.

- Information on passengers should be made readily available to SAR services in case of an undesirable event.
- There should be a **Decision Support System** (DSS) on the bridge for managing any combination of hazards: this DSS should be at least a printed emergency plan.

- The crew (depending on their position) should be able to:
  - Act according to **contingency plan** in case of emergency.
  - Assess damages and take initial actions.
  - Assess damage control.
  - Understand stability issues.
  - Limit damage.
  - Make decisions to maximise safety of the persons onboard.
  - Execute procedures to render assistance to a ship in distress.
  - Execute procedures to rescue persons at sea.
  - Apply medical first aid to passengers.
  - Protect and safeguard all persons onboard and help surviving at sea.
  - Maintain, prepare, launch, and use LSA.
  - Manage crowd situations by communicating with passengers, reassuring them, accompanying them in the mustering and embarking phases, limiting stress amongst them, etc.

Mustering

- There should be procedures for locating and rescuing passengers trapped in cabins.

Abandonment

- All LSA should be able to be fully loaded (passengers) in 30 minutes from the "abandon signal".

Rescue

- **Contingency plans** indicate which authority and organisation to contact.

- **Co-operation plans** between SAR and passenger ships: enhance mutual understanding between a ship, a company and SAR services, so that in the event of an emergency, all three parties will be able to work together efficiently. **SAR co-operation plans**, once they have been agreed for a particular ship, should be recognised by the SAR services of all Administrations.

- **Liferafts** shall be so constructed that the raft can be towed at a 3 knots speed in calm water with its full complement of persons and anchor and with one of its sea-anchor streamed. There shall be means to assist persons to pull themselves into the liferaft from the ladder.

- **Lifeboats** shall be capable of being launched and towed when the ship is making headway at a speed of 5 knots in calm water. They shall have a ladder to enable persons in the water to board. The speed of a lifeboat when proceeding ahead in calm water, when fully loaded and with all engine-powered auxiliary equipment in operation, shall be at least 6 knots and at least 2 knots when towing a 25-personliferaft fully loaded.

- There should be standard procedures for distress message routeing.
- Factors to be considered for alerting SAR authorities include position, time of day, weather conditions, number of persons at risk or potentially at risk, specific assistance required, etc.
- A passenger ship such as a ferry, which trades on fixed routes, should compile a co-operation plan incorporating details on all the SAR services along her route.
- Cruise ships will tend to use a SAR data provider: contact points between the global SAR service and cruise ship operators.

2.2 Interviews/Questionnaires

2.2.1 Analysis of questionnaire for masters

Introduction

As part of this deliverable a questionnaire was sent to ships' masters. The questionnaire was created with reference to previous work undertaken by partners (notably the Flagship and SAFECRAFTS projects). The purpose of the questionnaire was to determine, for benchmarking purposes, the experience of ships' masters in relation to the Mustering, Abandonment and Rescue (MAR) process, both in drills and in real life. Included in the questionnaire are both quantitative questions and subjective questions. By these means we tried to elicit the greatest amount of information possible.

From the data gathered by this questionnaire, it is hoped to inform the models that will be developed in the course of the later tasks. Task 5.5 proposes to measure the uncertainty inherent in the MAR model developed in WP5. The data assembled in task 5.1 will be extremely useful in this process as well.

The questionnaire has been sent to several independent ship owners on a voluntary basis, as no ship owners are involved in the project. In total 10 responses received (to date 09/02). We have also spoken to the MCA to make use of their experience of some real life situations; however, this information is generally included in the later sections on the SAR body questionnaire and the drills. This evidence is not in the form of answers to questionnaires, but more anecdotal in nature. They sometimes go into more detail than the questionnaire would. Their experience is particularly insightful as they are trained observers of such situations.

Of the 10 questionnaire responses 4 are from cruise liner captains and 6 are from ferry captains. They have each spent an average of 24 years as a Master, although there was a noticeable split with the ferry captains being much more experienced. Several of the participants have only partially filled out the questionnaire. This is possibly due to browser compatibility issues as highlighted in correspondence with one captain using a very old browser who could not access the survey at all.

Emergency procedures

The Masters were asked to explain the procedures that they would undertake in the event of a flooding emergency. They were mostly in agreement on the major actions that should be taken, for example:

- General Alarm.
- Stop engines.
- Close watertight doors and section valves.
- Drain swimming pools if present.
- Visual assessment of damage (boat party if necessary).
- Inform MRCC.
- Simulation in stability software program; a request is sometimes sent to an offshore office for assistance in this task.
- Passengers to assembly stations.
- Start pumps if necessary/feasible.
- Navigator looks for possible grounding.
- Search cardecks.
- If the stability software program's prognosis is bad, then begin abandonment to LSAs.

One of the participants was keen to point out that **the order of these actions will vary significantly depending on factors such as the severity of the damage, the depth of the water, the weather, number of passengers, evacuation facilities and even the temperature of the water may be taken into consideration.**

Some of these actions are physical actions that will be taken by members of the crew, who are being coordinated by the officers. Several of them involve looking to external agencies or situations for help. **Informing the MRCC may elicit some useful response or advice**. **The stability simulation software program offers some very useful information and expert opinions from shoreside will be available to the master to explain all the options**.

Interestingly, the indication that **the decision to begin abandonment might be at least partly influenced by the stability software program** shows the at least partial reliance of ships' masters on electronic systems to advise them of the situation. This sort of system will be the final aim of Task 7.2 in the FLOODSTAND project, so it is useful to see the niche for this system.

Issues during emergency operations

The Masters were then asked about problems with the actual MAR process. Two major difficulties were identified with respect to the mustering process. The first is that the **passengers can be extremely difficult to count, particularly when the ship is full and they fill the muster zones**. Secondly, **the equipment can sometimes be 'not fit for purpose' even on newer ships and the crew can have problems operating the unsuitable machinery**. Many difficulties were identified in the abandonment process. Most of the difficulties relate to the launching of the LSAs. **If the LSA is full, the ship is listing or the sea state is bad it can be hard to launch**. Also sometimes the equipment is not reliable or heavy and unwieldy and sometimes the crew members have not been trained with the particular equipment items available. Finally one Master mentioned problems with the Public Address (PA) system at the abandonment stage. At the LSA navigation stage, most Masters were happy with this, although one mentioned the **manoeuvrability of the LSAs**. Also, one mentioned that **there is sometimes not sufficient towing power to move the rafts away from the sinking ship**. Finally, at the recovery stage, it is mentioned that the **boats aren't built for easy retrieval** and are heavy. **This is specifically a problem when the sea state is high and the passengers may be suffering from exposure or hypothermia**.

In drills and real life situations the incidents listed included:

- Public Address (PA) system failure.
- Portable two ways radios ('Walkie Talkies') only have a 30 minute battery life and only work in some places – there are sometimes communication deadspots.
- Engine/rudder failure on lifeboat.
- Winch/davit/hook failure (this one is mentioned by multiple people and seems to have caused severe injury and even death).
- Minor injuries retrieving boats.
- Hooks damage LSAs.
- Bowsing gear poorly designed for its purpose.
- People show up at wrong muster station trying to be with family, which makes counting hard.
- MES chute too short, so it had to be stretched, which caused it to fail.

Decision making

The Masters were asked about the importance of a list of set criteria in the event of both the mustering and abandonment stages of the process. The results from the 4 Masters who completed this section in detail are shown in the table below with an average score applied to each category. A score of 5 indicates that the criterion is very important for decision making about whether or not to abandon the ship and 1 indicates that it is not important at all.

Note: Regarding the limited number of respondents, the results discussed below need to be looked at very carefully. The do not pretend to be representative of the population of passenger ships' masters neither in general, nor in Europe. There is no statistical significance of the results. However, even though reflecting the opinion of e few Masters, they are still very valuable for the purpose of this report.

Criteria	Importance score (1-5) mustering	Importance score (1-5) abandonment
Type of initial event	4.5	4.5
Location	4	4
How long the ship will remain afloat	5	5
The motion of the ship (heel, sea state etc.)	4.75	4.5
Advice on measures to mitigate problems (reballasting)	4.75	4.75
Time needed to abandon	4.25	4.25
Risk of LSA deployment failure	2.75	3.75
Conditions to which the evacuees will be exposed	3	4.25
Time at sea	3	3.5
Means of rescue	3.25	3.5

Table 1: Results of question 4.1 of the questionnaire for masters

There is generally good agreement between the two lists indicating that the Masters thought the same things were important in both different situations. Obviously, the last four criteria are not particularly relevant in the mustering phase; nevertheless, these things are in the master's mind when he/she makes the decision to muster. Looking at the variation in the scores in the first 6 categories, which are relevant to both phases, it is apparent that the variation seems slight. However, we can see here that the Masters rate some things more highly than others. For example, **the survival time of the ship is considered of paramount importance by all taking part**.

Indication of the time needed to abandon the ship is not considered as important as the masters presumably have some idea of this. The intention of this field was to refer to the fact that the evacuation time may be altered by, for example, the heel of the ship. However, from their experience, the masters probably also have some idea of how the evacuation time would be affected by this too.

The location of the ship is considered the least important of these criteria. This is perhaps surprising, particularly for the abandonment stage, as at this stage, the passengers are fully exposed to the elements for as long as it takes the rescue craft to reach them. However, if the captain has made the decision that the ship is going to sink, then it is perhaps useless for him to consider the location of the event as the passengers are going to end up in the water anyway. He will do better to put them in lifeboats than to have the ship sink with all hands, even if this action perhaps results in the loss of a large number of lives through the environmental conditions. Also, the later options referring to time at sea and environmental conditions may have confused the questionnaire participants into thinking that this referred to something else.

Later on, when referring to the time at sea and the environmental conditions, **the Masters seem much more concerned with the environmental conditions to which the evacuees will be exposed**. Time at sea is not considered as important and nor is the means of rescue. **The masters are clearly concerned about the well-being of their passengers. If the sea is fairly calm and the temperature reasonable, then the LSAs can potentially stay afloat with little or no harm to the passengers for a relatively long time. The only problem in this case might be the relative drift and dispersal of the LSAs.**

LSA deployment failure is considered a fairly high risk too. However, this is something that is beyond the master’s control. He can implement extensive training and maintenance procedures, yet sometimes unreliable/’not fit for purpose’ equipment will still fail.

Masters were asked about the possibility of panic and wrong decisions amongst the crew. The response to these questions was low, but they agreed on the fact that **wrong decisions could easily be made in the event of a disaster and that an advanced decision support system (DSS) would be useful.** Some Masters had used a DSS before and all thought it was helpful, but that it could be better if the systems could be made more user-friendly and use more reliable data.

When asked what information the DSS should provide the Masters were asked about 6 possible feeds of information.

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Information Feed	Score (1-5)
Compartment flooding/watertight doors closed	5
Ship stability advice including reballasting measures	5
After all actions: survival time of ship before sink/capsize	5
Evacuation times given a certain list angle	4.5
A recommendation of whether the ship should be abandoned based on the predicted survival time and evacuation time	4.5
A recommendation on whether the ship should be abandoned at all (given external weather, proximity of rescue services)	4.5

Table 2: Results of question 5.2 of the questionnaire for masters

There is not much variation in the opinion of the Masters when referring to the type of information. They generally seem to think that all the information is important in some respect. **Generally the ship Masters seem to think more of an emphasis should be placed on providing them with information rather than making recommendations to them**. The ships' masters are responsible for making the decisions on the ship, so they will be more concerned with having all the relevant information necessary to make their decision, than with having recommendations as to what decision they should make. For this reason, while these recommendations are useful, they are not as important as the raw information itself. Yet despite this, only half the Masters were interested in how the DSS derives its recommendations. Presumably, this is because they merely wish to compare the DSS findings with their own evaluation of the situation not to go into details in the middle of a crisis.

All Masters were agreed that the information should be made available to the Bridge and safety centre teams. Some also thought the engine room, or at least the chief engineer, should be interacting with the information. When asked if and how they would prefer to enter information, the consensus seems to be that information entry should be as simple as possible. If possible all the information should be automatically available to the DSS. If this is not possible simple drop down menus and clickable boxes would be best. A full study of the ergonomics of this would be necessary for the development of a full system.

2.2.2 Analysis of questionnaire from SAR organisations

Introduction

In addition to the questionnaire for ship's masters, a questionnaire was created for members of SAR organisations. This is extremely important as the models to be devised include a model of the rescue process. By gaining a response from SAR organisations, it should be possible to further inform the model to be developed later in the project.

The questionnaire developed in this section includes questions on the experience of the SAR body personnel with respect to full scale drills and real life situations. We have spoken to the

MCA and RNLI and gained anecdotal evidence on this stage of the process. The response to this questionnaire has been fairly low: only three responses have been received, so the inclusion of extra information in this section is essential.

Emergency preparedness

When asked if there was generally regular exchange of information between vessels and a SAR coordinator, two participants said yes and one said no. The typical scenario in the event of an accident is that the alarm will be raised by the vessel in distress. The coordinating SAR body will then organise the launch of the appropriate local SAR vessels. All local ships will be alerted and other SAR units may be activated (e.g. helicopters). **The coordinating body will attempt to organise the whole effort with the assistance of on scene ships. It will arrange reception points in the form of either another vessel, or a space on land.**

Issues during emergency operations

When asked for difficulties encountered in drills or real life the following points were raised:

- Keeping life rafts together after embarkation.
- Towing points on life rafts are fragile and can often come away from the boat.
- The rafts are often not rigid enough to withstand a high velocity. If towed at more than 3-4 knots they can crumple, which can trap the passengers and cause injuries.
- Most exercises involve fit, healthy, young volunteers in daylight, which is not really representative of real life situations.
- On recovery the egress points from liferafts over the inflated tubes need to be covered with a non-slip material, as the survivors must step on this tube to leave the liferaft.
- Getting SAR craft alongside ferry embarkation points, due to belting.
- Height of the access points above the waterline on both SAR craft and the LSAs once launched.
- One participant once observed an evacuee jumping onto a liferaft and bouncing overboard, breaking an ankle in the process.
- People on evacuations slides injured, as they get to the bottom of the slides.

Most of these issues relate to problems with the successful evacuation of the vessel, however, the point about the exercises occurring in benign conditions indicates that there is perhaps a lack of good data on how an evacuation would actually go in real life. Obviously, it is unethical and not in any organisation's interest to expose volunteers to real severe danger, by conducting dangerous sea trials in adverse conditions, however, the results would suggest that the realism of all onboard evacuation tests should be seriously considered.

The participants in this questionnaire have experienced both drills and real life situations. Their experience extends to both cruise liners and passenger ferries.

Decision making

When asked if the situation was clear at all times, the participants responded that it was. This is probably due to the fact that the SAR bodies are coming in externally and have a specific job to do. Once the ship is evacuating it is clear that the SAR personnel must retrieve the evacuees. However, the participants seemed to believe that the SAR personnel would be slightly more sure of what to do than of what is happening. This presumably refers to the training that the SAR personnel have received. They will know what they must do in any situation, but it may not immediately be clear what the situation is.

When asked whether wrong decisions could have been made in the stress of the situation, both participants who answered this question responded that it could. The same two both thought that advanced DSS for SAR bodies would be unnecessary. This is a fair assumption as most of the complexity in the situation arises aboard the ship prior to embarkation, so DSS would likely be more useful to the ship's master than to the SAR body.

The SAR personnel will assist the ship's master in the event of an accident, but will only ever advise him. The decision will always ultimately rest with the master. One example given states that the usual procedure on advice would be for the coxswain of an RNLI lifeboat to provide advice to the master of the ship on how long it would take to evacuate the ship.

The courses of action that are open to the SAR body in the event of passenger ship flooding vary depending on several factors. **The geographical location of the accident is extremely important as it restricts the speed at which help can arrive**. The severity of the flooding and the speed at which the water enters the ship would impact the ability of the crew and passengers to remain on the ship. It might also impact the manoeuvrability and speed of the ship. If the ship can maintain its course and speed, it can perhaps head for a place to beach or even a port. If the ship struggles too much the SAR vessels may attempt to tow it to a place of safety. **The main point made is that early and swift evacuation is usually the best option**.

The table below details the ranking of the importance of certain criteria in the event of both mustering and abandonment situations. The scores are again from 1 – not important, up to 5, very important. Unfortunately only one participant answered this section of the questionnaire, so we are not seeing a statistical picture at all. It is still possible to draw a few conclusions from this table though.

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Criteria	Importance score (1-5) mustering	Importance score (1-5) abandonment
Type of initial event	4	4
Location	4	4
How long the ship will remain afloat	5	5
The motion of the ship (heel, sea state etc.)	4	4
Advice on measures to mitigate problems (reballasting)	3	3
Time needed to abandon	5	5
Risk of LSA deployment failure	4	4
Conditions to which the evacuees will be exposed	4	4
Time at sea	4	4
Means of rescue	3	4

Table 3: Results of question 4.2 of the questionnaire for SAR bodies

This person does not consider advice on measures to reballast the ship to be very important at all. **As a member of a SAR body his job is to aid the evacuation of the ship and recovery of survivors**. Measures to reballast the ship, while extremely worthwhile, do not come under his area of command. Indeed, it is likely in most cases that measures to mitigate problems would already have been undertaken by the time the SAR bodies are on the scene.

To this person the most important criteria are the time to abandon and the survival time of the ship. The combination of these two times will determine how many people are to be successfully evacuated from the ship. If the time required for evacuation is considerably less than the projected lifetime of the ship then the people should all successfully embark and the job of the SAR body becomes a "simple" LSA recovery exercise. If the opposite is true then there will almost certainly be casualties. At the very least the SAR body will be retrieving people from the sea.

The means of rescue is unsurprisingly considered less critical for making the decision to muster passengers phase than it is for making the decision to abandon the ship. This is because at the mustering stage it is not yet known whether the abandonment will take place, so it is good to have the passengers together just in case.

2.2.3 Meeting with French SAR services

BV has organised meetings with the French SAR coordinator, and then French SAR centre responsible for the Mediterranean Sea (CROSS MED) and the French SAR centre responsible for the Channel (CROSS Gris-Nez). As regards the scope of FLOODSTAND, CROSS MED have a good experience of ferries travelling to/from Corsica and Cruise ships travelling in the Mediterranean sea while CROSS Gris-Nez have a good experience of navigation monitoring and rescue operations in an area with much traffic with some of the busiest shipping lanes in the world including ferries going to/from the UK and therefore crossing the shipping lanes several times a day.

Crisis management/evacuation procedures & routes

a) General procedures

- There is no particular communication between the Marine Rescue Coordination Centre (MRCC) and the shipowners apart from crisis situations; however **there are some evacuation tests organised by the MRCCs on a yearly basis in collaboration with shipowners**.
- The typical chain of events is, from a SAR body's point of view:
  - The MRCC in charge of the SAR area receives an alert message from the ship.
  - They analyse the message, communicate with the master and make a first assessment of the gravity of the situation: this is mainly dependent on the information provided by the crew.
  - If any incident has occurred, the master will generally first try to fix it with his personnel onboard (repair steering or machinery, fight fire, control flooding, etc.). However, he would always contact the SAR services in case of flooding.
  - Upon agreement of the master, the MRCC sends an evaluation team (experts for assessing damage and survivability, risk of capsize) to the ship by helicopter. If the incident is controlled by the crew, the SAR services would usually send a team of surveyors onboard the ship for a detailed evaluation.
  - The SAR team may then, depending on the extent of damage and the expected survivability of the ship, ask the master to go to the next port of destination or stop at the nearest French port for a deeper inspection.
  - If the situation requires support from SAR services, the MRCC elaborates tactics for deploying the SAR resources available.
  - They designate a coordinator on site and ensure a welcoming point for the ship and her casualties.

b) Managing the event/accident

- If a major accident/incident occurs, the strategy for managing the situation is defined by the regional Coastal State representative.
- **A crisis management team, comprising *inter alia* a ship owner's representative and a representative of the coastal State, would be set in the MRCC building in order to manage the event.**
- French MRCCs are the intervention management team. They define the tactics for addressing the emergency at an operational level. They can send support teams for managing passengers, avoiding panic onboard or provide medical resources such as doctors. These MRCCs are more widely in charge of:

  - Coordinating nautical and aeronautical resources for maritime rescue (coast guards, maritime administration, customs, national security, fire men, etc.).
  - Contacting and managing ships in the area of the incident that are able and have to provide assistance. These ships may help stabilising the area of rescue by protecting it from the waves and wind or may welcome some victims onboard.

- Assisting the master in his numerous responsibilities for ensuring passengers' safety.
- Organising medical response: send medical team for evaluation of the medical situation and communicate with the medical services onshore for maritime interventions (trained for managing crisis situations with massive number of victims).
- Firemen from the civil safety/security services.

- **All available means would be mobilised in case of a major flooding event on a large passenger ship**; the British or the Italians (respectively for the Channel and Mediterranean areas) would help and several OSC (On Site Commanders) would be sent to manage/coordinate actions for the search zones.

c) Remote areas

- **There are special recommendations for ships sailing in areas that SAR services are unable to access in less than five days**.
- If the event happens in relatively remote or hardly accessible areas, the MRCC will transmit the emergency call to ships in the same area.
- Practically, the 'twinnage' or 'pairing' principle is often used to ensure that another vessel would be able to help in the event of an emergency.

Feedback from evacuation drills/exercises

- There is a centralised database of the reports from tests carried out by French MRCCs. However, these tests even if they provide a good opportunity for SAR services to test their abilities to manage a crisis in which there is evacuation of passengers, are not so relevant regarding the volunteers who participate: they are mainly cadets or military sailors, almost all of them relatively young, physically trained or in very good shape.
- French MRCCs organise one evacuation drill per year.
- It is quite risky to carry out real trials using life-saving appliances and arrangements. **A couple of years ago, the MCA had a fatality during a test: one found himself struck in a MES chute and was then hit by the followers.**
- From experience of evacuation trials, French MRCCs quote crewmembers' professionalism and their ability to manage an emergency and take care of passengers as the most determinant factors for a quick and effective evacuation.
- From these exercises, it appeared that for the Mediterranean region, as far as they know, **passengers are almost never counted during the different stages of the evacuation**.
- During a trial when they counted evacuees, they experienced a difference between the number of passengers counted leaving the vessel and the number once ashore while in reality there were no people lost. In this case, there were only 200 persons to be evacuated. **It was concluded that counting is very difficult for large passenger ships and is very reliant on the company procedures.**

Feedback from evacuation in real crisis situation

We could not get any feedback of massive evacuations undergone or supported by the French SAR services. However, this section deals with their thoughts on the topic since this is one of their main current problems to figure out how thousands of passengers could be brought ashore safely in case of a major accident onboard large passenger ships.

How can massive recovery of passengers be managed?

a) Helicopters

- Actual French helicopter capacity is quite limited for intervention in certain areas: For the Mediterranean area, they have for instance one PUMA-SAR which can rescue ten to fifteen persons and several Dolphins whose capacity is three or four victims each.
- According to the French MRCCs responsible for the Channel area, **five hundred passengers could be rescued in two hours with 30 person capacity helicopters like those of the UK. However, their ability to intervene depends on the weather which has to be relatively clear and with limited wind and rain.**

b) Assistance by another passenger vessel

They never tested assistance by other passenger vessel; however some different options can be reasonably envisaged.

- Rescue boat/lifeboats to recover the LSAs
  - In some cases, a Fast Rescue Boat will not reasonably be launched from a ferry to recover people, because it is deemed to be too dangerous to launch it (too high location); rules may need to be changed on the FRB location.
  - Ferries tend to have fewer lifeboats which can be problematic if they have to help another passenger ship in difficulty by towing their liferafts.

- LSA to LSA transfer
  - One solution would be that (1) the passengers of the damaged vessel (vessel A) are evacuated with the life-saving appliances, (2) in the meantime the rescuing large capacity (passenger) vessel (vessel B) launches its LSA too, (3) then passengers are transferred from LSA of vessel A to those of vessel B, and finally (4) vessel B recovers her LSA with the victims onboard.

- Ship to ship transfer
  - **Ship to ship transfer from one passenger ship to another is almost impossible for so many victims.**
  - It is also envisaged to have a rescuing ferry open its bow door if the sea is calm so that survivor can climb in the vessel; however, here again it will be practically very difficult to climb, even for healthy people and moreover there is a significant risk of flooding for the rescuing ferry.

c) Assistance by rescue vessels

- They have no real experience of this**. It will take a very long time to recover life saving appliances once they are at sea, very difficult in adverse weather conditions.**
- **Even with lifeboats, it is very difficult to think of a safe way, firstly, to have people transferred from liferafts to lifeboats, and then a safe way to transfer people from lifeboats to the rescuing vessel, even with rescue vessels having a small freeboard (with bad weather, injured or elderly passengers, even impossible).**
- Some ships have a side door at a level so that some types of rescue boats can access it. It can be used for the transfer of passengers. However, here again it takes a lot of time to use these doors to evacuate thousands of passengers.

d) Tow/Support LSAs to the shore

- **Cruise ships provide more safety than ferries in terms of LSA: cruise ships ensure lifeboats for all passengers while on the contrary, ferries tend to replace lifeboats by liferafts** (alternative arrangements are regularly approved by the UK Administration).
- **There is additionally quite a lot of uncertainty on how to manage huge liferafts as those which tend to replace self propelled rigid lifeboats**. Can these rafts really be towed? How? Which towing boat should be used? The MRCCs have no clear answer at the moment. Moreover, they have serious doubts on the feasibility of towing a 150 passenger liferafts.
- In coastal areas, another solution is that self propelled LSAs reach the shore on their own but there are many risks due to the high level of traffic in the Channel for instance. The MRCCs may be able to help here but they have very limited ability of detecting LSAs with radar.

e) Massive LSA recovery by special vessels

- A more unconventional and very innovative solution would be to have the intervention of specialised ships able to recover all life saving appliances in one go.
- Designing massive means of recovering LSAs has been mentioned by the French authorities as a way forward, this vessel should be able to, for instance, be used in case of pollution as well.
- If they had an available vessel able to massively recover survival rafts (like some navy ships), they would seriously envisage to use it (in good weather conditions).

f) Additional remarks

- **For the Channel area, in case of the massive evacuation of a 2,000 pax ferry for the best scenario with calm sea, good visibility, sun shining, they think that they can have something like a 4-5 hours rescue operation with confidence to reach 100% or almost of success rate. However, in the worst scenario at night with rough sea, they think it is reasonable to expect something like a 50% success rate.**
- In case of massive evacuation, a support team (sent by the MRCC) can organise sorting and ranking passengers so that priority is given to evacuate by helicopter people requiring the most urgent medical care, mobile people can be sent to lifeboats, etc. and

once onshore they can all be disseminated in hospitals or redirected to victims psychological support etc.

- **Counting passengers is a real issue**; in the event of a massive evacuation in bad weather, one cannot expect the numbering of casualties to be definitive before several days.
- Crewmembers are trained for using classic life saving appliances (safety training or BAERS in French) but what happens if new types of appliances are fitted on the ship?
- A real step forward in the rescue process would be to stabilise liferafts by attaching them one to the other.
- **If the abandonment and rescue have to be performed at night, there should be a way to ensure light in the area because it is very complicated to manage LSAs at sea and search and rescue operations.**

Decision for abandoning the ship

- Three actors work closely together: the master, the ship owner (and his crisis management team or/and Emergency Response Services he subscribed to), and the SAR services (in the name of the Coastal State).
- The decision to evacuate the ship is made by the master but can be (relatively strongly) influenced by the MRCC if they feel that the crew (the master in particular) is not able to manage the crisis.
- **The decision to evacuate strongly depends on the assessment of damages by the crew.**
- **Maximum time before rescue is derived through the operational dialogue between the MRCC and the ship's master.**
- MRCCs may be reluctant to give a maximum time for rescue in a given area given the numerous variables to take into account, however we think that it is precisely one of the objectives of the project: determine time to rescue from a limited number of very significant variables that could be included in a decision support model for evacuation.

2.2.4 *Communications with MCA and RNLI personnel*

Introduction

In addition to the results of the questionnaire for SAR personnel, the MCA and RNLI have provided a good deal of information. Provisional figures[1] from the RNLI indicate that they made 9154 launches from their stations in 2009 for emergencies. There are 235 stations, the busiest of which saw 380 callouts and the least busy only 2. The average number of callouts per station is 39. Of the total launches, 218 were made for commercial vessels. A commercial vessel is defined as any vessel that is not registered as a fishing or pleasure vessel. This would include all passenger vessels and some tankers and cargo vessels.

Issues faced by SAR services

[1] The figures were provisional at the time of the communications with the MCA and RNLI. The actual figures are likely to be slightly higher.

The MCA have provided various anecdotal information from various sources. In some cases this duplicates the information provided in the questionnaires (see section 2.2.2), however this merely illustrates how important these points are given that they have been noticed by multiple people. Below is a list of points related by several MCA personnel who have experience in several different fields through their careers:

- DoT boats, small, rapidly deployable, all-inflatable boats, can be used in Man Over Board (MOB) situations.
- Most cross channel ferries use inflatable liferafts.
    - **These can deform if being towed by a lifeboat at more than 4 knots – causes flooding of passenger compartment.**
- DoT boats are not suitable to tow larger liferaft (~100 persons) away from side of ship due to suction. The thrust is too weak which can be problematic if the ship is on fire.
- **A lifeboat coming alongside a liferaft in only moderate sea can hit the liferaft with sufficient impact to damage it and possibly cause injuries to the evacuees on board.**
- **Inshore Life Boats (ILBs) are not so good at coming alongside a distressed ship, even in mild-moderate seas. They can receive damage from heeling action.** Following on directly, in this case an All Weather Life Boat (ALB) is needed to transfer passengers to the ILBs. It acts as a jetty.
- **Abandonment protocol – disabled are always left to last so as not to slow the effort. If anybody was to be left behind it would be them. The procedure tries to preserve family units if possible.**
- **Passengers in water – rescue boats can hit them in eagerness to go to help (Marchioness disaster mentioned) causing injuries with propellers etc**. The first ILB on scene should stand a good distance off to coordinate. There was a case of a lifeboat arriving and people jumping off ship in eagerness to reach the lifeboat.
- Use of Rigid Inflatable Boats (RIBs) – used to recover single passengers away from the main rescue effort. Also to transport firefighters, equipment etc.
- Procedure to usually put a man aboard the distressed ship to aid with communications (for example if crew is non-English speaking yet in English waters).
- On one exercise they tried ship-ship transfer and found that certain gangway openings had been painted shut.
- SAR personnel need to know which liferafts have been emptied when going round. When doing SAR for Estonia they cut the canvas off the top of liferafts when they were emptied so it was visibly empty.
- More resources are dispatched for larger problems, involving more potential casualties.
- Large numbers of survivors can overwhelm the police as they are responsible for logging and then caring for the survivors.
- **There are no dedicated units for more than 100 miles offshore.**

Many of the points above illustrate the difficulties that SAR bodies face. There is yet another mention of towing points failing on liferafts and the buckling at higher speeds. Several of the points contain recommendations in themselves.

Some of the issues raised are also of specific interest. The man who referred to using an ALB as a jetty to allow passengers to embark onto ILBs and be transferred to Ryde pier raised the point that transferral to such a location not only enabled the evacuees to be treated and sheltered immediately, but it also allowed for the confinement of the evacuees if they had been causing any trouble. **On more than one occasion the MCA have mentioned**

simulating awkward or aggressive passengers in drill exercises, so this is obviously something that might need to be considered at all stages of the evacuation process.

When asking Masters of SAR vessels it becomes all the more apparent how important the location of the ship is. As stated above if the ship is more than 100 miles from the shore then it is relying on other vessels and not specialist SAR vessels for rescue. This will have a major effect on the efficacy of the rescue.

2.3 Evacuation drills

2.3.1 Experience from the MCA and RNLI

This section includes information from many different sources, first of which are the questionnaires that are mentioned in sections 2.2.1 and 2.2.2. Additional sources of information for this section come from correspondence with the MCA and RNLI. Members of the consortium have also attended ship evacuation drills in the last year. Links have also been established with the SAFEGUARD project for the mutual exchange of data on an initially superficial level. From this, a firsthand view of the SAFEGUARD mustering trials, of September 2009, has been included.

Firstly, we have received a lot of information from the MCA relating to drills. Some of the basic information is listed below; it also refers to some of the points made in the regulatory analysis in section 2.1:

- There are fire drills organised weekly.
- Abandon ship and fire drill are required within 24 hours of leaving port if 25% of crew have not done an abandon ship drill on that ship in the previous month or if the ship is in service for the first time or has just been refitted.
- If passengers are due to be on board for more than 24 hours a full muster must take place within 24 hours of embarkation.
- There are no specific evacuation (abandonment) testing requirements. At time of build, the ship must satisfy SOLAS (can be done by computer modelling).

The above listing details the drills that both the crew and passengers will be subjected to on a typical voyage. It should be noted that if the passengers are on board a short haul ferry, they will not be required to do a muster drill, so on these ships the passengers will be more unfamiliar with procedure.

No evacuation test of any new ship is undertaken. This has all been considered in the build phase, so that the ship will comply with SOLAS regulations. It can be modelled on computer prior to building in the design phase. An actual evacuation test of a ship would be extremely time-consuming and expensive for all parties involved. As mentioned by one Master in the questionnaires (see section 2.2.1), there is also the problem that drills like this are generally conducted in calm conditions with young healthy volunteers. This will likely be far from the reality of an actual emergency situation.

One member of the MCA who has worked as a Coxswain of a Lifeboat gave this testimony with regards to his training for on scene duties. “I have never had formal MCA instructions on my duties and responsibilities in attempting to get these loaded Liferafts away from the casualty craft, ever been formally instructed by MCA how to tow them, where to tow them and what is supposed to happen to them once they are in the rafts". This is the same person was quoted in the questionnaire section talking about the propensity of liferafts to deform when being towed and to lose their towing points. This is obviously a real issue when involved in a real life, or even a drill, evacuation scenario.

Another member of the MCA was able to provide extra information on some of the problems they have experienced in drills. He expresses the fact that the passengers in the drill are often interested in being part of the drill, but can sometimes really resent the fact that they have to participate in a drill. He says that in most mustering drills the main difficulties are in getting the passengers to their relevant mustering stations. They will do things like go back to their cabin to retrieve their lifejacket, or valuables.

He mentions that **in one situation they were using actors pretending to be awkward passengers, but that the situation got out of hand and resulted in a real fight and subsequent arrests. This is important as it shows the sort of behaviour that the crew might have to deal with in a real incident and how they might respond in a tense situation. The tension would be far worse in a real incident too.**

In another situation, the MCA had an actor on board a ship pretending to be semi-conscious. The ship's doctor subsequently injected him with adrenaline and he had to be taken to hospital to recover. Again, if mistakes like this can be made in an exercise, it is important to see that people might make many more mistakes when under the intense pressure of an emergency situation.

Finally this MCA member mentioned various problems with automatic doors encountered in drills. On one occasion some fire doors closed suddenly and before they were supposed to, trapping passengers as they were walking through and causing some minor injuries and delay. On another occasion the watertight doors were set wrongly for the drill and the resulting confusion was so bad that the drill had to be abandoned. Fortunately, on both these occasions it was a drill and the doors had been set to react in a certain way. However, **it is important to note that the doors can be used in an unexpected way and this can cause confusion and injuries and severely delay the mustering and abandonment effort.**

The RNLI has several different types of boat available to it. There are five classes of weather boat, 3 of ILB, hovercraft and launch vehicles. The training that people would receive would depend on the sort of boat that they were being trained to use. Nevertheless, some sort of seagoing exercise is undertaken by each crew at a frequency of once per week. Onshore training is mostly aimed at new recruits, or people who are to receive some sort of specialist training in some particular field.

2.3.2 Attendance to a ferry ship evacuation drill

All of BMT, BV and SaS are involved in the SAFEGUARD project. SAFEGUARD hopes to undertake several sea mustering trials over the course of its runtime. So far, one mustering trial has taken place in Norway, involving a passenger ferry. While no personnel from the FloodStand project actually attended the trial, several members of BMT attended the trial, so a brief interview has been conducted with one of the persons who was in attendance. This interview was intended to provide an overview of the situation, not least because BMT is not currently in possession of the numerical data that resulted from this trial.

The ferry was on a crossing from Norway to Denmark taking a few hours only. At this trial, the passengers were offered tags on lanyards to go around their necks. This was on a voluntary basis. Some refused and some accepted the tags, but then didn't take part in the trial. Videos were set up in the main corridors to film people's interactions. Three decks were included and monitored, although the 3rd deck was mostly crew quarters and the bridge. There were 4 muster zones: one on the middle deck and three on the lower deck. At least two of the muster stations were in seating restaurant areas, which had the result that some people were already within the mustering areas when the alarm went off. Assembly times derived from the tags are still under analysis, but people also timed the mustering with stopwatches. All times were found to be satisfactorily within IMO guidelines. Exact times are not yet available though. Finally the varying dispersal of the passengers and their lack of knowledge of the location of the muster points resulted in slower movement of the passengers and uneven filling of the muster stations.

The general experience seems to have been good and that the process went fairly smoothly. The exercise has indicated that for a number of reasons, it would be beneficial to perform the exercise more regularly in future to allow for crew turnover and shifts. Indeed, shipowners are now investigating the implementation of this policy. Even the passengers were impressed by the importance of the trial and how it could be help save their lives.

2.3.3 Attendance to a cruise ship evacuation drill

BV had the opportunity to attend an evacuation drill on a cruise ship. After the drill, they had a debriefing session where they could discuss the evacuation procedures with some of the company's safety management personnel and have the feedback from experienced ship Masters. The outcome of these drill and discussions is summarised below:

<u>Population description</u>

Onboard a cruise ship there may be almost only retired people. There may be therefore a large majority of elderly persons with significant mobility difficulties. A small but significant percentage of them would possibly need a wheel chair or scooters, and the larger part would need a hand, a walking-stick, zimmer or a go-walker etc. to help them walk. Special care is given to the size of wheelchairs. They have to be narrow enough to pass through cabin doors so they are not parked in the corridors, possibly making an evacuation more difficult. Some passengers can also suffer from disabilities like blindness or deafness; they are identified even before they board the ship so that they benefit from special care.

Emergency procedure

Company procedure manuals are checked by the Flag State Administration. There are sometimes differences between emergency procedures with regards to the region where the ship is operated, the culture of the passengers and the corporate culture of the company.
As an example, a typical procedure used for the visited cruise ships is summarised below:

- Had an incident/accident occurred, the master sends an "assessment party": 4 crewmembers go on site to report the situation and assess the risks.
- Then, if required by the situation, the master makes a general announcement for crewmembers to reach their emergency position and to get ready (each of them has a clearly defined role to play in case of emergency).
- Then, if required by the situation, the General Emergency Signal (GES) is sounded. People can be asked to go to their cabin, put on warm clothes, and take their medicine, and then to reach their assigned muster/assembly stations. Normally on a cruise ship there is quite enough time to muster (the escalation of events is supposed to be slow compared to ro-pax ships). People who do not go to their cabin are welcome in any muster station and potentially redirected to another one.
- Then, if required by the situation, from the muster stations, people are sent to the Life-Saving Appliances (LSA). They can embark lifeboats, which will be launched at sea only when no other solution can be envisaged. The procedure to go to the LSA is well defined. From a psychological point of view it is never announced to passengers that they have to abandon the ship or any message that could alarm them too much and create disorder in a situation requiring calm. A typical announcement would be like: "As a precaution, you will embark the LSA which will not be launched…".
- Finally, if there is no other option, Life-Saving Appliances are launched and cleared from the vessel.

Additional comments/feedback from experienced drills or accidents

It should be emphasised that in emergency situations crewmembers are determinant in the success of the crisis management and the evacuation. They need to be very effective and there is no time for improvisation. They wear special clothes in order to be visible and easily identifiable.
First of all, they will sweep passenger cabins to be sure that nobody is left aside.
Their role is then to calm people down, direct them to the muster stations, and lead them sometimes; in case a passenger has forgotten his/her medicines or anything vital in their cabins, there are crewmembers at the muster ready to go and look for them.
More generally, crewmembers have to react to the different types of behaviours encountered in such situations: very few passengers will probably panic or be hysterical; some passengers will be active and try to help others while the remaining majority will be completely passive and will follow the flow of the crowd (high level of stress and fear).

2.4 Accident reports

2.4.1 Introduction

In order to collect data concerning accident reports of large passengers ships (more than 250 passengers), a search for flooding accidents in the following data base has been performed.

- MAIB: Marine accident investigation branch.
- TSB: Transportation safety board of Canada.
- ATSB: Australian Transport Safety Bureau.
- NTSB: National transportation safety board.
- USCG: US Coast Guard.

In addition a search of the web for accidents not recorded in the previous databases was performed. Passengers' testimonies, news articles, blogs, videos etc. were also studied.
Although we are only concerned with flooding accidents, some other incidents /accidents (fire, bad weather conditions, life saving appliances) were also considered when the pertaining information was deemed relevant.
The initial sequence of events that led to the accident is not considered relevant to our analysis. For example navigational errors that caused collision or grounding are not mentioned. We focus only on the following aspects:

- Once the situation is identified how it is managed by the master.
- How the crew respond.
- How the passengers react.
- How the evacuation is carried out.
- How the search and rescue is organised.
- How the passengers are rescued.

We consider three critical phases:

- Mustering of passengers.
- Abandonment.
- Rescue of passengers.

Not all accidents have a detailed account of the events and some phases may be more documented than others.

2.4.2 Grounding/flooding accidents

<u>Investigation reports</u>

An extensive search of the databases mentioned above, have been performed. The search has been conducted using the criteria: "large passenger ships", "flooding", "grounding" and "collision". As a result 8 investigation reports have been selected for further study:

- Grounding of the Star princess.
- Grounding of the Royal majesty.
- Grounding of Empress of the North.
- Grounding of Monarch of the Seas.
- Sinking of the MV Explorer2.
- Striking and subsequent seeking of the Queen of the North.
- Capsize of the Herald of Free Enterprise.
- Sinking of the Estonia.

Each accident will be discussed below, highlighting the most relevant aspects for our purpose in this work package 5. More details about each accident can be found in Annex III: Accident investigation.

a) In the grounding of the *Star Princess* no loss of life or injuries were reported. There was only damage to the ship. There were 1568 passengers and 639 crew members on board. The accident occurred 21 miles northwest of Juneau (Alaska). **The Coast Guards were alerted really quickly**. **The Master ordered the crew to assess the situation** and after **he was informed of the extent of the damage and that the ship was stable and in no danger of sinking**, he decided to proceed to a nearby bay where the ship was anchored. **As a precaution he decided to lower the lifeboats to the embarkation deck but did not wake the sleeping passengers and inform them of the situation** as he thought "it would have upset them unnecessarily". Passengers were informed of the situation only the following morning. Passengers were later transferred to shore.

b) In the Grounding of the R*oyal Majesty* which was carrying 1 509 persons, right after the grounding the Master dispatched crew members to assess the situation. The ship did not sustain any damage and no leakage was found. Once this had been reported to the Master, he informed the passengers that the ship had run aground and that they were trying to free the vessel.
The Coast Guards, after receiving a call from a passenger, contacted the Master 45 minutes after the grounding.
It was decided to transfer passengers to ferries to take them to shore but because of bad weather conditions the transfer was cancelled. The ship was finally refloated and after receiving permission from the Coast Guards, the vessel continued its trip.

A parallel can be drawn for these two incidents. In the first case, *the Star Princess*, although the ship sustained damage and there was water ingress the Master decided not to wake passengers and inform them of the situation which could have degraded, but he ordered the lifeboat to be lowered as a precaution. He also informed the Coast Guard immediately. In the second case, the *Royal Majesty*, no damage was sustained. Passengers have been informed of the situation but not the Coast Guards. The Master said he was about to call them, when they contacted him. In any case they were not informed of the situation until 45 minutes after the

[2] Although the MV Explorer is not a large passenger ship as its capacity is 100 passengers, it was included in the study because of the specificity of the accident.

incident. It is also worth mentioning that on board *the Star Princess*, where the situation could have deteriorated, there were almost 700 persons more than onboard the *Royal Majesty.*

c) In the Grounding of the Empress of the North, which happened 20 miles southwest of Juneau (Alaska), **the evacuation of 206 passengers and 46 non-essential crew members took more than 6 hours**. **The Master informed the Coast Guards of the emergency about 3 minutes after the grounding. The crew immediately reported to the damaged area and worked to control the flooding.**
Passengers were informed of the situation and **asked to wear their lifejackets and to proceed to the muster station**. **Once in the muster station, passengers were accounted for and the crew searched and marked all the cabins.**
The Master decided to launch the liferafts as a precaution but considered them only as a last resort because of the large number of elderly passengers.
When launching the liferafts **the hand pumps failed to activate the mechanism in almost half of the liferafts**. Crew had to cut the lines to launch the liferafts. There was also a **problem with 2 evacuation slides** which inflated upside down blocking the embarkation and the exit. They had to be cut loose and manually turned over and secured to allow the embarkation. It took 15 minutes for the crew to deploy each slide.
About an hour after the accident the first rescue vessels came alongside the ship. It took about 3 hours to transfer passengers to a small passenger vessel, a towing vessel and a cutter which were among the vessel which replied to the distress call. **Among the passengers there were 4 wheel chair users and 5 people needing assistance**. It took different times to transfer different groups of people as shown in the table below.

Number of persons	Time	Transferred to
30 passengers and 3 non essential crew members	16 minutes	1st fishing vessel*
13 passengers and 1 non essential crew members	17 minutes	2nd fishing vessel*
52 passengers including 4 wheel chairs and 5 people needing assistance to walk	55 minutes	Small passenger vessel
22 passengers	56 minutes	Towing vessel
89 passengers and 38 non essential crew members	43 minutes	Coast Guards Cutter

Table 4: Results of question 4.2 of the questionnaire for SAR bodies

* Passengers and crew on board the two fishing vessels were then transferred to the towing vessel.

After all passengers and crew members left the *Empress of the North*, the Coast Guards decided to have all passengers and crew members transferred on board a ferry which came to assist, as they thought it a better platform that could accommodate everybody. **It took more than 2 hours and a half to transfer all the persons onboard the ferry.**

d) <u>In the Grounding of the *Monarch of the Seas*</u>, **it took around 2 hours and a half to disembark 2 400 passengers**. Compared to the previous accident, it took roughly the same time for the *Monarch* to evacuate 10 times more passengers. In both cases the ships were safe and allowed for an orderly evacuation.

Some interesting facts about the *Monarch of the Seas* grounding are:

- The Master was quick to react to the situation. He **informed the Port authorities about 10 minutes after the ship hit the rocks and after he was informed about the state of the flooding, he took the decision to intentionally ground the ship on a sandbank, which was done 1 hour after the collision.** An hour and a half after the grounding the damage control reported that the water level was stabilized and less water was coming in.
- **Passengers were mustered and cabins (crew and passengers) were cleared 50 minutes after the collision with the reef.**
- **As a precaution, once the vessel was grounded the Master decided to disembark passengers** who were kept informed of the situation from the beginning. He informed them that they will not use the lifeboats, which were already lowered and ready for embarkation 40 minutes after the collision, and that tenders will ferry them to shore. **As there was no power in the hydraulic pumps of the passengers' shell gates, they could not be opened so the crew gate was opened and passengers disembarked through it.**
- It is worth mentioning here that there were no prearranged procedures or advance consideration for a large scale evacuation of the vessel through the side shell ports.
- **Passengers had to come down several decks and use obstructed corridors to reach the side shell gate.**

e) <u>The sinking of the *MV Explorer*</u> was included in this study although it is not considered to be a large passenger vessel, because of the location of the accident i.e **Antarctica,** which is more and more visited by large passenger ships nowadays.
The *MV Explorer* entered an ice field on the 22nd November 2007 with 100 passengers (including 9 members of the expedition Group) and 54 crew members at about 2200. Two hours later it hit a "wall of ice" and sustained damage to a section of the hull which led to rapid flooding.
The damage control group reported to the cabin in which the water was entering the ship and tried to control the flooding. The water was flooding the Separator room from above and although the watertight door between the Separator room and the Generator room was closed, water was seeping through the bottom corner of the watertight door into the Generator room.
At about 0215 a black out occurred and the ship started drifting back to the ice field. The Master decided to abandon the ship as a precautionary measure.
At that time **passengers were already mustered and were left to the care of the members of the Expedition Group (who were not crew members).**
When the order to abandon came, there was some confusion as passengers did not know which lifeboat was assigned to them. Some passengers had to go from lifeboat to lifeboat to search for a place.
Thanks to the crew effort, power was restored which helped the abandonment process. **Zodiacs were launched and were used to tow the lifeboats as their engines failed to start.**

There were reports of a lifeboat almost being lowered onto another one as the one already in the water had difficulties clearing the vessel. Another lifeboat tipped outboard as it slid along the hull because of the list.
Some passengers were transferred to Zodiacs to ease some overcrowded lifeboats.
The crew left the ship when they realised it could not be saved.
Passengers who stayed more than 5 hours in the open lifeboats suffered from seasickness.
Once the rescue vessels arrived**, passengers were transferred from the Explorer lifeboats onto the rescue ship lifeboats which were lowered down**. Once full, they were hoisted up the embarkation deck of the rescue vessel. Passengers who were in the Zodiacs had more difficulty as they had to reach a rope ladder hanging from the sideport of the rescue ship. **Some passengers were too cold to climb the ladder and needed help from the crew**. Three incidents where passengers almost fell into the water were reported.
The rescued passengers were extremely lucky as the weather was calm**. The outcome of the accident would have been different if the weather conditions had deteriorated to gale force wind** as occurred two hours after the passengers boarded the rescue vessel.

f) The RoPax *Queen of the North* sinking accident is a good example of the importance of the passenger head count. The RoPax vessel, which had a maximum capacity of 650 passengers and 50 crew, had 59 passengers and 42 crew members at the time of the accident. The ship sustained extensive damage after it truck the side of Gil Island (British Colombia) at about 0021. Five minutes later the ship Port authorities were informed. The bridge was informed that the engine rooms were being evacuated. The watertight door between the main engine room and the workshop was obstructed by debris, and, as there was flooding on both sides, the crew did not close it. The crew did not have the time to fully ascertain the extent of damage to the hull before evacuating.
Water was accumulating in the crew accommodation spaces on deck 2 and in some cases was waist deep.
An announcement was made over the public address system that passengers and crew were to go to the upper-deck boat and liferaft stations.
All passenger cabins except those on the starboard side of Deck 7 were eventually cleared but not all rooms were physically searched and chalk marks were not placed on doors. Not all cabins were cleared by those assigned to that particular muster duty: **some crew members were delayed by water ingress**; others had already cleared the areas; and **there was some confusion about whether to follow the public announcement (directing people to proceed directly to the upper-deck boat and liferaft stations) versus following the procedure of clearing all passenger areas.**
On Deck 6, the lounges were cleared. On Deck 5, the cafeteria and bar were locked and inaccessible to passengers. It is not known if other public areas on Deck 5 were cleared. Deck 3 was observed to be flooding and was not cleared.
Difficulties were encountered when making accurate passenger counts. As passengers boarded each survival craft, a count was carried out to prevent overcrowding, and these counts were relayed to the Master but were not recorded.

After abandoning the vessel, the Master detailed one person in each lifeboat and liferaft to do a head count, but this was hampered by insufficient flashlights, no means of recording the counts, and no practised method of carrying out counts.
The Master requested several recounts as the totals were not consistent.
When the first rescue ship arrived it was instructed to make a sweep around the *Queen of the North* using a high-powered light, but no one was seen on board or in the water.
One crew member, with the Master's permission, took the fast-rescue boat, with two deckhands and circled the vessel looking for people. The interior of the vessel was visible through the windows. The outer decks were still lighted. **The rescue boat remained on station as the vessel sank, and afterward conducted a surface search.**
Rescue vessels began to transfer the survivors to shore. Arrangements were made to have them met at the dock for a head count and to take their names. Some passengers displayed signs of hypothermia when they reached the shore.
Throughout the remainder of the rescue operation, the number of survivors reported recovered fluctuated so the search was continued.
An aircraft search a radius of 5 nm from the debris field and barrier searches were established at 1.5 nm and 5 nm from the accident site to search for anyone who did not make it into survival craft. The search was concluded about 43 hours after the accident.
Two persons were unaccounted for, and have been declared dead. Their location onboard at the time of the striking could not be determined by the investigation.
3 crew members were treated for minor injuries and 4 others required medical attention for stress.
Although the number of passengers on board was small compared to the actual capacity of the ship (59 passengers and the max capacity 650) an accurate head count has not been achieved. It seemed that passengers had enough time to abandon the ship and no panic was reported.

g) <u>The *Herald of Free Enterprise*</u> with 459 passengers and 80 crew members capsized in about 4 minutes after it passed the outer mole at Zeebrugge. The ship did not sink totally as her port side took the ground. 150 passengers and 38 crew members lost their lives.
The rapid capsize made the deployment and the use of the life-saving appliances impossible, except for the lifejackets. Survivors who had access to the lifejackets found donning them difficult.
A big rescue operation followed the accident as several ships (32 ships according to the report) divers and helicopters assisted and helped rescue the survivors.
The chief Officer of one of the rescue vessels, who was later designated On Scene Commander boarded the wreck, and started coordinating the rescue efforts. Several windows of the Herald were broken to help out survivors by pulling them out.
The lack of lighting was reported as a major obstacle to the rescue operations as diving had to cease due to the danger within the darkened hull. In addition the noise from the helicopters made the communications onboard the wreck almost impossible.

Five hours after the ship capsized it seemed that most of the survivors above water level had been rescued so the rescue effort was organized to start recovering the bodies while still searching for survivors.
Almost 6 hours after the accident three survivors were found in the forward drivers' accommodation. Two hours later the operation was completed.

h) For the sinking of the *Estonia* the main focus was on the passengers and crew reactions and the different obstacles they faced during the evacuation and abandonment of the ship as well as the rescue operation.
Nine hundred and eighty nine persons were onboard the Estonia. **The rapid development of the accident made organised efforts impossible.**
Some individual crew members took the initiative for alarming passengers and organized the evacuation locally.
There was a lot of panic among the crew and the passengers. People were behaving without control and screaming. Others were apathetic and others held on to something without making further effort to save themselves. Many elderly people were seen making no or faint effort to escape.
A few of those who survived behaved in an irrational way but most did not.
Due to the heavy list, objects broke loose and slid away injuring some passengers and preventing other from moving. **Also sliding carpets and slippery floors prevented some passengers from evacuating and slowed down others.**
The time span from the first passengers evacuating until the 45° list was between 15 to 20 minutes. This was greatly reduced for the people who reacted only after the first list. It was estimated that 237 reached the open decks.
None of the ten lifeboats could be launched. Passengers who had access to lifejackets had difficulties understanding how to use them.
Some liferafts were launched by the crew and other inflated automatically when the ship sank. **Many capsized and drifted upside down and many did not fully inflate.**
Some people were forced to jump but most were swept into the sea by waves or slid into the sea inside or outside liferafts. Some 160 people succeeded in climbing onto liferafts or lifeboats which broke free when the ship sank. About 20 of them succumbed to hypothermia or hypothermia induced drowning.
The first rescue vessel arrived about 20 minutes after the Estonia sank. At shore the rescue efforts took time to be organized. The first helicopter arrived about an hour after the first rescue vessel. Its crew started to hoist survivors from the liferafts.
Due to the adverse weather conditions, launching lifeboats to rescue people was considered too risky. Instead, liferafts and slides were used. One liferaft was lowered from one of the rescue vessels with three volunteer rescuers. They managed to get about 20 people on board. While hoisting the liferaft, the bottom ripped and at least five people fell into the sea. Four were later lifted by helicopter and one or more persons were lost. The damaged liferaft with 16 people hanging onto it was lower back to the sea and people were rescue using the evacuation slide.
During the rescue, the winch wire of three helicopters malfunctioned and they had to interrupt the rescue operations for hours. A fourth helicopter had an engine problem and had to return to the base.
Only one helicopter made a successful landing on one of the rescue ship setting down 36 people but it was considered dangerous to land on the vessels so people were transported to land.

Thirty four people were rescued by the vessels and 104 by the helicopters.

Accounts from the web

In addition to the investigation reports, a search of the web provided additional accident accounts for which an official investigation report was not available or was not found on the web.
The information collected came mainly from news articles, blogs, videos or Wikipedia.
A total of eight accidents were selected. All are sinking accidents:

- The Mikhail Lermontov.
- Admiral Nakhimov.
- Royal Pacific.
- Oceanos.
- Sun vista.
- El Salam Boccacio 98.
- Sea Diamond.
- Express Samina.

a) The *Mikhail Lermontov* with 743 people onboard (372 passengers including 5 children) struck a rocky reef at Cap Jackson (New Zealand). Three watertight compartments were flooded and according to the Master's calculation the ship had 4 hours before sinking. He decided to try and **intentionally ground the ship** but the engines stopped. At that time he made the decision to abandon the ship.
He **ordered the lifeboats to be lowered so that passengers could evacuate through the gun port door**. **Passengers were directed by the crew down the stairs and through corridors which were quite dark. Passengers started to board the lifeboat which was level with the deck with the help of the crew. Because of the list passengers were not able to use the gun port door anymore and they were rushed back to the top levels where rope ladders were tossed. As the vessel listed further the rope became too short and passengers had to jump.**
Crew members who search the vessel for passengers at the Master order found 4 **elderly passengers and help them evacuate**.
Once the rescue vessels arrived they lowered their lifeboats and passengers were transferred into the rescue lifeboats. They were then hoisted to the rescue vessel deck.
One person fell into the water unnoticed during the passengers transfer from lifeboats to lifeboats. He spent 2 hours in the water before being rescued by launches towing back the abandoned lifeboats.
A head count of the passengers was performed while passengers were ferried to land. When a check of the crew against the list was performed, they found out that one crew member was missing. It was an Engineer who was in one of the flooded compartment at the time of the accident.
Passengers suffered hypothermia and broken bones. It is worth noting that, the average age onboard the *Lermontov* was 70 years.

b) <u>The sinking of *the Admiral Nakhimov*</u> was due to a collision with a freighter. The light went out upon impact as the impact was between the engine and the boiler room (84 m^2 hole). **The ship sank in only seven minutes preventing any evacuation.** Hundreds of people dove into an oily water clinging to anything they found.
Rescue ships began arriving just 10 minutes after the ship went down. 64 rescue ships and 20 helicopters came to the rescue. 811 people were rescued from the 1234 who were onboard. Some passengers were difficult to pull out of the water because of the fuel oil. 423 people perished.

c) <u>The *Royal Pacific*</u> sank too after a collision with a small fishing factor, which caused extensive damage. There were 355 passengers and 179 crew members onboard.
The engine room was flooded within minutes and the ship quickly heeled over as water rapidly entered the cabins on the decks above.
The Captain quickly ordered to "abandon ship" and all lifeboats were launched. Survivors were picked up by passing ships.
Rescue officials said it appeared there had been more than sufficient time to launch lifeboats from the Royal Pacific. The cruise ship sank about two hours after the collision.
Three people drowned during the rescue and six others were reported missing. It assumed that they were trapped inside the hull.
At the time of the collision, the *Royal Pacific* was just 12 miles out of Singapore.

d) <u>In the sinking of the *Oceanos*</u>, the ship lost power and water was entering through a 10 cm hole in the bulkhead, after a muffled explosion was heard at about 2130 hrs.
The crew fled in panic when they realized the fate of the ship. **Passengers were not informed of the situation until they witnessed the signs of flooding in the lower decks.**
Most of the crew used the lifeboats to evacuate. **According to passengers testimony the entertainment staff took the situation in hand and organised the evacuation of the passengers. Women with children were the first to board a lifeboat.** They then stayed on the boats for more than 10 hours without water or food before they were rescued. **The bad weather conditions prevented them from being rescued earlier.**
It was also reported that the **lowering mechanism of the lifeboats was stuck and that the rowing mechanism jammed in a lifeboat and broke in another one.**
The remaining passengers on board the ship which was listing heavily (25°-30° according to a passenger) were hoisted by helicopters which arrived when it started to get lighter.
Some passengers had to jump into the sea and were pulled onto a rubber dinghy. They were later transferred to a lifeboat.
The helicopters were responsible for hoisting and evacuating 225 from the 571 initially onboard. There was no loss of life.

e) The Sinking of the *Sun vista* is another account of crew panicking.
A fire broke out in the main engine room switchboard of the *Sun vista* with 1,104 passengers and crew onboard causing a power cut. A distress signal was sent more than three hours after the fire was first reported.
Passengers were banned from returning to their cabins because of the power-cut but they were told there was not a problem.
It is believed that the heat from the fire buckled plates below the water line, allowing the sea to rush in.
After crew failed to control the fire the order to abandon ship was given.
The crew of the *Sun Vista* was said to have panicked during the evacuation.
A 62 years-old passenger reported that the crew did not seem to know what they were doing as passengers pulled on lifejackets and scrambled into lifeboats. He reported **problems lowering the lifeboat as it took about 10 minutes to lower one end of the boat**. Nobody seemed to want to take charge. Luckily there was a passenger in the boat who seemed to know what he was doing.
Passengers were taken off in 18 lifeboats and four life rafts. Some floated up to 8 hours awaiting rescue ships with nothing to eat or drink. Some passengers suffered seasickness.
It was reported by a 76 years-old passenger that the lifeboat he boarded was overloaded. There were 76 people in when the capacity was 45, and the person responsible for it didn't seem to be very confident. They started the engine and it cut out. They started it again and it still didn't last long. Eventually they got the oars out but couldn't make much progress.
The ship sank around seven hours after the first distress signal. At least 16 passengers were admitted to hospital with minor injuries.

f) Sinking of *Al Salam Boccaccio 98* seemed to have been the result of indecision, lack of leadership, a disorganised and unstructured response from the Master, and the fact that officers and crew had little or no idea how to respond to a fire on board.
Shortly after departing, survivor accounts indicate that a fire broke out either in the engine room or a storage area below decks. Some survivor accounts indicate that the ship was listing shortly after leaving port and, after several hours the list gradually became more pronounced. At no time did the ship send an SOS signal indicating that it was in trouble.
The ship's captain had attempted to effect a 180-degree turn between 60 and 80-kilometers from the ship's intended destination. The ship capsized during the turn and sank in less than 10 minutes.
The ship was carrying about 1310 and 100 crew.
The automated distress signal was relayed to the Egyptian Authorities. However, it would be almost 12-hours before any rescue attempt would get underway.
Once rescue efforts commenced, 4 Egyptian frigates and other rescue boats searched the area as well as an aircraft from the U.S. government.
Of the over 1,400 passengers and crew onboard, almost 400 were reported rescued.
The number of bodies recovered was reported the day after the accident as being 185.
According to one passenger's testimony four hours into the trip, He was in his cabin when two crew members broke into the room and ordered to go up on the deck because there was fire down below.

He reported that they heard a voice from the ship's speakers ordering passengers to go to one side to help balance the ship. The situation was terrible.
He said that the crew told the passengers that the situation was under control, but then the fire spread to the first floor. The ship's listing got worse. When the ship began sinking, he and his friends jumped into the cold water; his two friends died drowning. He survived by clinging to an upturned lifeboat. No one according to him knew how to use the lifeboats.
He tied himself to the boat with other people and they helped each other to stay awake. He reported bodies of dead people everywhere.
He saw some people sinking because others were holding on to them trying to save themselves.
In less than six hours, three of the people holding to the boat died. He said they were in terrible psychological shock. He reported that at 1 a.m. they saw a big private boat passing near them. They signalled to the boat with the light they had and it came to their rescue.

g) The *Sea Diamond* took about 16 hours to sink after it ran aground on a volcanic reef near a Greek island. 1,193 passengers were evacuated in three and a half hours. Two passengers were reported missing and their bodies never found.

The ship was really close to the shore.
Many passengers (mostly elderly people) found it difficult to overcome the physical obstacles during the evacuation. They had to climb down rope ladder or climb into lifeboats to be transferred to safety.
Many passengers also reported panic and a lack of preparedness from the crew. They described the early stage of the evacuation as being chaotic. They also reported not being kept informed about the situation.

h) The *Express Samina* accident is another instance of **a situation developing rapidly not allowing for an evacuation**. The ship with about 472 passengers and 61 crewmembers hit with her side the rocks of an islet.
The ship sailed with all watertight doors open.
The main engine room was quickly flooded and soon afterwards a black-out occurred. The emergency power generator also failed.
No measures to delay flooding or close the watertight doors were taken. It was reported that the engine room crew did not report in time to the bridge, and they were the first to try to abandon the ship. The radio officer also abandoned the ship without the permission of the Captain.
Passengers were not informed of the situation or instructed to abandon the ship. The ship listed heavily in few minutes and it was impossible to launch the lifeboats. It took only 15 minutes for the embarkation deck to reach the sea level. The ship sank approximately 50 minutes after hitting the rocks.
Panic was reported by the survivors. A group of about 12 people managed to board a lifeboat which later hit rocks. Passengers managed to clamber onto the rocks and waited 3 hours before they were rescued by a helicopter.
Survivors were reported having suffered from hypothermia, shock and minor cuts and bruises. It is believed that of the 80 people lost a large number did not manage to escape the ship.

The ship sank very close to the port of Paros, (merely 0.3nm from the closest shoreline). Consequently, many boats coming from the port took part in SAR what significantly accounted for the limited number of fatalities (80). Regarding the speed at which the ship sank, the sea state (storm) and the dark night, it would have been most likely a major ship disaster if the ship were far from the shoreline.

Summary

In total 16 accidents were studied. In 7 cases no loss of life or injuries were reported.
In four accidents ships were stable and in no danger of sinking.
For the 12 sinking accident survival time is reported in the table below along with the loss of life. In 4 cases there was not enough time for a proper mustering and evacuation of passengers.

Ship	**Approximate survival time**	**Loss of life**
MV Explorer	20 hours	None
Queen of the North	1 hour and 20 minutes	2 missing, declared dead
Herald of Free Enterprise	Capsized in 4 minutes did not sink completely	188
Estonia	50 minutes	94 bodies, 757 missing
Mikhail Lermontov	5 hours	1
Admiral Nakhimov	7 minutes	423
Royal Pacific	2 hours	6 missing
Oceanos	18 hours	None
Sun Vista	10 hours	None
Al Salam Boccacio	10 minutes	About 1000
Sea Diamond	15 hours	2 missing
Express Samina	50 minutes	80

Table 5: Summary of the flooding accidents investigated

In two of the total 16 accidents, loss of life was reported during rescue operations (at least one death for the *Estonia*, and 2 deaths for the *Royal Pacific*).
The following table gives, when available, the times to muster and evacuate as well as the time for the rescue to arrive for all the studied accidents.

Ship	Persons onboard	Casualties	Mustering time	Time to evacuate	Time for rescued to arrive	Length of rescue (/search) operation	Ship state	Notes
Star Princess	2 207	0	No mustering	No evacuation	N/A	N/A	Stable	Water ingress but passengers not informed
Royal Majestic	1509	0	No mustering	No evacuation	N/A	N/A	Stable	No water ingress. Passengers kept informed
Empress of the North	281	0	N/A	3 hours	52 minutes after accident	6 hours	Stable	Passengers transferred to several rescue vessel, then transferred to one platform.
Monarch	2557 (Pax)	0	less than 50 minutes	2 hours and half	10 minutes after grounding	about 3 hours	Stable	Time for the rescue to arrive is after the intentional grounding.
MV Explorer	154	0	N/A	N/A	6 hours	N/A	Sank	Fair weather
Queen of the North	101	2	N/A	Less than 30 minutes	52 minutes after accident	43 hours	Sank	The reason for the long rescue operation is the search for the 2 missing passengers
Herald of Free Enterprise	539	188	No time to muster	No time to evacuate	2 minutes	8 hours	Sank	No time for proper evacuation. Calm weather
Estonia	989	851	No time to muster	No time to evacuate	20 minutes after sinking	18 hours + 6 days	Sank	Passengers had at the most 20 minutes to reach the embarkation deck. Adverse weather
Mikhail Lermontov	743 (pax)	1	N/A	N/A	2 hours after distress call	N/A	Sank	Person fell unnoticed during rescue and stayed in water for 2 hours

Ship	Persons onboard	Casualties	Mustering time	Time to evacuate	Time for rescued to arrive	Length of rescue (/search) operation	Ship state	Notes
Admiral Nakhimov	1234 (Pax)	423	No time to muster	No time to evacuate	10 minutes after accident	N/A	Sank	
Royal Pacific	534	6	N/A	N/A	N/A	N/A	Sank	Two death during rescue operation
Oceanos	571 (pax)	0	N/A	More than 10 hours	N/A	7 hours	Sank	Part of the people onboard evacuated the ship by lifeboats but stayed in them for 10 hours. The rested left the ship several hours later by helicopters
Sun vista	1104 (pax)	0	N/A	N/A	N/A	N/A	Sank	Passengers had to stay in lifeboats at least for 8 hours
Al Salam Boccacio 98	≈1400	≈1000	No time to muster	No time to evacuate	N/A	N/A	Sank	
Sea Diamond	1195 (pax)	2	N/A	3 hours and half	Immediate	N/A	Sank	
Express Samina	533	80	No time to muster	No time to evacuate	N/A	N/A	Sank	Some survivors waited 3 hours before being rescued. Bad weather conditions

Table 6: Times to muster and evacuate as and time for the rescue to arrive for all accidents investigated

2.4.3 Other incidents/ accidents

While searching for the accident data, some other incidents not related to flooding or grounding were pin-pointed as some aspects were deemed relevant for this report.

a) List due to heavy weather: in the Pacific Sun incident[3], with 1730 passengers and 671 crew on board which resulted in 77 injuries (7 with major injuries) to passengers and crew, two aspects are worth mentioning:

- Many of the injuries sustained by the passengers and crew were caused by falls and contact with unsecured furnishings and loose objects in the busy public rooms, **including those designated as passenger emergency muster stations**. Following the accident, **the moving furniture and debris made many of the public rooms unusable**, and the Master instructed the passengers to return to their cabins for their own safety. Following the Master's instructions it took almost **4 hours to the crew to account for all the passengers.**
- Sight of the crew in lifejackets caused concern to many passengers as the crew alert normally precede the general alarm meaning that the crew were in possession of their lifejacket when passengers were not.

  In this situation, muster stations were unusable.

b) Rescue unable to reach the accident scene: in the capsize of the *Princess of the Stars* with 700 or 800 passengers onboard, only 4 survivors were reported. The extreme weather conditions (Typhoon) prevented any rescue operation to be launched. Contact with the ship was lost at about 12:30 on Saturday. The Navy tried to send its vessel at 10:00 a.m. Sunday to help rescue the victims. But due to bad weather and big waves, the vessel retreated.

A **rescue vessel** battling huge waves managed to **reach the scene more than 24 hours after** they lost radio contact with the ship.

c) Casualties during evacuation: The Achille Lauro was sailing 50 miles off the Somali coast with 1090 people on board. A fire broke out in one of the cabin. The fire could not be controlled so the ship was abandoned. **During the transfer** of passengers to the rescue ship **two people lost their lives** and eight were injured.

Several lifeboats incidents were also noticed. This issue was already identified in the Safecrafts project.

[3] MAIB report 14/2009. June 2009

2.5 Summary/conclusion

The purpose of FLOODSTAND Task 5.1 is to provide benchmark data for developing and testing the models of mustering, abandonment and rescue that will come out of WP5, as presented in section 3 of this report. This information will inform the models to be developed, hopefully making them as accurate as possible. The data was collected through various sources from interviews to accident investigation.

The analysis of interviews mainly provides input for the rescue phase for large passenger ships. It appears that this is a quite problematic phase regarding the means allocated due to the fact that it is almost never addressed (only now shipowners and SAR are sounding the alarm). There are here several factors to be taken into account for the assessment of the risk linked to the abandonment of the ship.

The questionnaires with the additional information provided, give the user an insight into the state of affairs in the MAR process from the point of view of people who have actually experienced such situations. The majority of information is of the form of a broad overview of the situation, but the details are particularly interesting, not least when they are repeated by multiple persons. These are the things on which specific efforts need to be focussed when analysing the data. The response to the questionnaires has been generally good although the participation in the SAR body questionnaire was not very high. However, the extra information provided from the MCA and RNLI is felt to adequately make up for the slight lack of response.

Generally, the data analysis allowed us to identify a certain number of factors/issues/phenomena which can have a significant impact on the assessment of the risks associated to the abandonment (MAR) of the ship and consequently, on the decision of abandoning the ship or not. These factors/issues/phenomena are summarised in the following sections regarding their relevance to:

- The whole MAR process.
- Mustering.
- Abandonment.
- Rescue.
- Decision-making (master).

2.5.1 The whole process

<u>Passengers</u>

- There are enough abandon ship drills and safety briefings or demonstrations to assume that both the crew and passengers have a quite good understanding of how to behave in an emergency.
- The population of cruise ship passengers can vary a lot from one ship to the other depending on the theme of the cruise. However, generally, there is a significant part of the passengers who are elderly persons.
- Elderly persons who generally represent a significant part of passengers on cruise ships can have significant mobility issues; they may require help for walking or a wheelchair. Moreover they can be more easily injured and it may impact the masters' decisions to evacuate the ship as a precaution.

<u>Crew</u>

- The crew is assumed to be efficient in helping passengers along the MAR process, guiding them and safeguarding the passengers' life as much as they can
- The master may or may not inform immediately the SAR services of an incident/accident occurring onboard.

<u>Procedures</u>

- The typical sequence of events or procedures assumed for cruise ships and ro-pax or ferry ships are derived from the table below:

DECISIONS FOR EVACUATION	ASSESSMENT OF THE SITUATION	MITIGATION/CONTROL ACTIONS
Alert/inform MRCC services	Assessment party sent by the Master	Close watertight doors
Send distress signal	Assessment party sent by MRCC	Stop engines
Ask all crewmembers to get ready for managing a possible evacuation	Stability calculations computed onboard	Ballasting operations for stabilising the ship
Sound the General Emergency Signal	Stability calculations processed ashore by the ship operator	Start pumps
Ask passengers to go to their cabins to get their lifejacket	Stability calculations computed ashore by emergency response services	Beach/ground the ship
Ask passengers to go assembly stations		SAR personnel
Ask passengers to (get ready to) embark LSA		Deployment of aeronautical SAR means of rescue
Ask passengers and crewmembers to abandon the ship		Deployment of nautical SAR means of rescue
		Help from other ships

Table 7: Elements of the MAR sequence

- The sequence of actions and decisions will significantly depend on:
  - Severity of the damage
  - Depth of the water

- Weather.
- Number of passengers.
- Evacuation facilities.
- Temperature of the water.

Other

- We can assume that ships operating in polar zones are provided with adapted equipment and arrangement and that these are maintained in good condition.

2.5.2 Mustering

Crew

- We assume that crewmembers go and find passengers trapped in their cabins.
- Passengers can be extremely difficult to count; particularly when the ship is full and they fill the muster zones.

Passengers and crew

- There may be numerous obstacles slowing or injuring people on the route: sliding carpets, slippery floors.
- Moreover, when the ship is listing, it is much more difficult to evacuate because of mobility difficulties and objects falling, obstructing the way to embarkation decks or being projected on passengers.

2.5.3 Abandonment

Embarking LSA

- We assume that in normal conditions, the maximum time for filling in all LSA is 30 minutes.
- Passengers can get injured as they get to the bottom of the evacuation slides.
- Injuries can easily happen in the MES chutes, particularly with elderly persons.
- Abandoning the ship at night with poor luminosity means a longer abandonment time and a more difficult abandonment process.

Launching LSA

- The equipment can sometimes be quite old even on newer ships and the crew can have problems operating the old machinery.
- If the LSA is full, the ship is listing or the sea state is bad it can be hard to launch.
- Because of the list lifeboats may slide along the hull and tip outboard.
- Launching lifeboats is even impossible when the vessel is significantly listing.
- Winch/davit/hook failures do happen and have caused severe injury and even death.
- Hooks may damage LSAs.
- An ALB may be needed to transfer passengers to ILBs.

Clearing off the flooded ship

- Manoeuvrability of the LSAs can be an issue: there is sometimes not sufficient towing power to move the rafts away from the sinking ship.

- Rescue boats can be useful for retrieving passengers at sea during the abandonment.
- Lifeboats may have difficulties for clearing the vessel.

2.5.4 Rescue

SAR operations

- Masters know exactly the relevant MRCCs to contact in case of an emergency. Or at least the distress message is quickly forwarded to the relevant MRCCs.
- Boats aren't built for easy retrieval: this is specifically a problem when the sea state is high and the passengers may be suffering from exposure or hypothermia.
- The SAR coordinating body will attempt to organise the whole effort with the assistance of on scene ships. It will arrange reception points in the form of either another vessel, or a space on land.
- The main point made by SAR services is that early and swift evacuation is usually the best option.
- The time before rescue may be assessed by SAR services during discussions with the master.

LSA

- LSAs are designed so that people in the water can board them or can be recovered easily by them.
- There is no evidence that liferafts can be safely towed at a speed higher than 3knots or/and for a sea state other than calm.
- Engine/rudder failure on lifeboat can happen.
- Towing points of liferafts are fragile.
- Height of the access points above the waterline on both the SAR craft and the LSAs once launched can be unsuitable.
- A lifeboat coming alongside a liferaft in only moderate sea can hit the liferaft with sufficient impact to damage it and possibly cause injuries to the evacuees on board.

Survival at sea

- If the sea is fairly calm and the temperature reasonable, then the LSAs can potentially stay afloat with little or no harm to the passengers for a relatively long time. The only problem in this case might be the relative drift and dispersal of the LSAs: keeping liferafts together after embarkations is not easy.
- Survivors in the water may be hit and injured by rescue boats.
- Hypothermia may have a very significant impact on the passengers' capacity to survive. They may not be able to climb ladders anymore for instance.
- Weather conditions will have a strong impact on the human casualties during all stages of the MAR process.
- Elderly passengers would definitely suffer from hypothermia and likely bone fractures too.
- In heavy weather conditions, people may slide from the liferafts into the sea.

Recovery

- Rescue ships may be able to recover hundreds of people from the sea, in case they did not have time to evacuate in LSA.

- On recovery passengers can slide while stepping on the egress points from liferafts over the inflated tubes.
- In case of the distressed ship relying on assistance from other vessels (for example, ship at more than 100 nm), these vessels are not equipped to lift survivors from liferafts or on the surface. It is hard to expect people to climb service ladders when cold or even hypothermic.
- Evacuation slides and liferafts may be used as a means to transfer people from LSA to a rescuing ship.
- Bad weather can prevent rescuing boats from launching their lifeboats to recover people at sea.
- There are different solutions for the massive recovery of passengers by SAR services:
  - Helicopters: only a very restricted number of coastal States can provide such means and they cannot be used in bad weather.
  - Assistance by passenger or rescue vessels: raises the issue of how the transfer is practically done.
  - Towing of LSAs to the shore or self-propelled LSA reach the shore by themselves.

Remote/polar areas

- Passenger ships operating in areas remote from SAR facilities are likely to receive support from a ‘paired’ passenger vessel.
- The geographical location of the accident is extremely important as it restricts the speed at which help can arrive.
- Rescue of a ship in a remote area can mean that SAR services need more than 5 days to access the accident scene, however ‘pairing’ is a common practice: a rather quick response from the paired ship can be expected.

2.5.5 Decision-Making

Decision support system

- Damage stability simulations are already used as Decision Support Systems for the master.
- Trim and stability booklet, damage control plans and booklet and contingency plans are mandatory so we assume that:
  - For a given flooding condition, the master has a good idea of what options he has for controlling/limiting the escalation of events and the consequences.
- Wrong decisions could easily be made in the event of a disaster and an advanced decision support system (DSS) would be useful.

Criteria

- The master will generally try to keep passengers onboard the ship as long as possible. Therefore, survivability of the ship is the priority.
- For making the decision to abandon the ship or not, the most important thing that the master need to be provided with is the survival time of the ship; they seem to be able to assess by themselves the time required to abandon the ship.
- Then comes the environmental conditions as a criterion for making the decision for abandonment of the ship: if the ship is going to stay afloat a long period but is

likely to sink at the end, regarding the environmental conditions, is it safer to wait onboard or immediately abandon the ship?

- Location of the ship (proximity of SAR services, traffic in the area) is not judged a very important factor for making the decision.
- SAR services may help in finding the appropriate strategy for managing the event.

3. SCOPE OF WP5

3.1 The concepts

3.1.1 Human Health Status

Passenger ships' masters will normally try to keep passengers onboard as long as the ship is considered as a safe place because evacuating and abandoning the ship represents a certain potential for hazardous situations, congestion issues, injuries and death of passengers. **In order to assess the risk for passengers to abandon the ship, some indicators have to be chosen. One of them is the Health of passengers**.
Health of passengers onboard the ship can be modelled as explained below:

- 'h' is a continuous variable representing human health, taking values in [0;1], 0 being perfect health and complete mobility, 1 being a fatality.
- 'a' is a continuous variable representing age, taking values in [0; amax].

For a given age 'a', f(h,a) is a probability density function providing the probability of having a passenger in health 'h' defined by:
$f(h,a)\cdot dh$ is the probability that health status is comprised between 'h' and 'h+dh'

$p(h \le HS < h+dh)$ so that $\forall a \in [0, a_{\max}]$, $\int_0^1 f(h,a)dh = 1$

In other words, the health status of a given passenger is represented by a probability density function, function of its age 'a'.

A surface describing the probability of having a passenger of a given age in a certain health can be plotted with f(h,a). An example is provided on figure 1 below:

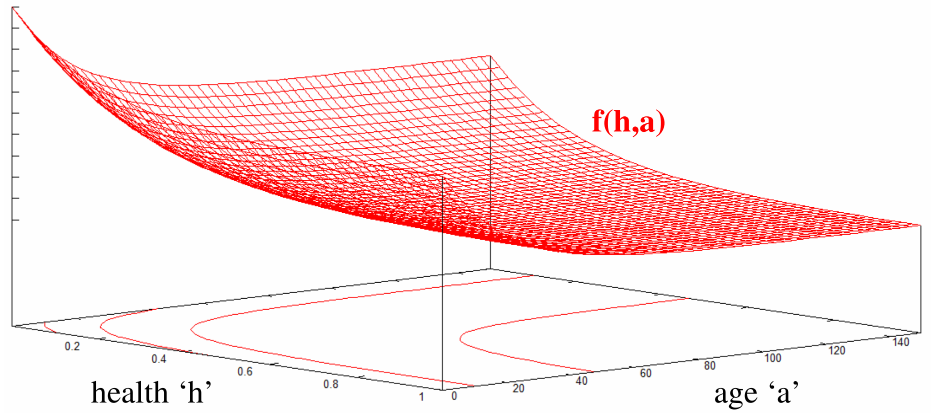


Figure 1: f(h,a)

a) Escape and rescue route

The escape and rescue route is a sequence of actions to perform in order to evacuate safely the entire population onboard from the initial position of passengers when the general emergency alarm is sounded, to the rescuing vessels or the shore. It involves the passengers, the crew and the hardware components of the Life Saving System (LSS). Each LSS is associated with a specific escape and rescue route depending on characteristics such as the way they are boarded, the way they are launched, the way they clear off the vessel, the way passengers are disembarked, etc. Conventional families of existing systems have very similar escape and rescue routes. This route can be split up in several phases regardless of the LSS looked at:

Phase	*Description*
1	Mustering, preparing to board LSA
2	Abandon the ship
3	Surviving at sea
4	Rescue from LSA

Table 8: Phases of the MAR process

Each phase can then be split up in several further elements which depend on the Life-Saving System. For instance, for a conventional LSS composed of lifeboats, some of the elements for phase 2 "abandon the ship" are:

- Deployment of the lifeboats.
- Boarding.
- Lowering to the water.
- Clearing off the vessel.

Moreover, along the escape and rescue route, the hardware systems and the passengers may be damaged / injured as they progress through each element. Therefore, we consider that a series of obstacles have to be overcome in order to complete each element. Thus, the escape and rescue route can also be considered as the *series of obstacles* that the hardware and humans must overcome for the whole rescue to be completed as shown on figure 2 below. *An obstacle* is characterized by the hazard generated when the system meets with it. Some hazards directly affect the human body (like hypothermia for instance), whereas some primarily affect the hardware system (like mechanical failure or structural failure).

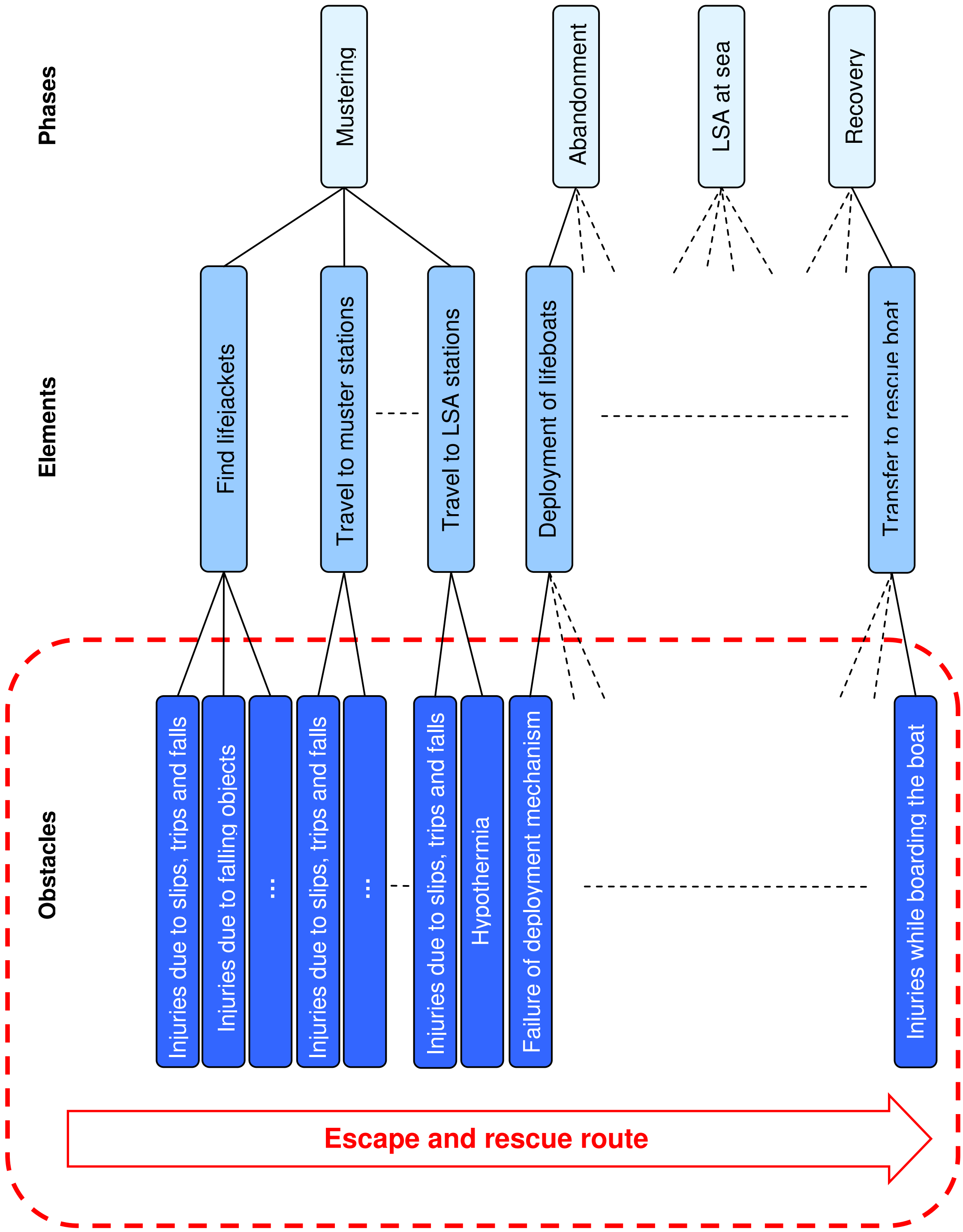


Figure 2: MAR process split up into phases, elements and obstacles

3.1.2 Obstacles

Each obstacle is likely to have either a direct impact on passengers' health, or an indirect impact through the hardware. An example of indirect impact may be that if the survival craft capsizes, the majority of its passengers are likely to die; in this case the obstacle is "capsizing of the survival craft".

For a given obstacle 'k', every state taken before this obstacle is indexed 'k-1'; every state taken after the obstacle is indexed 'k'

The health status of a passenger is modified each time the passenger passes an obstacle. If 'f_{k-1}' is the passenger's health status before the obstacle and 'f_k' after the obstacle, the degradation of health associated to the obstacle 'k', D_k, is defined as:

$$f_k(h,a) = D_k[f_{k-1}(h,a)]$$

Some characteristics of the transformation D_k:

- D_k is also a function of age: the health of an elderly person will generally degrade more than the health of a young adult, for a given obstacle.
- Health cannot improve through an obstacle.
- The probability of having a given health status 'H' after the obstacle 'k', $f_k(H,a)$, is a function of the probability of having a health status 'h ≤ H' before the obstacle, $f_{k-1}(h \leq H, a)$: all health status better than or equal to 'H' can possibly lead to 'H' after the obstacle. In other words, there is a certain probability that a person who is in very good health before the obstacle is severely injured after the obstacle and there is a certain probability that a person who is 'only' slightly injured before the obstacle is also severely injured after the obstacle.

Therefore, the transformation D_k can be described as:

$$D_k[f_{k-1}(h,a)] = \int_0^h \Psi[h,a,f_{k-1}(u,a)]du = f_k(h,a)$$

$$D_k[f_{k-1}(h,a)] = \int_0^h \Phi(h,a,u) \cdot f_{k-1}(u,a)du = f_k(h,a)$$

The escape and rescue route is composed of a succession of 'N' obstacles. Therefore the health status of a passenger of a given age 'a' at the end of the route $f_N(h,a)$ is:

$$f_N(h,a) = D_N[D_{N-1}[\ldots\ D_k[\ldots\ [D_1[f_0(h,a)]]]]]$$

With $f_0(h,a)$ being the initial health status of a passenger of a given age 'a'

Therefore, the health status of a passenger of a given age 'a' at any obstacle 'k' of the escape and rescue route is:

$$\forall k \in [0;N],\ f_k(h,a) = D_k[D_{k-1}[\ldots\ [D_1[f_0(h,a)]]]]$$

3.1.3 Passengers' health distribution

The population of passengers is distributed according to a certain probability density function of age that can be described by:

P(a) is the probability that the age of a passenger is comprised between 'a' and 'a+da'

$p(a \le age < a + da)$ so that $\int_0^{a_{max}} P(a)da = 1$

Example of a typical repartition of age amongst passengers of a cruise ship:

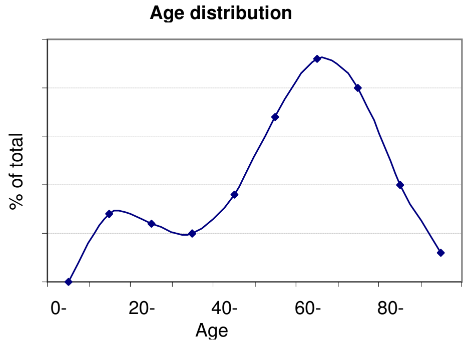


Figure 3: Age distribution amongst passengers of a cruise ship (Carnival Corp. & Plc, 2006)

Note: The age distribution provided in figure 3 has to be seen as an illustrative example. It was built from the demographic figures of the cruise ships passengers in 2006 and therefore does not pretend to be representative of the situation in 2010.

3.1.4 Discretisation

f_k, Ψ_k, and Φ_k are unknown continuous functions, or at least, determining their shape requires unmeasured effort. However, the problem can be simplified by first discretising f_k in **f_k' – a probability mass function of f_k.**

We choose to describe the 'health' axis with four ranges:

- [0; h_1] for Good Health (GH).
-]h_1; h_2] for Minor Injuries (MI).
-]h_2; h_3] for Severe Injuries (SI).
-]h_3; h_4] for Deceased (D).

HHS	*Category*	*Description*	*Related mobility*
Good Health	GH	Good physical and mental health	Good mobility
Moderate Injury	MI	Superficial scratches Moderate bleeding	Mobility degraded
Severe Injury	SI	Fractures and/or trauma	Mobility requiring assistance
Deceased	D	Fatal injury	No mobility

Table 9: Health categories

And the ‘age’ axis with three ranges: [0; 50],]50; 75], and]75; a_{max}].

f_k’ can then be described with 3 x 4 = 12 constants: for each age range, four constants describing the probability of having a passenger of such age range in each health category as shown on figure 4 below:

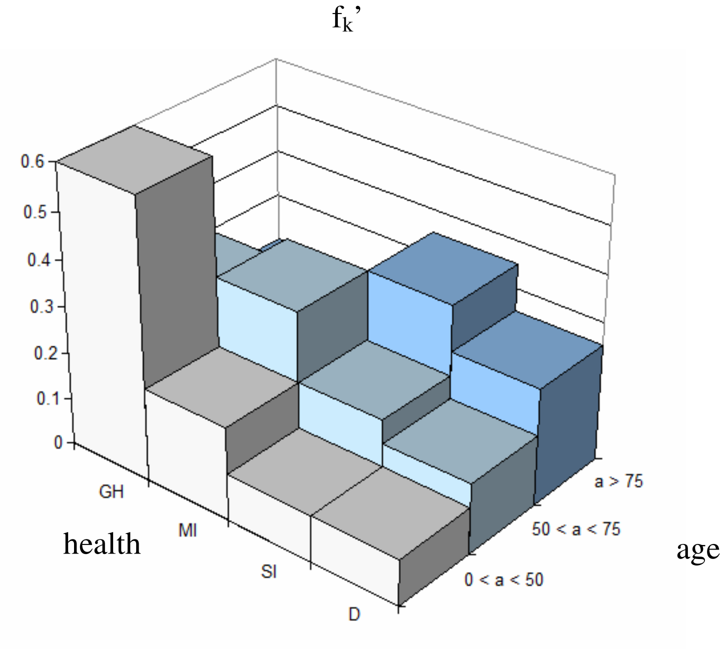


Figure 4: Discretisation of f_k – f_k’

A simpler representation is a combination of three vectors, one for each age category, describing the health of a passenger.

Age category a_1 $a \leq 50$	$\begin{bmatrix} \alpha_1 \\ \beta_1 \\ \chi_1 \\ \delta_1 \end{bmatrix}$	*Probability for a passenger in age category* a_1 *to be in GH* // // // // // a_1 // *in MI* // // // // // a_1 // *in SI* // // // // // a_1 // *in D*
Age category a_2 $50 < a \leq 75$	$\begin{bmatrix} \alpha_2 \\ \beta_2 \\ \chi_2 \\ \delta_2 \end{bmatrix}$	*Probability for a passenger in age category* a_2 *to be in GH* // // // // // a_2 // *in MI* // // // // // a_2 // *in SI* // // // // // a_2 // *in D*
Age category a_3 $a > 75$	$\begin{bmatrix} \alpha_3 \\ \beta_3 \\ \chi_3 \\ \delta_3 \end{bmatrix}$	*Probability for a passenger in age category* a_3 *to be in GH* // // // // // a_3 // *in MI* // // // // // a_3 // *in SI* // // // // // a_3 // *in D*

Moreover, the transformation D_k is substantially simplified as a combination of three triangular matrixes $D_{k,1}$, $D_{k,2}$, and $D_{k,3}$ corresponding to age categories a_1, a_2, and a_3 respectively defined as:

For each age category a_i (i = 1, 2, 3):

$$\begin{bmatrix} \alpha_{k,i} \\ \beta_{k,i} \\ \chi_{k,i} \\ \delta_{k,i} \end{bmatrix} = D_{k,i} \cdot \begin{bmatrix} \alpha_{k-1,i} \\ \beta_{k-1,i} \\ \chi_{k-1,i} \\ \delta_{k-1,i} \end{bmatrix} = \begin{bmatrix} l_{k,i} & 0 & 0 & 0 \\ m_{k,i} & p_{k,i} & 0 & 0 \\ n_{k,i} & q_{k,i} & s_{k,i} & 0 \\ o_{k,i} & r_{k,i} & t_{k,i} & 1 \end{bmatrix} \cdot \begin{bmatrix} \alpha_{k-1,i} \\ \beta_{k-1,i} \\ \chi_{k-1,i} \\ \delta_{k-1,i} \end{bmatrix}$$

$$\text{With } \begin{cases} l_{k,i} + m_{k,i} + n_{k,i} + o_{k,i} = 1 \\ p_{k,i} + q_{k,i} + r_{k,i} = 1 \\ s_{k,i} + t_{k,i} = 1 \end{cases}$$

The health status of a passenger in age category 'a_i'at the end of the route is:

For each age category a_i (i = 1, 2, 3):

$$\begin{bmatrix} \alpha_{N,i} \\ \beta_{N,i} \\ \chi_{N,i} \\ \delta_{N,i} \end{bmatrix} = D_{N,i} \cdot D_{N-1,i} \cdot \ldots \cdot D_{k,i} \cdot \ldots \cdot D_{1,i} \cdot \begin{bmatrix} \alpha_{0,i} \\ \beta_{0,i} \\ \chi_{0,i} \\ \delta_{0,i} \end{bmatrix} = \begin{bmatrix} l_{N\ldots1,i} & 0 & 0 & 0 \\ m_{N\ldots1,i} & p_{N\ldots1,i} & 0 & 0 \\ n_{N\ldots1,i} & q_{N\ldots1,i} & s_{N\ldots1,i} & 0 \\ o_{N\ldots1,i} & r_{N\ldots1,i} & t_{N\ldots1,i} & 1 \end{bmatrix} \cdot \begin{bmatrix} \alpha_{0,i} \\ \beta_{0,i} \\ \chi_{0,i} \\ \delta_{0,i} \end{bmatrix}$$

With $\begin{bmatrix} \alpha_{0,i} \\ \beta_{0,i} \\ \chi_{0,i} \\ \delta_{0,i} \end{bmatrix}$ representing the initial health status probability mass function of a passenger in age category 'a_i'

And the health status of a passenger in age category 'a_i' at any obstacle 'k' of the escape and rescue route is:

$$\begin{bmatrix} \alpha_{k,i} \\ \beta_{k,i} \\ \chi_{k,i} \\ \delta_{k,i} \end{bmatrix} = D_{k,i} \cdot D_{k-1,i} \cdot \ldots \cdot D_{1,i} \cdot \begin{bmatrix} \alpha_{0,i} \\ \beta_{0,i} \\ \chi_{0,i} \\ \delta_{0,i} \end{bmatrix} = \begin{bmatrix} l_{k\ldots1,i} & 0 & 0 & 0 \\ m_{k\ldots1,i} & p_{k\ldots1,i} & 0 & 0 \\ n_{k\ldots1,i} & q_{k\ldots1,i} & s_{k\ldots1,i} & 0 \\ o_{k\ldots1,i} & r_{k\ldots1,i} & t_{k\ldots1,i} & 1 \end{bmatrix} \cdot \begin{bmatrix} \alpha_{0,i} \\ \beta_{0,i} \\ \chi_{0,i} \\ \delta_{0,i} \end{bmatrix}$$

3.1.5 Number of fatalities

One of the interesting results that can be taken out of the calculation of the Human Health Status of a passenger in age category 'a_i', is the probability that he/she loses his/her life during the whole MAR process. This probability is $\delta_{N,i}$.

$$P_{Fatality}(a_i) = \delta_{N,i}$$

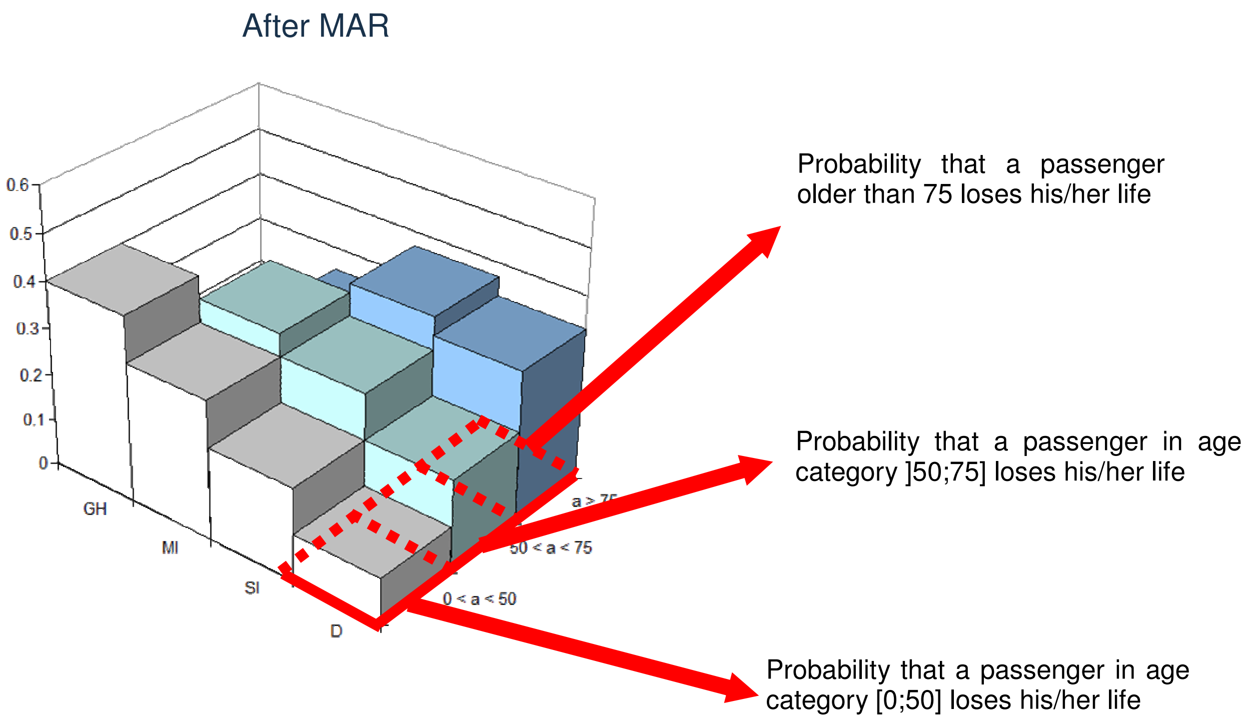


Figure 5: Probability of having one fatality during the MAR process

Note: We can also use the equivalent number of fatalities as a weighted indicator based on the probabilities of having minor injuries, severe injuries, and a fatality.

$$P_{EQfatal}(a_i) = c_1 \cdot \beta_{N,i} + c_2 \cdot \chi_{N,i} + \delta_{N,i}$$

With c_1 *and* $c_2 \in [0;1]$ two coefficients accounting for the fact that 1 fatality is equivalent to $\frac{1}{c_1}$ minor injuries and $\frac{1}{c_2}$ severe injuries.

Then, the question to be answered is: What is that probability that 'q' passengers lose their life during the MAR process?
In our model, passengers may lose their life for two distinct reasons:

- They suffer from injuries, or their health degrades as time goes by (objects falling, falls in the stairs, trapped in flooded spaces, effects of hypothermia and seasickness for example).

- Their life-saving appliance or the rescue means suffer from a failure and are lost (capsized, broken, cannot be launched properly).

As a first assumption, we consider that obstacles acting on life-saving appliances, or hardware obstacles, dealing with failure of the LSA are binary. Either there is no failure and passengers do not suffer from any health degradation, or there is failure of the LSA (or its arrangements) and all passengers are lost (fatalities). Therefore, the probabilities of losing their life for all passengers of the same LSA, are linked.

Therefore, the model is described according to the following.

Fatalities are due to:

a) Health degradation of passengers along the MAR process due to "Human Factors (HF) obstacles" – The death of one given passenger is totally independent from the death of the other passengers, it only depends on his/her age and initial health.

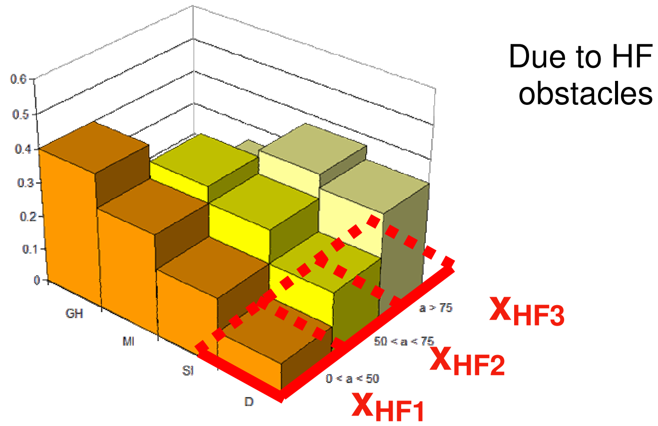


Figure 6: Probability of having one fatality due to Human Factors obstacles

'$\mathbf{P_{HF}(q)}$' the probabilities of having 1, 2, 3, …, q, …, n_{ship} fatalities due to Human Factors obstacles is calculated using the **Binomial distribution**.

With:

- 'n_{ship}' is the total number of passengers onboard.

Therefore, for each age category, the probability of having 'q' fatalities is:

$$\begin{cases} P_{HF}(q;age1) = C_{n_{a1}}^{q}(X_{HF1})^{q}\cdot(1-X_{HF1})^{n_{a1}-q} \\ P_{HF}(q;age2) = C_{n_{a2}}^{q}(X_{HF2})^{q}\cdot(1-X_{HF2})^{n_{a2}-q} \\ P_{HF}(q;age3) = C_{n_{a3}}^{q}(X_{HF3})^{q}\cdot(1-X_{HF3})^{n_{a3}-q} \end{cases}$$

For the entire ship, the probability of having 'q' fatalities is:

$$\forall(q_1;\ q_2;\ q_3) \in [0; n_{ship}]\ \text{so that}\ q_1 + q_2 + q_3 = q,$$
$$P_{HF}(q) = \sum_{(q_1;q_2;q_3)} P_{HF}(q_1;a_1) \cdot P_{HF}(q_2;a_2) \cdot P_{HF}(q_3;a_3)$$

b) Failure of LSA due to "Hardware (HW) obstacles" – As a first approximation, we assume that, as a result of a failure of a LSA, a certain percentage of its passengers will die while the remaining part will not be injured at all.

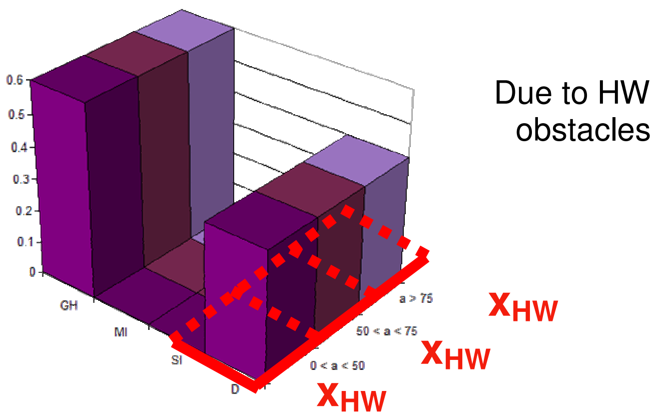


Figure 7: Probability of having one fatality due to Hardware obstacles

We can calculate the probability of having 'n_{LSA}' fatalities due to HW obstacles very simply since all passengers will die as a result of a loss of the LSA:

$$P_{HW}(n_{LSA}) = X_{HW}$$

With:

- 'n_{LSA}' is the total number of passengers in the LSA.

Then, '$\mathbf{P_{HW}(y.n_{LSA})}$' the probabilities of having n_{LSA}, $2.n_{LSA}$, $3.n_{LSA}$, …, $Y.n_{LSA}$ fatalities due to the loss of several LSA is calculated using the **Binomial distribution**.

With:

- 'y' the number of LSA lost.
- 'Y' the total number of LSA on the ship.

$$P_{HW}(y \cdot n_{LSA}) = C_Y^y (X_{HW})^y \cdot (1 - X_{HW})^{Y-y}$$

Finally, for the whole MAR process, considering a passenger ship having an evacuation system composed of a-type (for example totally enclosed lifeboats), b-type (e.g. partially enclosed lifeboats) and c-type (e.g. liferafts) LSA, any number of fatalities ‘q’ can be decomposed like (a) combination(s) of:

- z_j fatalities due to Human Factors obstacles.
- $y_{j,a} \cdot n_{LSA,a}$ fatalities due to Hardware obstacles using a-type LSA.
- $y_{j,b} \cdot n_{LSA,b}$ fatalities due to Hardware obstacles using b-type LSA.
- $y_{j,c} \cdot n_{LSA,c}$ fatalities due to Hardware obstacles using c-type LSA.

$$\forall q \in [0; n_{ship}], \quad \forall (z_j, y_{j,a}, y_{j,b}, y_{j,c}), \quad \textit{so that}$$

$$q = z_j + y_{j,a} \cdot n_{LSA,a} + y_{j,b} \cdot n_{LSA,b} + y_{j,c} \cdot n_{LSA,c}$$

The probability of having ‘q’ fatalities is therefore:

$$P(q) = \sum_{(z_j, y_{j,a}, y_{j,b}, y_{j,c})} P_{HF}(z_j) \cdot P_{HW}(y_{j,a} \cdot n_{LSA,a}) \cdot P_{HW}(y_{j,b} \cdot n_{LSA,b}) \cdot P_{HW}(y_{j,c} \cdot n_{LSA,c})$$

Note: The equivalent number of fatalities can also be used with the same principles and equations.

3.2 Use of evacuation simulation models

Evacuation simulation models allow for the calculation of the time required to muster passengers. These models can also be used to make an assessment of the evacuation time from muster stations to LSA. Moreover it is important to have an idea on the filling in of LSAs (with passengers) so that the time to abandon can also be assessed (through another model). In fact, if the ship is supposed to capsize before all passengers have abandoned the ship in LSA, it doesn’t mean in reality that all passengers couldn’t abandon the ship. A certain proportion of LSA may have been launched and have cleared off the capsizing vessel already.

As an example of the factors influencing the evacuation times, random variations in the response times of passengers means that people will turn up in clusters, which can then clog the doorways causing larger aggregations of people. This is something to be expected in any drill, but it does slow the response time slightly. It would be a difficult organisational problem to improve this.

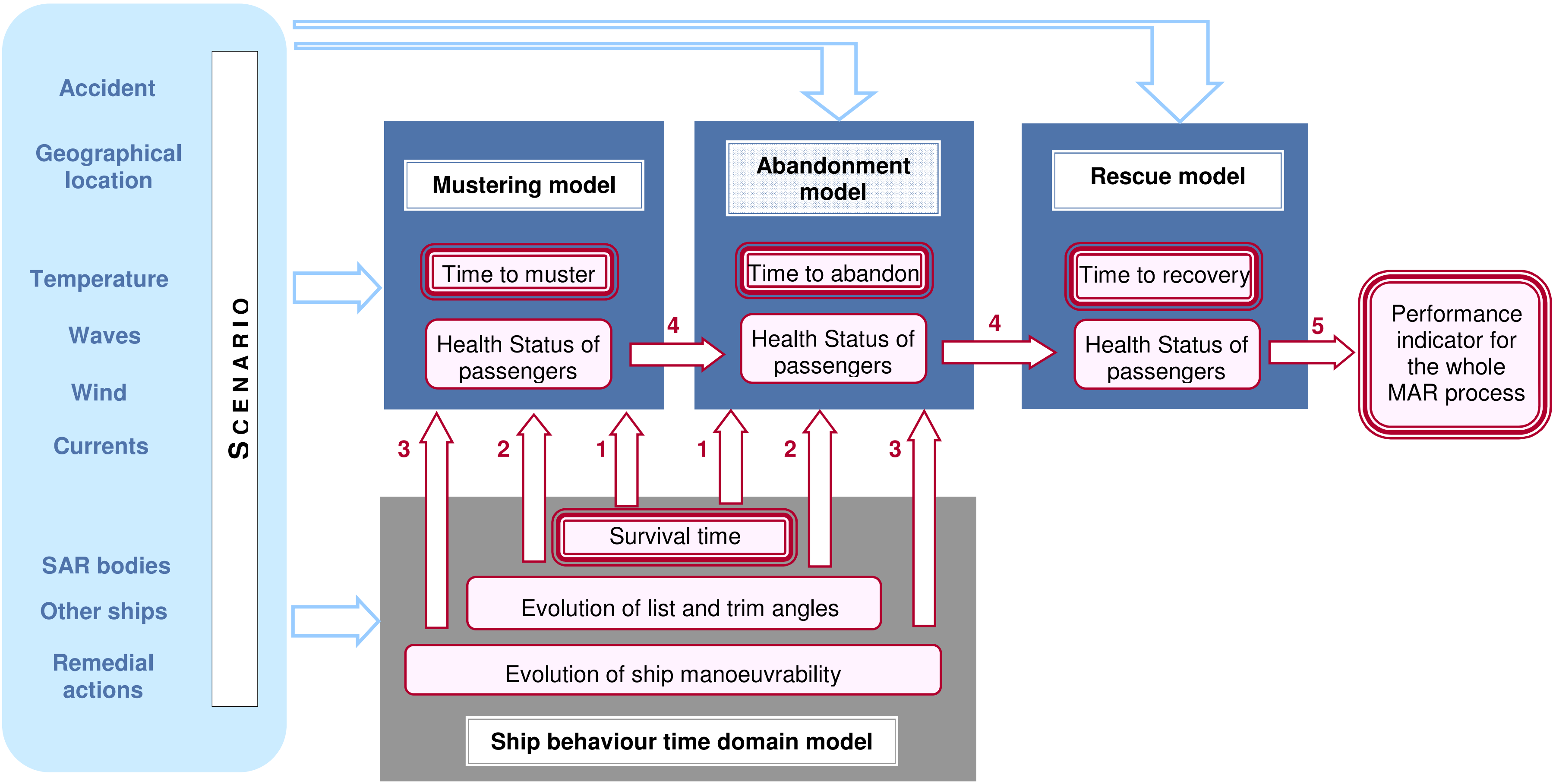
3.3 Use of flooding simulation models (ship behaviour time domain models)

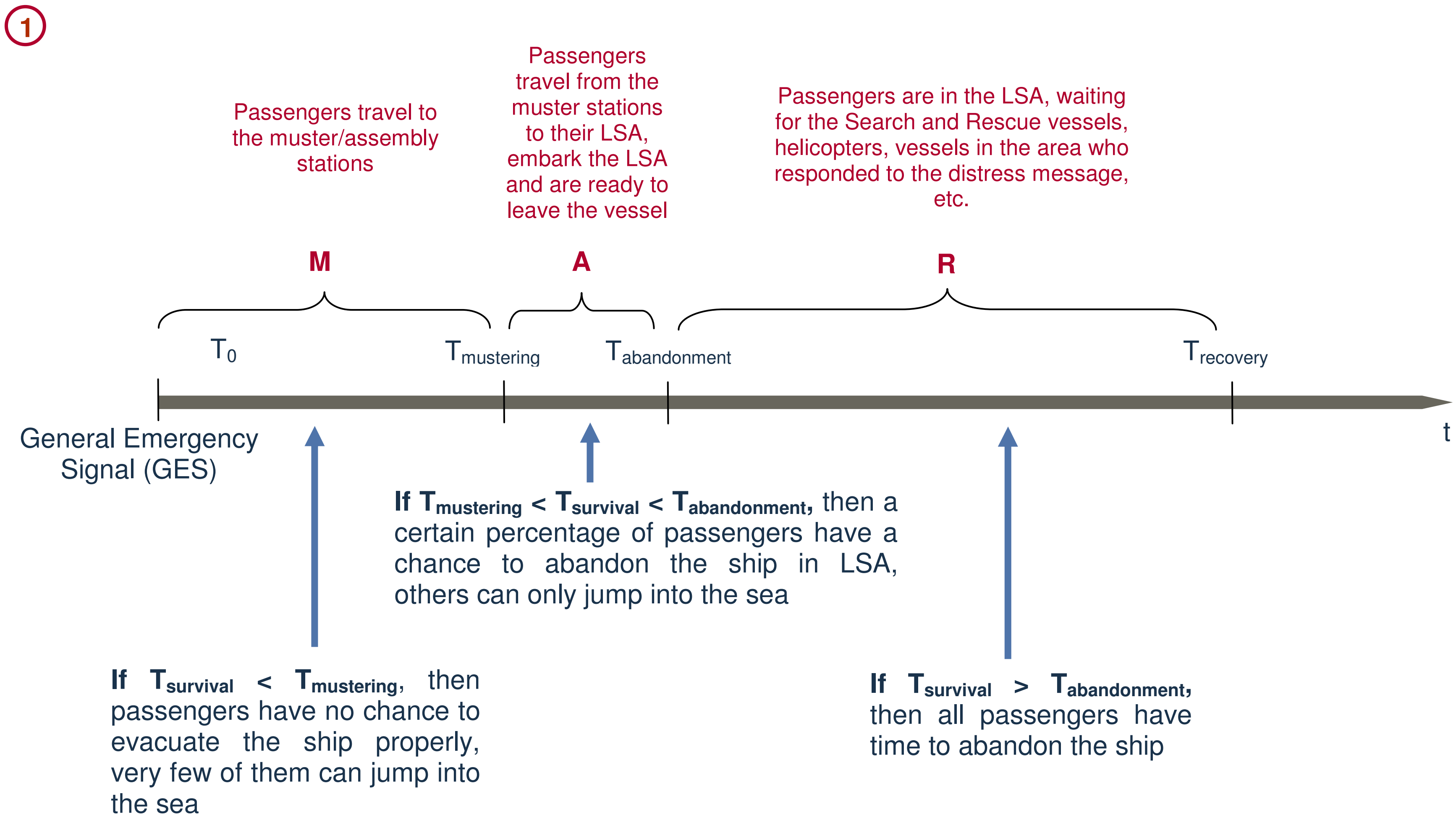
Flooding will first impact the passenger ship's stability and manoeuvring capabilities. Indirectly, it will therefore influence some factors of the mustering and abandonment phases. In fact, list will strongly influence passengers' mobility, increase the risk of slips, trips and falls during evacuation, limit the capacity of the ship to adopt a safer position regarding the waves direction, make LSA launching difficult or impossible, etc. This will finally impact important indices like the time for mustering, the time for abandoning the ship and the health of passengers after having been through these phases of the rescue route. Moreover, inputs from flooding analysis like the 'survival time' are crucial for assessing the tradeoffs between staying onboard and evacuating the flooded vessel.

It is consequently very important to consider the way the ship stability and manoeuvrability are likely to evolve during the mustering and abandonment phases so that flooding is accounted for when assessing the important indicators for the abandonment of the vessel.

3.4 Integration into a global model to be used for decision making

A global model would integrate the three approaches presented before. Regarding a certain scenario of flooding and environmental surrounding of the ship, what is the risk in terms of passengers' safety (health indicator) to abandon the ship? How many passengers are likely to die during the Mustering, Abandonment and Rescue? The general architecture of the integration is presented in figure 8 below:


Accident
Geographical location
Temperature
Waves
Wind
Currents
SAR bodies
Other ships
Remedial actions
SCENARIO
Mustering model
Time to muster
Health Status of passengers
Abandonment model
Time to abandon
Health Status of passengers
Rescue model
Time to recovery
Health Status of passengers
Performance indicator for the whole MAR process
4
4
5
3
2
1
1
2
3
Survival time
Evolution of list and trim angles
Evolution of ship manoeuvrability
Ship behaviour time domain model


1
Passengers travel to the muster/assembly stations
Passengers travel from the muster stations to their LSA, embark the LSA and are ready to leave the vessel
Passengers are in the LSA, waiting for the Search and Rescue vessels, helicopters, vessels in the area who responded to the distress message, etc.
M
A
R
T_0
$T_{mustering}$
$T_{abandonment}$
$T_{recovery}$
General Emergency Signal (GES)
t
If $T_{mustering} < T_{survival} < T_{abandonment}$, then a certain percentage of passengers have a chance to abandon the ship in LSA, others can only jump into the sea
If $T_{survival} < T_{mustering}$, then passengers have no chance to evacuate the ship properly, very few of them can jump into the sea
If $T_{survival} > T_{abandonment}$, then all passengers have time to abandon the ship

(2) Influence of list and trim on the mobility of passengers
Influence on the health of passengers (slips, trips and falls, dropping objects, etc)

(3) Capacity of the vessel to manoeuvre so that the impact of waves on the evacuation is limited.
Practically, the corresponding input for the model is the evolution of the ship's heading angle

(4) The mustering model provides the health status of passengers as an input for the abandonment model
The abandonment model provides the health status of passengers as an input for the rescue model

(5) Simple performance indicators are derived from the Health Status of passengers at the end of the rescue process:

- Probability to have 'q' passengers with minor injuries during MAR
- Probability to have 'q' passengers severely injured during MAR
- **Probability to have 'q' fatalities or equivalent fatalities during MAR**

Figure 8: General model for the assessment of the MAR process

At a higher level, the MAR models have to be used for the decision support system. This means that in case of an emergency, environmental conditions are supposed to be known and are used as inputs for the MAR models and, the different options (remedial actions, abandon the ship, do not abandon the ship, muster passengers then wait for rescue, etc.) have then to be assessed in terms of risk for passengers. This is presented in figure 9 below:

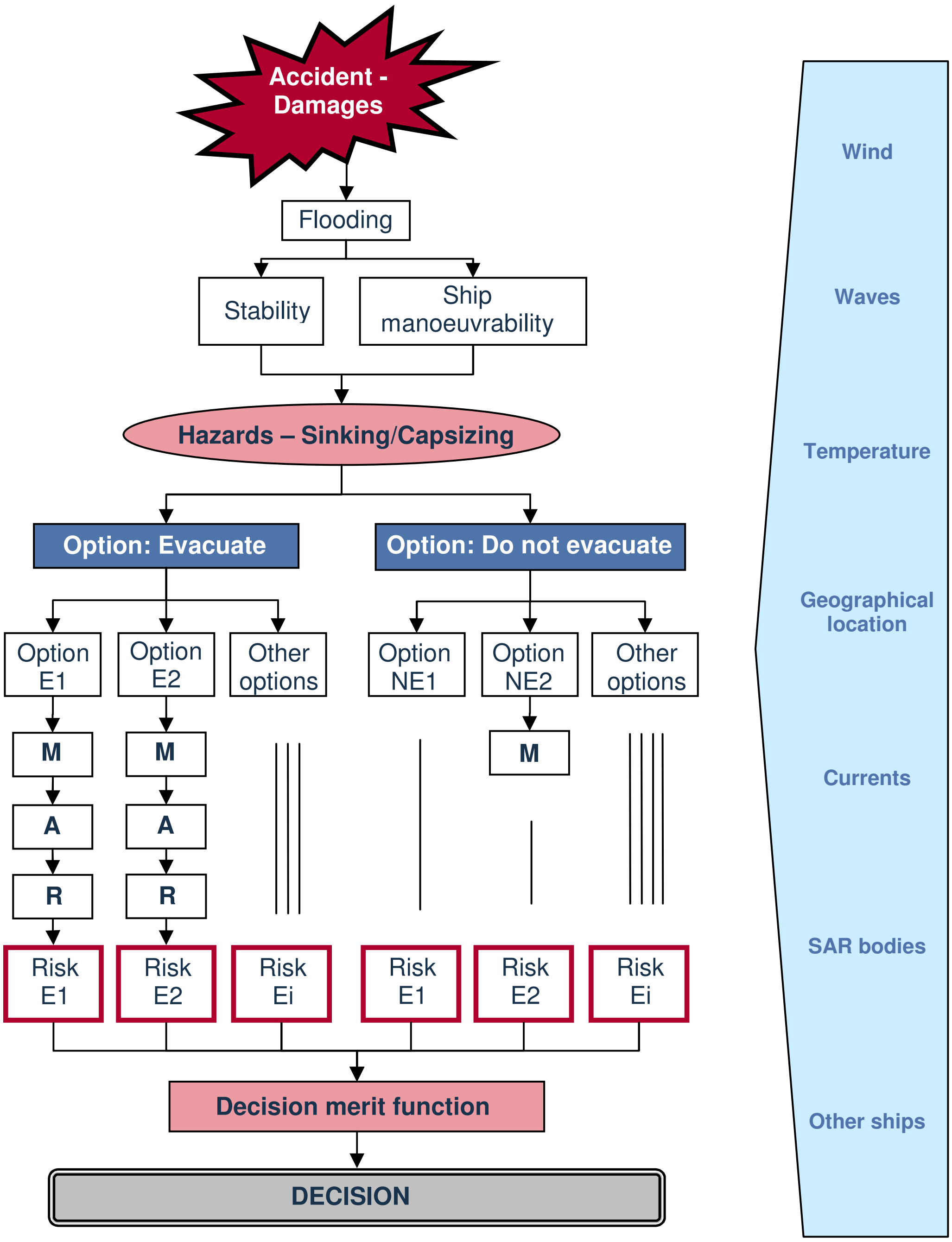


Figure 9: Architecture of a Decision Support System for the MAR process

4. REFERENCES

Bureau Veritas “Rules for the Classification of steel ships”, 2010

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5. ANNEX I: SUMMARY OF MAR RELATED REGULATIONS

See attached document FLOODSTAND D5.1 ANNEX II.doc

6. ANNEX II: QUESTIONNAIRES

See attached document FLOODSTAND D5.1 ANNEX II.doc

7. ANNEX III: ACCIDENT INVESTIGATION

See attached document FLOODSTAND D5.1 ANNEX II.doc