EXAMENSARBETE INOM FARKOSTTEKNIK,
AVANCERAD NIVÅ, 30 HP
STOCKHOLM, SVERIGE 2019

A study of risk management for serie produced vessels, in relation to the IMO risk perspective.

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Abstract

The International Maritime Organization, IMO, aims to at a larger extent build their work in relation to and around risk management. It is therefore here investigated how IMO standards comply with industry risk management processes. The IMO risk perspective used in this study is the Formal Safety Assessment, FSA. The FSA was created to evaluate and compare new regulations in regards to cost and administrative or legislative burden and is a risk management methodology, which goal is to improve maritime safety. The FSA uses risk analysis and cost benefit assessment, and covers both technical and operational issues.

By comparing the IMO risk perspective with industry risk management processes, and analysing the practical use of the FSA by applying it to three maritime accidents the goal with this report is to find similarities and differences of the two perspectives and present possible carryovers from industry risk approaches to the IMO risk perspective.

It was found that the IMO risk perspective, here represented by the FSA, does overall comply with industry risk management processes. The main difference is that general industry risk management processes focuses on all phases of the development and use of a vessel, from the concept phase to the operation phase but the FSA focuses mainly on the operative perspective of the design phase and the operation phase. The largest deficiency of the FSA is the non-existing demands on safety culture which is found to be a requirement when doing a successful risk management assessment. If IMO is considering the FSA as their main risk management method to be used, it is important that requirements on safety management is added.

Abstract

Den internationella sjöfartsorganisationen, IMO, vill i större utsträckning utveckla sina standarder och rekommendationer med avseende på riskhantering. I denna rapport undersöks det hur dagens IMO-standarder stämmer överens med generella riskhanteringsmetoder.

"The Formal Safety Assessment", FSA, representerar i denna rapport IMOs perspektiv på riskhantering. FSAn skapades som ett verktyg för att utvärdera och jämföra nya regleringar och standarder ur ett kostnadsperspektiv samt administrativ och lagstiftande börda, och syftet med FSAn är att förbättra sjösäkerheten. FSAn är en riskanalysmetod och inkluderar både det tekniska och operativa perspektivet, samt kostnadskalkyler.

I denna rapport jämförs IMOs riskperspektiv med generella riskhanteringsmetoder och den praktiska användningen av FSA analyseras genom att utreda hur man hade kunnat använda FSAn för att påverka utfallet av tre maritima olyckor. Målet med detta arbete är att hitta likheter och skillnader mellan de två perspektiven och undersöka om det finns lärdomar att dra från de båda perspektiven.

Slutsatsen av detta arbete är att FSAn stämmer bra överens med generella riskhanteringsmetoder. Skillnaden som upptäcktes var att generella riskhanteringsmetoder inkluderar alla faser i utvecklingen och användandet av ett fartyg, från konceptfasen till den operativa fasen, men FSAn huvudsakligen fokuserar på det operativa perspektivet inom designfasen samt den operativa fasen. Det konstaterades också att en förutsättning för att en riskanalys ska vara effektiv och tillförlitlig är närvaron av en bra företagskultur och att den största bristen i FSAn är avsaknaden av uttryckliga krav på säkerhetskultur inom företaget som utvecklar eller använder båten, samt avsaknaden krav på en plan för hur företagen hanterar avvikelser. Utan en bra företagskultur, inklusive en säkerhetskultur, ökar risken för att avvika från designkrav och standardrutiner, vilket i sig ökar risken för olyckor.

Acknowledgements

Hans Liwång, supervisor, for endless support and supervision during the spring.

Emma Skoglund and Scania as a whole, for giving me the opportunity to go back to school to finish my degree.

Familjen Mindus Söderlund and Sina Amini, for all the mental support and help.

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1. Introduction

On the night of the 14th of April 1912, the ship RMS Titanic collided with an iceberg and sank in the North Atlantic Ocean. Titanic had estimated 2224 passengers on board, and where going from Southampton to New York City. Around 1500 people lost their lives.

As a response to the disaster, the first edition of The international convention for the Safety of Life at Sea, SOLAS was created in 1914 by the International Maritime Organization, IMO (2019b).

IMO has for a long time been a reactive organization, creating new rules and standards as a reaction to an accident, for example SOLAS after Titanic. But after the oil platform Piper Alpha exploded in 1988 and 167 where killed, the IMO decided to at larger extent build their work in relation to and around risk management, and the Formal Safety Assessment, FSA, was created as a tool to be proactive of risks. The FSA was created to evaluate and compare new regulations in regards to cost and administrative or legislative burden. The goal of the FSA is to improve maritime safety and being proactive by analysing and defeating hazards, threats and risks before an accident occurs, IMO (2019f).

This study will describe how state of the art engineering risk management approaches support operational risk reduction according to the IMO perspective. The study will also describe the strengths and weaknesses of the IMO risk perspective in relation to reducing the number of incidents and the consequences of incidents with serial produced vessels. It will be investigated how IMO standards today comply with industry risk management processes. Which similarities and differences exist? Are there possible carryovers from industry risk management processes to IMO standards?

The practical use of the FSA will also be analysed by investigating three maritime accidents in the sight of the FSA, for example the accident with the RIB SFC-7153 outside Djurö in 2006 where a RIB boat collided with a buoy, with the tragic loss of one man. If the designers and the operators of the boat would have used the FSA, would it have been possible to prevent the accident?

2. Approach

Existing risk management methods for state of the art engineering and industry will be analysed, as well as existing IMO risk perspectives, which in this report is represented by the Formal Safety Assessment, FSA. The focus will be on to what extent the risk management methods of state of the art engineering handle the risk during operation and how that risk corresponds to the IMO risk perspective. The two different perspectives will be compared with each other, and similarities and differences will be presented. Possible carryovers from industry risk approaches to the IMO risk perspective shall be stated if found.

Three maritime accidents with serial produced vessels will be analysed in the sight of industry and IMO risk management methods. The three maritime accidents that are chosen are the capsizing of Viking 7, LG8351, Northwest of Mehamn on 6 July 2014, Norway, the accident with the RIB SFC-7153 off Djurö 2006, Sweden and the capsizing of the RF2 rescue boat 1981, Denmark. These accidents are chosen since they are all serial produced vessels, which in this report is defined as a vessel that are produced more than once, and with the same design. The accidents have been investigated by an accident commission, and there is a clear course of events leading up to the accident presented for all the accidents. The accidents are similar in both the size of the boat and the number of people on board and also the consequences of the accidents.

To get a wider understanding of risk management, both risk management in general and the IMO risk perspective is analysed in chapter 3. Focus lies on which methods and techniques that are used to manage risk and reduce accidents when operating a system. Later in chapter 4 a comparison between the two are made, and similarities and differences are analysed. The accidents are presented and analysed from the FSA perspective in chapter 5 and 6. The question asked is whether the companies would have used the FSA, would the accidents been possible to prevent? Finally in chapter 7, the results of the analysis is presented and followed by a discussion in chapter 8.

3. Risk management

Every project, system and organization faces risks, for example risk of fatalities, risk of not meeting financial expectations, risk of delaying a project and many more. It is therefore important to identify, evaluate and handle risks.

A general definition of risk is “the probability distribution of loss” and risk management is “the set of techniques for controlling the uncertainty”, Munier (2014a). Risk management can in general be divided into three steps; analysing the risks, evaluating the risks and controlling and reducing the risks. Many industries have similar challenges with risks and uncertainties and therefore a number of methods and techniques are used.

There are many types of risks. Risks that projects and organizations often creates themselves and therefore can be controlled, for example if the responsibilities are not defined in a clear manner are defined as internal risks. There are also risks that are not created by or possible to control by the project or organization, for example the weather, and this is called external risks. Inherent or effective risks are risks that are existing and no action have been made to control it. When such an action is taken, the risks are transformed to a residual risk. A risk unrelated to other risks is called an independent risk and a dependent risk is a risk that depends on other risks. Risks that happens only if another risk happens is called conditional risks. Correlated risks are risks that behaves and vary in the same way, but are not dependent on each other, Munier (2014a).

When doing a risk analysis, it is analysed which unwanted events that can occur, and the probabilities of it occurring and the consequences if occurs. There are two ways of reducing the risk, either by reducing the probability of the unwanted event to occur or to reduce the consequences if the event occurs. To be able to evaluate the risks, an acceptance criteria must be defined, what are acceptable and not?

There are many aspects that includes risks, this thesis will however focus on the operational risks, or risks for accidents, occurring in technical systems which are designed, operated and taken care of by humans. An accident is according to Rausand and Utne defined as “an event or a chain of events that can cause loss of life or harm to health, the environment or other values”, Rausand & Utne (2009a).

3.1 Risk management in general

3.1.1 Identify and assess risks

To be able to manage, control and reduce the effects of risks, it is crucial to identify all potential risks. To do this, different techniques can be used. Below, some examples are presented.

- *Risk Breakdown Structure*

The technique “Risk Breakdown Structure”, RBS, can be used to identify, understand and rank risks. The RBS is mainly used to understand risks within a project; for example finding triggering factors that can lead to delays or increased project costs, but can also be used to evaluate operational risks. It breaks down the project into categories, risk producing factors, severity and which risk triggering factors that exists. It is also a good tool to identify correlated risks, Munier(2014c).

- *Probabilistic Risk Assessment (PRA)*

The probabilistic risk assessment tries to answer the question “What can happen? What is the probability of it happening? If this does happen, what are the consequences?”, Munier (2014b).

There are two phases in the probabilistic risk assessment; the “Forward analysis” - “Event Tree Analysis (ETA)” and the “Backward analysis” - “Fault Tree Analysis (FTA)”.

The Event Tree Analysis uses inductive logic and assumes that something has happened and evaluates how this event affects a sequence of events until it reaches the final event. The sequences of events or specific combination of events can either reduce or amplify the consequences of an initiating event.

The Fault Tree Analysis uses deductive logic and assumes that something can happen, and starts at a possible final event and goes backwards to find an initiating event that can start that chain, Munier (2014b).

The PRA was created within the space industry, after the Challenger accident in 1986 where seven astronauts were killed, and the method is still used within the industry. This method is also widely used within the aviation industry and the nuclear power industry, Rausand & Utne (2009a).

- *Bowtie diagram*

To be able to identify the causal relationship between a potential cause and a potential consequence, the Bowtie diagram can be used, see below in figure 1.

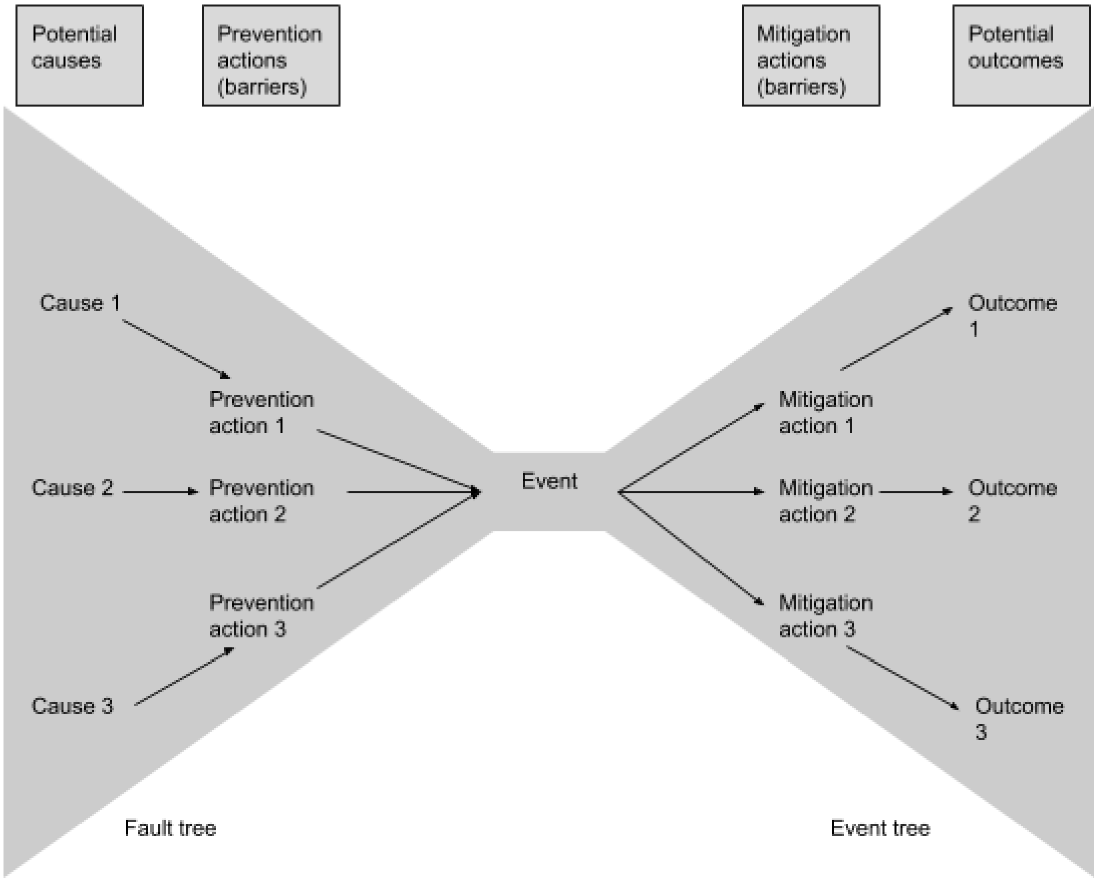

Figure 1, Bowtie Diagram, Munier (2014c)

Prevention actions are barriers that prevent or reduces the probability of an unwanted event to occur. If the event however happens, mitigation actions are barriers that can stop or reduce the potential outcomes, Munier (2014c).

- *SWIFT method.*

The SWIFT method is very similar to the PRA method and uses brainstorming where experts asks and answers "what can happen if..?", in regard to areas or activities that are considered hazardous, for example, "what can happen if the engine stops while the waves are high?". The group analyses the possible causes of the unwanted event and possible effects, and rank them according to how serious they are. If the system have barriers, these should be listed and evaluated in reliability. If possible improvements are found, they should be listed as well. To help the group of experts, a checklist is often used for areas to evaluate, for example technical breakdowns, human errors, instrumental errors or support system errors, Rausand & Utne (2009b).

- *Failure Mode and Effects Analysis, FMEA*

The Failure Mode and Effects Analysis (FMEA) breaks down the system into subsystems and components, and investigate possible failures that can affect other components and the system as a whole. The FMEA looks at both the design and production, Munier (2014b). When the FMEA has been done, it should be clear which failure mode each component in the system can have, what the reason for these are, which effect they have on the system as a whole and how it is recognized. It should also be known how often these failure mode occurs, how serious they are, which risks for the system they carry with them and whether any risk reducing measures can be made.

The FMEA method is one of the main risk methods used within the aviation industry, in combination with the Fault Tree Analysis, Rausand & Utne (2009b).

3.1.2 Evaluate risks

When every risks have been identified, it is important to understand which risks that can affect the project or system the most, so the management team knows which risks that is the most important to control and reduce.

- *Risk matrix*

To be able to visualize the risks, a risk matrix can be used. The risk matrix consider the probability of a risk occurring and the consequences of it, see figure 2.

Probability/ Consequence	1 Very unlikely	2 Unlikely	3 Likely	4 Quite likely	5 Very likely
5 Disastrous	6	7	8	9	10
4 Very large	5	6	7	8	9
3 Large	4	5	6	7	8
2 Medium	3	4	5	6	7
1 Small	2	3	4	5	6

Figure 2, Risk matrix, Rausand & Utne (2009d).

Based on the probability and severity of a risk, the risks are placed out in different regions in the matrix.
If the unwanted event is in the red area, indicating that a risk is likely to happen and the consequences are large, risk reducing measures must be applied. For events in the yellow area, meaning that the risk either is very likely to happen but the consequences are small or that the risk is very unlikely to happen but the risks are disastrous, risk reducing measures should be evaluated and compared with the costs of them. Events in the green area are considered acceptable and no measures need to be taken. Here the risks are either very unlikely to happen and the consequences large or the risks quite likely to happen but with small consequences. The risk matrix is a good tool to visualize risks and to rank them, Rausand & Utne (2009c).

- *ALARP method*

Another method used to rank risks into different acceptance areas is the ALARP method(As Low As Reasonably Practicable), which divides the risks into three areas; unacceptable risk, tolerable and acceptable risks, see figure 3.

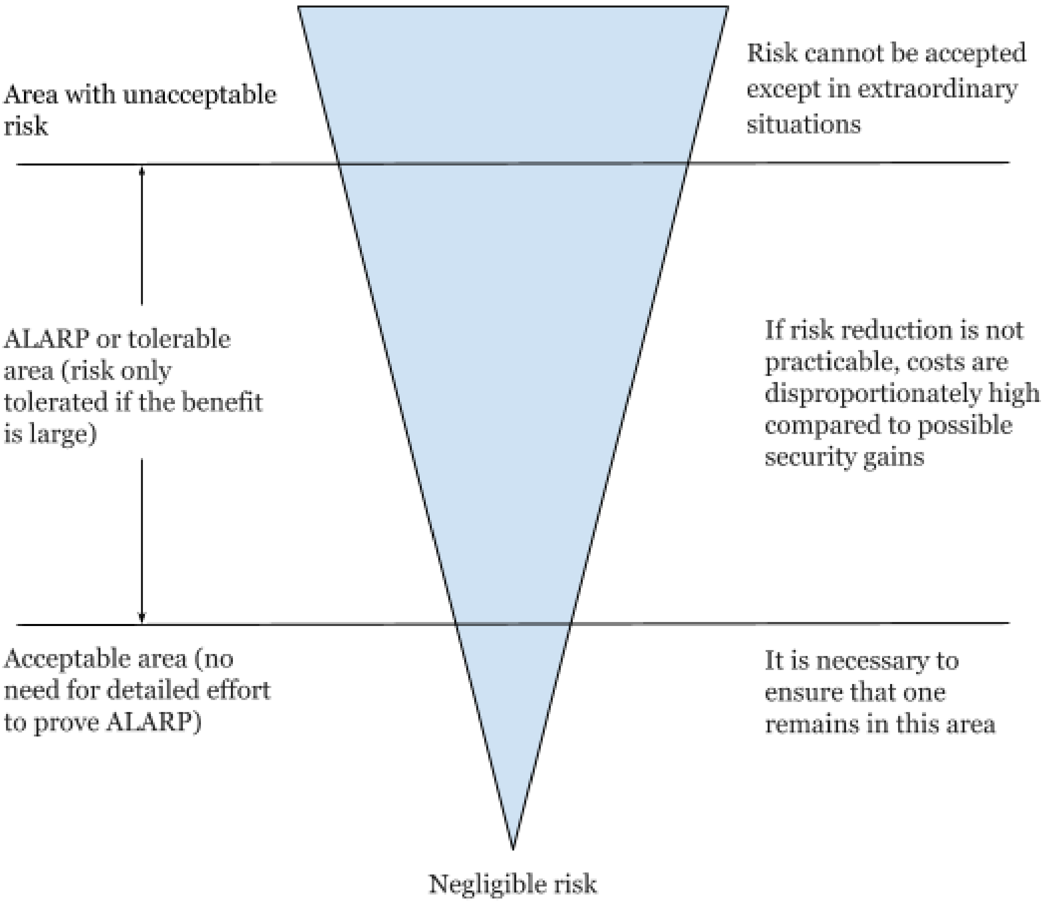

Figure 3, Acceptable risk, ALARP , Rausand & Utne (2009c).

The risk measured is the average individual risk(AIR), which is the annual risk of harm or death of a person. If one person gets harmed or killed in one accident, and similar accidents happen many times in a year, leading to a high death toll, the individual risk will be high.

3.2 Risk management approaches within the maritime industry

When general industry risk management methods and techniques now has been explained, it is interesting to see if the maritime industry and the International Maritime Organization uses similar approaches.

"IMO – the International Maritime Organization – is the United Nations specialized agency with responsibility for the safety and security of shipping and the prevention of marine and atmospheric pollution by ships", IMO (2019a).

IMO was created in 1948 and consists of over 170 member states which together creates a regulatory framework regarding safety at sea, maritime environment and seafare trade and put a minimum standard of the regulations of the member states, IMO (2019a).

On the night of 14 of April 1912, RMS Titanic collided with an iceberg and sank in the North Atlantic Ocean. The ship had estimated 2224 passengers on board, and where going from Southampton to New York City. Around 1500 people lost their lives. Titanic received iceberg warnings, but did not take proper actions and went into the area with nearly maximum speed. When Titanic hit the iceberg, six water compartments out of sixteen was ripped open and flooded. The reason for why the effects of the accident was so large, was first of all the number of lifeboats, which was not enough for holding every passenger onboard simultaneously. Secondly, due to lack of management during evacuation, the lifeboats were not maximum filled, leaving an even larger number of people onboard, Ryan (1985, 1986). As a response of the disaster, the first edition of The international convention for the Safety of Life at Sea, SOLAS was created in 1914, IMO (2019b).

The SOLAS Convention regulates the minimum standards for safety of life at sea. It covers the construction of the ship, the equipment onboard it and the operation. The Flag state, which is the jurisdiction where the ship is registered, is responsible for that the ship comply with SOLAS and that the certificates necessary are carried out , IMO (2019c)

From the chapter "General provisions" it is understood that the application of SOLAS, only apply to "ships engaged on international voyages". An international voyage is "a voyage from a country to which the present Convention applies to a port outside such country, or conversely", IMO (2004e).

There are a number of exceptions, where SOLAS is not applicable by law, IMO (2004e);

- Ships of war and troopships
- Cargo ships of less than 500 gross tonnage
- Ships not propelled by mechanical means
- Wooden ships of primitive build
- Pleasure yachts not engaged in trade
- Fishing vessels.

SOLAS describes how, by whom and when the ships and the equipment shall be inspected. It also describes how the surveyor shall proceed if the ship does not fulfill the requirements, or "not fit to proceed to sea without danger to the ship or persons on board", IMO (2004e). SOLAS also regulates how the ship shall be maintained after a survey to remain in the same conditions, and which changes of the ship that are allowed to do.

If the ship is involved in an accident or a defect is discovered, SOLAS regulates if and how an additional investigation of the ship shall be made, IMO (2004e).

Even though SOLAS does not apply on ships going on national voyages and also on exceptions stated above, most countries uses SOLAS as the minimum standard for safety of life at sea for all ships and also for national voyages. This is easier than having different standards for different types of ships, and many countries have laws demanding the shipbuilders to do extensive risk analysis and calculations if deviating from SOLAS, even though the ship is exempted from the rules by for example not doing transnational voyages. The shipping industry is a very international industry, and ships are often sold over national borders. It is therefore also beneficial for the first ship owner if the ship is build after international standards, as SOLAS, so the ship can be sold and used within another business than the original.

IMO has for a long time been a reactive organization, creating new rules and standards as a reaction to an accident, for example SOLAS after Titanic. But after the Piper Alpha accident 1988, where an oil platform exploded and 167 where killed, the Formal Safety Assessment was created as a tool for being proactive of risks and today IMO aims to at larger extent build their work in relation to and around risk management, IMO (2019f). In this report, the FSA is used as the IMO risk perspective, and the risk management methodology is further analysed to investigate whether the FSA can be used as a risk management methodology for the design and use of vessels.

3.3.3 FSA - Formal Safety Assessment

The Formal Safety Assessment, FSA, was created to evaluate and compare new regulations in regards to cost and administrative or legislative burden. The FSA is a risk management methodology, which goal is to improve maritime safety and being proactive by analysing and defeating hazards, threats and risks before an accident occurs. The FSA includes risk analysis, risk management and cost benefit assessment, and embraces both technical and operational issues, in relation to maritime safety, IMO (2019f).

The FSA methodology is divided into five steps, as seen below in figure 4, IMO (2002d):

1. Identification of hazards
2. Risk analysis
3. Risk control options
4. Cost benefit assessment
5. Recommendations for decision-making

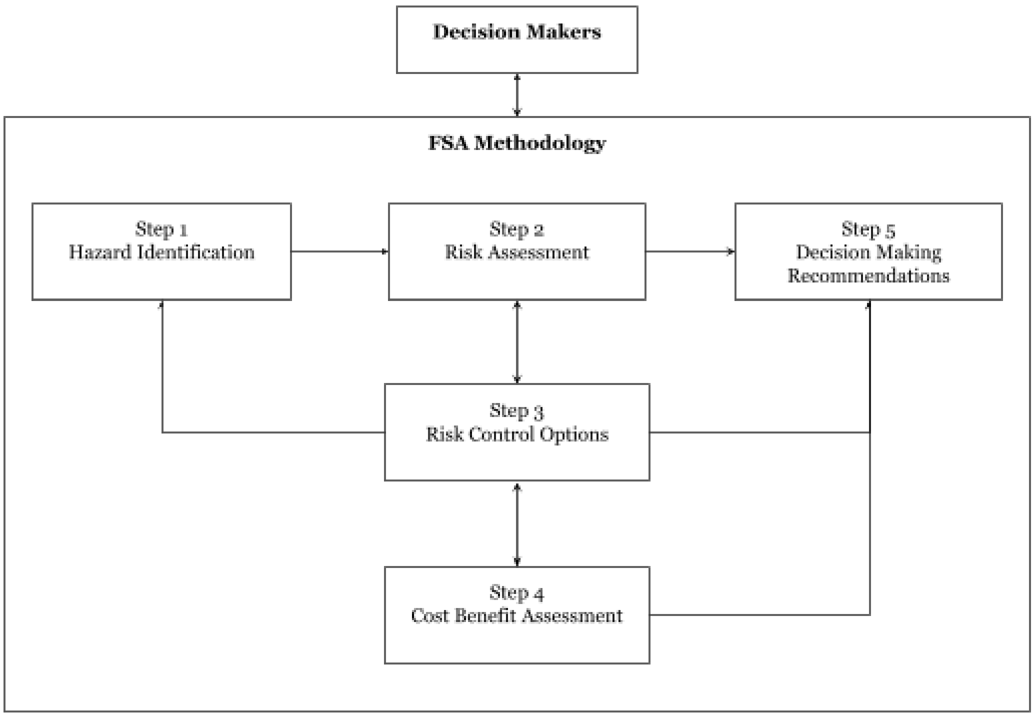

Figure 4, Flow chart of the FSA methodology, IMO (2002d).

Since the human factors are one of the largest contributors to accidents, human elements are incorporated within the FSA framework through Human Reliability Analysis (HRA). Examples of human element issues can be stress, leadership, working condition factors and task complexity, IMO (2002d).

The HRA process is divided into five steps, IMO (2002d):

1. Identification of key tasks
2. Task analysis of key tasks
3. Human error identification

4. Human error analysis
5. Human reliability quantification

To incorporate the HRA into the FSA process, following division is used, IMO (2002d):
- HRA step 1 in FSA step 1
- HRA step 2, 3, 4 and 5 in the FSA step 2
- Consider risk control options in FSA step 3.

- *FSA Step 1: Identification of hazards*

In FSA step 1 a list of hazards and its consequences shall be produced. For the human reliability analysis, it is important to identify human interactions which could lead to system failure if not performed correctly. To identify possible hazards, standard techniques are used, both analytical and creative. Analytical techniques analyses previous near misses and accidents, to make sure those do not repeat themselves. A creative risk analysis technique that is used is a "What If" Analysis, for example the SWIFT Technique.

The Failure Mode and Effects Analysis, FMEA, and the Hazard and Operability Studies, HazOp, are also used to analyse how human interactions can lead to system failure. The HazOp technique focuses on finding potential hazards and deviations that can endanger normal operation and lead to operational problems, and the FMEA is further explained in chapter 3.

When the risks, and their causes and effects, are identified, the risks should be ranked in a risk matrix, seen in figure 2, IMO (2002d).

- *FSA Step 2: Risk analysis*

When FSA Step 1 is done, the most severe risks are further analysed in step 2. This is done by using risk analysis techniques as the Fault Tree Analysis and the Event Tree Analysis. A Risk Contribution Tree (RCT), figure 5 can be made, which divides and visualises risks depending on the accident category, and plot them against a FN Curve, which is a function of how many people (N) that are killed by an accident over a specified time (F, frequency), IMO (2002d).

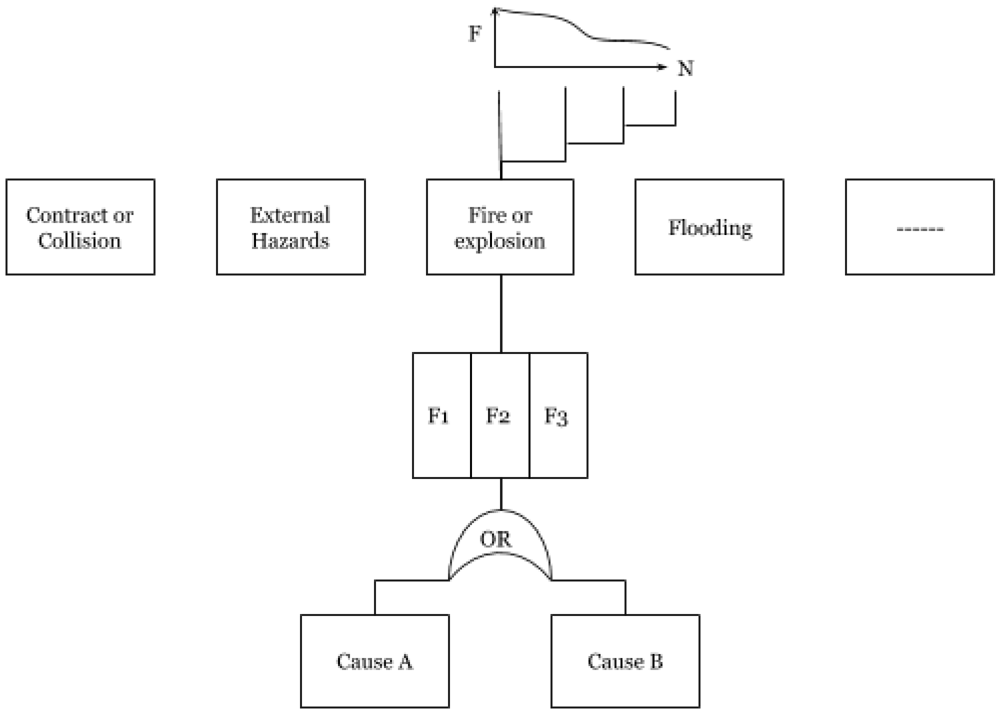

Figure 5, Risk Contribution Tree, IMO (2002d).

In FSA step 2, areas where there is a high risk of failure due to human element need to be identified.

To analyse this, human error analysis is used. There, a list of human errors that can lead to a system error or failure is created. The errors are then classified, depending on the causes, if there are mitigation possibilities, and the consequences of the error. To quantify human errors, "Probability of Human Error" (HEP) techniques can be used. The Absolute Probability Judgment (APJ) is an expert judgement technique. Technique for Human Error Rate Prediction (THERP) is a technique which models human as a sub-system, and analyses all the systems that humans are in contact with and influences during operation. All the human operations are listed and the probability of human errors and it effects are determined.
Human Error Assessment and Reduction Technique (HEART) looks especially on ergonomics, task and environmental factors that affects the human performance.
The FMEA and HazOp is also used to analyse the consequences of the risks listed in the FSA step 1, IMO (2002d).

- *FSA Step 3: Risk control options, RCO*

In FSA step 3, risk control options are created for risk areas needing them. To determine which risk areas that need to be controlled, four aspects are considered; the risk level, the probability of the risk occurring, the severity of the risk and which area that the uncertainty of any of the mentioned aspects are the highest. To identify potential Risk Control Measures (RCM), a causal chain, figure 6, can be developed, IMO (2002d).

Figure 6, Causal Chains, IMO (2002d).

The goal of creating a RCMs is to both reduce the probability of a failure occurring and to control the development of an accident. This is done by developing a RCM which either reduces the frequency of a failure or reduce the consequences of a failure occurs. If that is not possible, the RCM should reduce the probability of that failure leading to an accident. If an accident nevertheless occurs, the RCM should reduce the consequences of that accident. To develop effective RCMs it can be useful to divide the task according to the comprehensive view where the system is divided into the technical/engineering system, the working environment, the personnel and the organizational/management sub-system or the environmental context, see figure 7, IMO (2002d).

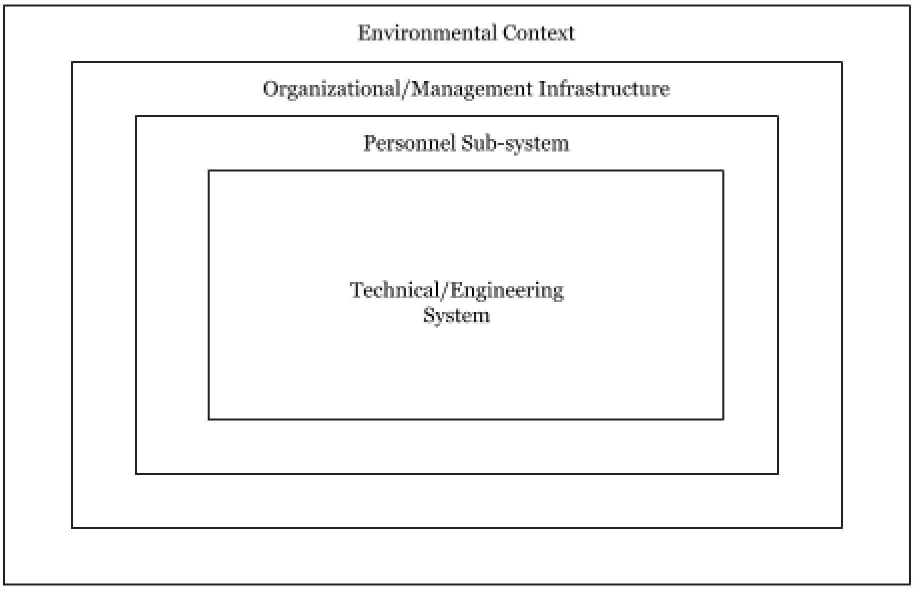

Figure 7, Components of the Integrated system, IMO (2002d).

The technical and engineering system is built by humans, and are therefore affected by human behaviours, but also by physical laws. Examples of factors that belongs to the technical system is the design of the ship. Is the ship design ergonomic? Is it enough space for the crew to do their work in a safe and qualitative way? Is the interface between the crew and machines designed so the use of it is intuitive and clear?

Passengers and crew uses the technical systems, and their actions are affected by human behaviour as well as the existing management culture, infrastructure and organizational regulation. Examples of factors that belong to the personnel system is for example sufficient training of the crew, but also the levels of stress and fatigue of the crew that can be affected by for example scheduling and workload. The crew acts in a working environment that can affect their behaviour and ability of performing as intended, IMO (2002d). The working environment is defined as "the physical environment of the workplace and how a person matches up with the task to be carried out". Examples of factors and elements that are considered when evaluating a working environment is the vibration levels, the space available for the work to be done at and which tools and protective equipment that are available for the workers, (Kuo, 2007b).

The organizational and management infrastructure includes factors as organizational processes and policies, and if the company is using safety management systems, IMO (2002d). The organizational culture is defined as "how the individuals have interpreted and put into practice the philosophy adopted by the organization. This is reflected in its attitude to issues such as quality and safety". Examples of a good organizational culture is whether the employees understand the safety goals and if they follow and uses them in their work and if the employees can express their thoughts and concerns without fearing reprimands, Kuo (2007b).

The environmental context is everyone that affects the design or use of the vessel beside the companies designing and operating it, for example the country that the vessel is flagged in, or the IMO that sets rules and standards of both design and operation, IMO (2002d).

No methods are however mentioned to measure which affects the RCMs will have on the unwanted event.

- *FSA Step 4: Cost benefit assessment*

In the fourth step of the FSA, the Risk Control Options benefits and costs are evaluated. The costs are presented as Life Cycle Costs. To evaluate the cost effectiveness of the RCOs in comparison to safety of life, measures like Gross Cost of Averting a Fatality (Gross CAF) or Net Cost of Averting a Fatality (Net CAF) can be used. Here the cost per ship of the risk control option is compared to the reduction of fatalities due to the risk control options. In the Net CAF, the economic benefit per ship due to the risk control option is also included, IMO (2002d).

- *FSA Step 5: Recommendations for decision-making*

In order for decision makers to be able to determine whether to implement a risk control option or not, recommendations must be presented in such a way so they can be understood by all stakeholders, independent of their experience of risk management. The most accepted way of measure and visualise risk levels is the ALARP method, IMO (2002d).

Each report of the FSA result shall, IMO (2002d):

1. *"Provide a clear statement of the final recommendations, ranked and justified in an auditable and traceable manner",*
2. *"List the principal hazards, risks, costs and benefits identified during the assessment",*
3. *"Explain the basis for significant assumptions, limitations, data models and inferences used or relied upon in the assessment or recommendations",*
4. *"Describe the sources, extent and magnitude of significant uncertainties associated with the assessment or recommendations",*
5. *"Describe the composition and expertise of the group that performed the FSA process."*

4. Comparison of state of the art engineering risk approaches and IMO

When now both the general industry and maritime industry risk management processes and has been presented, a comparison between the two can be performed.

A ship is a system that can change in many ways, without changing the design of the ship. For example, a cargo ship is a system that can vary from being fully loaded to being empty. Both the centre of buoyancy and gravity can change drastically when loading, and there is always a risk of loading wrong, which can have disastrous consequences. When the cargo is loaded, there is a risk of losing cargo at sea due to bad weather or large waves, which also can change the system completely. All these factors are heavily controlled by human elements. Therefore, the FSA is mainly focused on human elements and risks linked to operation. Generally in the shipping industries, the design is standardized and controlled by either IMO or registrar and classification societies. Due to this, the FSA, focuses mainly on the operational perspective in the design phase.

If a company is building a new ship, standard risk analysis can cover the whole project and product development, from the concept to the design phase, to the production phase and the operational phase. The FSA can be considered as a part of a whole risk analysis, covering the design phase and the operational phase, and in order to perform a complete risk analysis other parts need to be added, for example the risk of not meeting the time plan or financial expectations.

The structure of a general risk management approach is the same as in the FSA. First the risks must be identified. In the FSA step 1 it is mentioned that both analytical and creative methods can be used. An example of a creative method is the SWIFT method, which is used in general risk management analysis as well. Other methods mentioned to identify risks, most focusing on risk connected to human behaviour, is the HazOp and FMEA. One method that is used in general risk management is a Risk Breakdown Structure, which can be used to identify, understanding and ranking risks. One can say that the Risk Breakdown Structure is an example of an analytical method, which is mentioned as one of the methods used in the FSA. In general risk analysis a risk matrix is used to rank the most severe risks to be further analysed, and this is used in the FSA as well.

In the FSA Step 2, a risk analysis is performed. In both general risk management and the FSA, the Probabilistic Risk Assessment (PRA) is used.

In FSA Step 3, Risk control options are listed .In general risk assessment, the method called Bowtie diagram is often used for this purpose. In the FSA, the causal relationship between risks and consequences and which prevention or mitigation actions that can reduce the probabilities and consequences of this risk is partly analysed in the probabilistic risk assessment, but not by using the Bowtie diagram. In both the FSA and in risk management in general, a cost benefit assessment is made. Here it is investigated whether the risk control options or mitigation actions are cost effective. The method used in the FSA, and also widely used in risk management in general is the Life Cost Analysis. In both risk management in general and in the FSA the importance of sharing the results of a risk analysis to their shareholders are emphasized.

According to Kuo (2007a), one fundamental drawback in the FSA is the non-existing demands on safety management. Kuo means that it is humans that causes accidents, and therefore it is also human who can prevent them. To improve and reduce the risk of accidents due to human factors, the working environment and organizational culture, among other, plays a big part of this, Kuo (2007b). It is mentioned in the FSA that risks in different areas shall be analysed and controlled, from the technical system, to working environment to passengers and crew and management culture, infrastructure and organizational regulations, but, as Kuo writes, there are no explicit *demands* on safety management. It is stated in the FSA that an example of a risk control option for the organizational system is "the use of safety management systems", IMO (2002d).

The FSA presuits examples on factors to evaluate when analyzing the working environment, personnel system and organizational system, but one could question whether this is enough to highlight the importance of a full safety management system. Doing a qualitative risk analysis that discovers potential risks, where the probability of failure is reduced, is a difficult task. To maximize the outcome where as many designers as possible could use the FSA as a risk analysis tool with a successful result, a clear demand on safety management is essential.

5. Maritime accidents with serial produced vessels

To understand the practical use of the FSA, three maritime accidents will be investigated. If the designers of the boat would have used the FSA, would it have been possible to prevent the accidents?

The accidents that have been investigated are the capsizing of Viking 7, LG8351, Northwest of Mehamn on 6 July 2014, Norway, the accident with the RIB SFC-7153 off Djurö in 2006, Sweden and the capsizing of the RF2 rescue boat in 1981 outside Denmark. These accidents are chosen since they are serial produced vessels, which in this report is defined as a vessel that are produced more than once, and with the same design. The accidents have been investigated by an accident commission, and there is a clear course of events leading up to the accident presented for all the accidents. The accidents are similar in both the size of the boat and the number of people on board and also the consequences of the accidents.

Below the accidents will be explained and investigated and the reasons behind the accident will be stated.

5.1 The capsizing of Viking 7, LG8351, Northwest of Mehamn on 6 July 2014, Norway

Type of ship	Rental fishing boat
Size of ship	6.9 m long
Purpose of tour	Familiarisation trip
Date and time of accident	2014-07-06, 13:26
Type of accident	Boat flooded, capsized
Where	Mehamn, Norway
Consequences of accident	1 person died of hypothermia, 1 admitted to hospital
Number of people at the ship	6 men, of them 1 guide
Weather	Fresh breeze, daylight, clear sky

Table 1, Data of the accident of Viking 7

On the 6th of July 2014, five Swedish tourist and a guide where on a fishing trip on a Viking 7 in Mehamn, Norway, see data on the boat in table 1. The tourist had rented the boat and the purpose of the trip was to get to know the boat which they had rented and to get to know the area and good fishing spots. On their last stop, the guide noticed that the boat was low in the water, and taking in water through two drain openings in the transom. The bilge pump was activated but the boat was taking in more water then the pump pumped out. At this point, the guide ordered the tourists to move forward in the boat so the stern was raised, and also handed out thermal protection suits. Three of the tourists put the suits on correctly, with the life jacket on top of the suit, but none of them managed to make their suits watertight since the suits were not closed properly. One of the tourists put the suit on top of the life jacket and the fifth tourist put the suit back to front, which was uncomfortable and therefore the tourist only wore his life jacket. Eventually, boat capsized and all tourists and the guide ended up in the water. Everybody was pulled out of the water after approximately 20 minutes, and at this point one of the tourists was unconscious, and later passed away. Another tourist suffered from hypothermia.

Later when an investigation of the accident was made, it was discovered that one of the reasons of the accident was that a large volume of the space between the outer hull and the inner liner was filled up with water that was coming in through the drain openings and a flush hatch that was not watertight. This space was supposed to be filled up with foam, but this was not the case. This space made it possible to be filled up with water and also for the water to move. If this would not have been the case, it is likely that the accident would not have occurred, or at least not in that pace. Due to this, the boat lost buoyancy and stability was drastically reduced and lead to the boat capsizing.

It was also discovered that other parameters and functions of the boat did not meet minimum requirements and standards. The drain openings in the transom, which was letting in water, did not comply with freeboard requirements. The company building the boat was aware that there was possible to make exceptions from these requirements, but misunderstood these exceptions and the criteria for making them. Neither did the boat ´s intact stability meet the ISO standard. The system that should detect and remove water entering the boat, did meet the requirements in the ISO standard, but did however not work, due to reasons not clarified in the investigation report. The bilge pump was supposed to start automatically but did not work as intended and was activated manually by the guide when water was discovered to enter the boat. This delay can possible have affected the accident.

One conclusion, or reflection, made during the investigation is that ISO standards are rather difficult to understand and follow.

It was concluded that if the supervision authority would have supervised the manufacturer and the company designing the vessel, it could have been possible to detect the non conformity with standards and requirements, and that might have prevented the accident. Another conclusion that would perhaps have reduced the consequences of the accident was if there was requirements of safety culture and safety management at the rental company, which does not exist today. One example is that the tourists had been showed how the protection suits should have been put on, but they had not trained on it, leading to that none of the tourists managed to put on their suits correctly, (Aibn, 2016).
A summarization of the reasons of the accident can be found in table 2.

Main reason:	**How could this have been prevented?:**	**Barriers that could have prevented the accident, but failed:**	**Barriers that could have mitigated the consequences, but failed:**
The space between the outer hull and the inner liner was filled up with water	The manufacturer of the boat had understood rules for making exemptions from the requirements	Drain openings in the transom meeting freeboard requirement	Better safety culture of the rental company, training of safety routines if event of accident.
		Watertight drain openings and a flush hatch	
		The system that should detect and remove water entering the boat, did not work as intended	Automatically start of bilge pump.
The boat ´s intact stability did not meet requirements	ISO standards difficult to understand and follow.	The supervisory authority would have supervised the vessel and the manufacturer	

Table 2, Data of the reasons of the accident of Viking 7

5.2 The accident with the RIB SFC-7153, Sweden

Type of ship	RIB, Rigid Inflatable Boat, charter boat
Size of ship	9.5 m long, 2.7 m wide, 0.5 m draught
Purpose of tour	Private
Date and time of accident	2006-07-01, 02:34
Type of accident	Collision
Where	Södra Kanholmsfjärden, Artipelago outside Stockholm
Consequences of accident	One person fatally harmed, heavy damage on the boat
Number of people at the ship	9 men, of them 3 crew
Weather	Dawn, almost no wind, good visibility

Table 3, Data of the of the accident of the RIB SFC-7153

On the night of the 1th of July 2006, 9 Swedish men were going on a RIB boat from Sandhamn to Djurö, when they hit a buoy and one of the persons where fatally harmed, see table 3.

The company consisted of three persons owning and working in a company doing RIB boat trips in the artipelago outside Stockholm, and 6 friends or acquaint of them. This trip was a private trip and not part of the company's ordinary activities. The night started in a garden at an island called Djurö. During the night, it was decided that they were going out for a ride with the RIB boat. The owner of the boat declared that he would not drive the boat since he had been driving the boat all day. The trip first went to Strömma kanal and then to Sandhamn. On both places, alcohol was consumed.

On the drive back to Djurön, many of the passengers where not sitting on the designated passenger seats, but instead standing up and leaning over the boat. The driver increased the speed to approximately 63-65 knots temporarily. During the drive, the driver showed the passengers how the navigator plot worked, and it was during this time that the boat collided with the buoy. One person was at that moment leaning over the side of the boat, and hit the buoy and was then thrown out of the boat. This person died of his injuries.

The main reason of this accident was, according to the investigation, due to the fact that the driver was under the influence of alcohol, distracted and tired. The investigation did not find any technical deficiencies of the boat, and the weather was clear, calm and light and there was no traffic.

Another reason for the accident, and the consequences of the accident was that the shipowner deviated from their rules and safety routines. Examples of this was that the driver had been drinking, that the passengers were not sitting on their designated seats in a safe way and that the navigator plot was shown during the trip. Another example is that the company usually strictly forbid that the driver is under the influence of alcohol, (SHK, 2007a). The accident is summarized in table 4.

Main reason:	**How could this have been prevented?:**	**Barriers that could have prevented the accident, but failed:**	**Barriers that could have mitigated the consequences, but failed**
Deviated from rules and safety routines	Ignition interlock device	Not driving while under the influence	Inform the passengers about the designated passenger seats and how to be seated safely
	If the owner of the ship would have reacted on that the safety routines was deviated from	Not showing the navigator plot while driving	

Table 4, Data of the reasons of the accident of the RIB SFC-7153

5.3 The capsizing of the RF2 rescue boat 1981, Denmark

Type of ship	Rescue Vessel
Size of ship	15 m long, 4.4 m wide, 2.1 m draught
Purpose of tour	Rescue mission
Date and time of accident	1981-12-01, late evening
Type of accident	Struck by a wave, capsized
Where	Skagenrak, Denmark
Consequences of accident	6 persons drowned
Number of people at the ship	6 men, all crew
Weather	20 m/sec wind, strong current

Table 5, Data of the accident of the RF2 rescue boat

On the night of the 1st of December in 1981, a rescue vessel capsized outside Skagerak, and 6 men were lost. The rescue vessel was on a rescue mission, and the weather conditions were rough, with wind in combination with a strong current. On the way back to port, the vessel was hit by a breaking wave and turned around. The vessel was designed to be self righting but did not have that ability. The two windows in the port side was blown in and the entire top of the wheel house was torn away. The whole crew, 6 men, was found drowned, see table 5.

The reason of the capsizing was the two windows imploding. The ship was supposed to be self-righting, something that later calculations showing not being the case. An inclination test was made before the boat was given to her owner, but the documentation of it was not correctly made, so no conclusion of the correctness of the test could be evaluated by the accident commission. The self-righting test was not made correctly since the turning in the test was made to fast. The requirement is that it should take at least 90 seconds from 0 to 180 degrees, but in the performed test it took about 20 seconds. One authority supervisor was present at the test but did not react to the incorrect performed test, Guldhammer (1986).

Main reason:	**How could this have been prevented?:**	**Barriers that could have prevented the accident, but failed:**
Insufficient stability	Stability calculations	Intact windows
	Inclination test, self-righting test carried out correctly	Intact wheel house

Table 6, Data of the reasons of the accident of the RF2 rescue boat

6. Analysis

To further analyse the accidents, the FSA structure will be used as an example of the IMO risk perspective. Could a use of the FSA prevented or reduced the consequences of the accidents? Is there any other techniques within risk management that could have been used, but is not included in the FSA? In the analysis it is assumed that the companies designing the vessels and the companies operating the vessels is aiming towards using a risk based ship design and having a risk based safety culture.

The following chapter includes the root causes leading to the accidents described earlier, found by the accident investigation board. It should be noticed that more risks or hazards would have been discovered and analysed in a full risk analysis. As stated before, the FSA method is divided into the following steps.

1. Identification of hazards
2. Risk analysis
3. Risk control options
4. Cost benefit assessment
5. Recommendations for decision-making

6.1 FSA step 1: Identification of hazards

In FSA step 1 hazards and the associated scenarios should be listed. Techniques that are used are both analytical techniques that analyses previous accidents and near misses but also creative risk analyses, like the SWIFT method which try to answer the question, “what can happen if..?” Human element risk factors are also analysed, especially those that can be a risk to normal operations. When all risks have been listed, the risks should be ranked in a risk matrix.

The root causes identified by the accident investigation boards leading up to the three accidents is analysed below.

6.1.1 The capsizing of Viking 7, Norway

- *Risk owned by the company designing the vessel:*

The space between the outer hull and the inner liner not filled with foam. This space was supposed to be filled up with foad, to avoid flooding. Since it was a design feature, it could have been possible to list "space between outer hull and inner liner is not filled up with foam" as a potential risk, in other words - the failure of the design feature.

The failure of the watertight function of the drain openings and flush hatches. This could also have been possible to identify as a potential risk, since it was a chosen feature of the ship.

The failure of the system detecting and removing water entering the boat. This could have been possible to notice, since it was a designed function of the system.

The misunderstanding of the requirements. This risk could eventually have been possible to detect, or at least listed as a risk. The way of discovering this could for example be peer reviewing or a scrutiny of the design built into the design process. That might have led to the discovery of the misinterpreted requirements. One way of discovering this would also have been to make control calculations of the boats intact stability. It should be possible to list the risk "incorrect design", and break this up into many parts, which one of them would be "insufficient intact stability".

Lack of supervision from the supervision authority. Unless the company designing the vessel usually gets supervision from the supervision authority, it is unlikely that this risk would have been noticed.

- *Risk owned by the company operating the vessel:*

The ship capsizing. With all ships, this is always a risk. A plan for how to reduce this risk but also reducing its consequences is vital.

The passengers not using the life and protection suits correctly. Since the correct use of life and protection suits is an important factor in the plan of rescuing people if falling overboard, or if the ship capsizes, the risk of this not being the case must be analysed.

Not sufficient safety culture of the company. The FSA does not explicit demand the company to have a safety culture. It is assumed that the company did have a safety culture of some sort, but according to the investigation board, it was not sufficient. In the FSA, safety culture is mentioned as an example that might have to be controlled and analysed, as a part of the management system. If the company would have used the FSA, it is therefore possible that the term "safety culture" would have been encountered. It is however not guaranteed that the company would have listed "not sufficient safety culture" as a risk.

6.1.2 The accident with the RIB SFC-7153, Sweden

- *Risk owned by the company designing the vessel:*

The driver using the vessel while under the influence of alcohol. By analysing accidents that have occurred(both on sea and on land), it is possible to see that many of them are partly or directly due to that the driver or other crew is under the influence of alcohol.

The passengers not using the designated passenger seats. Since the safety of the passengers is dependent on that the passengers are using designated passenger seats, the risk of deviating from this should be analysed.

- *Risk owned by the company operating the vessel:*

The driver using the vessel while under the influence of alcohol. See above

The passengers not using the designated passenger seats. See above

The deviation from its own routines. The company using the vessel should list the potential outcomes of the risks deviating from their routines.

6.1.3 The capsizing of the RF2 rescue boat, Denmark

- *Risk owned by the company designing the vessel:*

The boat not being self-righting. This could also have been possible to identify as a potential risk, since it was a chosen feature of the ship

The windows failing. It is not obvious that the scenario of the windows failing would have been discovered, but the chances of this increases if using the FMEA.

The supervisor from the authority not reacting on the test being performed correctly. It is not obvious that this would have been discovered as a risk. If the test would have been discussed between the design engineer and the supervisor, the chances of noticing possible failures in the planning or proceeding of the test would have increased.

- *Risk owned by the company operating the vessel:*

The boat not fulfilling the demands. Even though the company owning the vessel did not design it, it is still important for the company to have demands on the features of the boat, and also to have knowledge of how to ensure that these demands are fulfilled.

6.2 FSA step 2: Risk analysis

When FSA Step 1 have been performed, the most severe risks are further analysed in step 2. Since all risks in FSA step 1 was involved in actual accidents, they are all viewed as severe risks. If a risk analysis would have been done on these vessels and its operations before the accident occurred, it is likely that more risks would have been listed and that these risks would have been evaluated differently.

According to FSA step 2, the risks are analysed by using Probabilistic Risk Assessment, PRA, which tries to answer the question what can happen and what is the probability and consequences of this event? The PRA is divided into two techniques, the “Forward analysis” - “Event Tree Analysis (ETA)” and the “Backward analysis” - “Fault Tree Analysis (FTA)”. The Event Tree Analysis assumes that something has happened and evaluates how this event affects a sequence of events until it reaches the final event. The Fault Tree Analysis assumes that something can happen, and starts at a possible final event and goes backwards to find an initiating event that can start that chain.

Human error analysis is also used. A list of human errors that can lead to a system error or failure is created. The errors are then classified, depending on the causes, if there are mitigation possibilities, and the consequences of the error.

By using the FMEA the components of the vessel are analysed and the effects of them not working as intended.

In FSA step 1, all potential risks are supposed to be listed. As mentioned before, in this chapter the risks list leading to the discussed accidents is further analysed. The risks are also evaluated according to the ALARP method. Are the risks and its possible consequences acceptable or unacceptable and are there a need for risk control measure? By using the ALARP method it is possible for the company designing and using the vessel to determine which risks that are necessary to reduce and which risks that are acceptable. Since all risks analysed in this report, have been listed as contributing factors to actual accidents, most of them are evaluated as “unacceptable risks” that are in need of mitigation actions.

6.2.1 The capsizing of Viking 7, Norway

- *Risk owned by the company designing the vessel:*

The drain openings not watertight. Water can enter the boat. Unacceptable risk, mitigation action is needed.

The flush hatches not watertight. Water can enter the boat. Unacceptable risk, mitigation action is needed.

The system detecting and removing water failing. Water entering the boat is not detected and not removed automatically, more water can possibly enter, leading to dependence of human interference. Unacceptable risk, mitigation action is needed.

The space between the outer hull and the inner liner not filled with foam. Water coming into the boat can move around, which can make the boat unstable. Unacceptable risk, mitigation action is needed.

Misunderstanding of requirements. A misunderstanding of the requirements can lead to unwanted events, that can lead to both serious and less serious consequences. It is therefore difficult to rate the consequences of this risk, but since some consequences of misunderstanding requirements can be serious, this risk is classified as unacceptable and mitigation actions are needed.

Incorrect design leading to insufficient intact stability. Can lead to the ship capsizing, which is an unacceptable risk and need mitigation actions.

Lack of supervision from the supervision authority. It is unlikely that this risk would have been noticed if the company was not used to being supervised. It is unclear whether the supervision authority had the responsibility to supervise the company designing the boat, but if that was the case, the risk is unacceptable and need mitigation actions. If the supervision authority did not have the responsibility to supervise the company, the investigation board indicates that supervision could have prevented the accident, but it is unclear whether the company designing the vessel could have influenced this risk.

- *Risks owned by the company owning the vessel:*

The ship capsizing. Can lead to a great danger to passengers and also environment, unacceptable risk, mitigation action is needed.

The passengers not using the life and protection suits at all or not in a correct way. Can lead to a great danger to passengers, unacceptable risk, mitigation action is needed.

Not sufficient safety culture of the company. When the safety culture is not sufficient, the risk of not having frameworks for controlling working procedures or routines exists as a consequence. This risk is unacceptable and need mitigation actions. It is however unclear if the risk of not having a sufficient safety culture would have been noticed.

6.2.2 The accident with the RIB SFC-7153, Sweden

- *Risks owned by the company building the vessel:*

The driver using the vessel while under the influence. Risk of collision, capsizing, losing control and overestimating one's ability. By using the analytical technique in FSA step 1, it should be clear by evaluating near misses or lessons learned, that alcohol in combination with handling the ship is a not wanted situation and an actual risk. Unacceptable risk, mitigation action is needed.

The passengers not using the designated passenger seats. Risk of falling overboard. Since RIB boats are designed for going in a high speed, and have that capacity, both the company designing the vessel and the company using it should evaluate risks connected to that. The combination of high speed and passengers make the situation even more special. This fact is known to the engineer designing the vessel, and a risk assessment of this is necessary. When going at a high speed, with passengers most likely not used to high speed crafts, it is critical that the designated area where the passengers are supposed to be in is designed and thought of thoroughly. It is important that both the design of the passengers seats are inviting and comfortable to sit in and feel safe , but it is equally as important to take away other areas where the passengers could sit in, but not supposed to. To recognize the risk of the passengers sitting on bunkers or on places other than their seats is important and by both doing the Forward analysis where the initial event is, “passenger sitting on the bunker” or the Backward analysis where the final event is “passenger overboard”, should show the need of well designed passenger seats. Unacceptable risk, mitigation action is needed.

- *Risks owned by the company owning the vessel:*

The driver using the vessel while under the influence of alcohol. See above

The passengers not using the designated passenger seats. See above

Deviating from the safety routines. Deviating from the safety routines can lead to unwanted events, that can lead to both serious and less serious consequences. It is therefore difficult to rate whether this is an unacceptable risk or a tolerable risk. It is therefore difficult to rate the consequences of this risk, but since some consequences of misunderstanding requirements can be serious, this risk is classified as unacceptable and mitigation actions are needed.

6.2.3 The capsizing of the RF2 rescue boat, Denmark

- *Risks owned by the company building the vessel:*

The boat not being self-righting. Can lead to the boat capsizing. Unacceptable risk, mitigation action is needed.

The windows not being intact. Can lead to that the windows implode, which can lead to water coming into the boat. For the company designing the vessel, one technique that actually could have prevented this accident, or perhaps reduced the consequences of it, is if a FMEA would have been done. By doing a FMEA, the windows should have been a component to analyse. The failure mode of the windows and the effects of this would have been analysed, and by doing this, and realizing the importance of the windows being intact, could have led to making sure that the windows would have withstood the impact that was made if the ship was turning around. Unacceptable risk, mitigation action is needed.

The tests not performed correctly. If test is not performed correctly, it is difficult to evaluate the ships quality. The stability of the boat should had been evaluated both in a correctly performed turning test but also by doing control calculations. A Probabilistic Risk Assessment, PRA, on the risk of the vessel not being self-righting, or the stability not sufficient enough the engineers could have resulted in this, "what can happen?" - the boat can turn over and not being able to turn it self up again. It is also possible that the vessel turns around earlier than calculated, if the stability is not sufficient enough. The probability of this happening, must be determined by doing a turning test, and doing complementing calculations of the stability. The consequences of the ship not having sufficient stability could in the worst case be loss of crew and ship. When understanding the consequences, the reduction of the probability of this happening should be a high priority. By doing a backward analysis, with the final event "ship capsizing and not being able to turn upright again", several initial events could be listed. Among them, the stability not being sufficient could be one. By pushing this further, and understanding why this is the case, one could for example list following events; calculations are incorrect, the interpretations of standards are wrong, test of stability and turning test not performed correctly. Unacceptable risk, mitigation action is needed.

- *Risks owned by the company operating the vessel:*

The boat not fulfilling the demands. If the boat is not fulfilling the demands, and the company does not have a standardized method of measuring this, the risk of the boat not performing as intended is high. Since the difference between the boats performance and the companies specifications or intended use can vary, it is difficult to rate whether this is an unacceptable risk or a tolerable risk.

6.3 FSA step 3: Risk control options

In FSA step 1 and 2 the most serious risks are presented as well as suggestions on how they might occur and what consequences they can lead to. In FSA step 3, the control options and risk control measures for the risks needing them are created.

The purpose of create and analyse Risk Control Measures, RCM, is to find ways of reducing the probability of failure and also to mitigate the consequences if a failure occurs. In general risk assessment, the method called Bowtie diagram is often used for this purpose. Prevention actions are barriers that prevent or reduces the probability of an unwanted event to occur. If the event however happens, mitigation actions are barriers can stop or reduce the potential outcomes. In the FSA, the causal relationship between risks and consequences and which prevention or mitigation actions that can reduce the probabilities and consequences of this risk is partly analysed in the probabilistic risk assessment, but not by using the Bowtie diagram. The Bowtie diagram and the risk control measures can contribute with suggestions of the barriers or risk control measures RCM that prevents or reduces the unwanted event and the consequences of it. There is however no method proposing which RCM that can be used to prevent or mitigate an unwanted event, neither if the RCM will work.

When analysing human interactions, and prevention and mitigation actions for human errors, four areas are usually analysed; the technical/engineering, the working environment, the personnel and the organizational/management sub-system. These are further explained in chapter 3.3.3 Below the risks will be divided into these areas depending on which area that is believed to have been able to mitigate the risks the most.

6.3.1 The capsizing of Viking 7, Norway

- *Risk owned by the company designing the vessel:*

The drain openings not watertight. Technical/engineering system, a mitigation action could be to install a system detecting and removing the water.

The flush hatches not watertight. Technical/engineering system, a mitigation action could be to install a system detecting and removing the water.

The system detecting and removing water failing. Technical/engineering system, If the system that are supposed to detect and remove water is failing, in combination with that the watertightness of the drain openings and flush hatches are failing, one control action could be to install two systems that are not dependent on each other, so if one system fails - the other one is most likely functioning.

The space between the outer hull and the inner liner not filled with foam. The personnel and the organizational/management sub-system. It is important for the company producing the vessel to have a process that ensures that the production is of a high enough quality, and a control of the quality is made.

Misunderstanding of requirements. The personnel and the organizational/management sub-system. The company designing the vessel could have recognized this, and thought of ways of reducing this risk, or mitigating the consequences of it. One possibility could have been the peer review system, avoiding that only one engineer is responsible for the design or the design features. The culture of the company could have been discussed. What happens if the engineers are insecure of their calculations? What kind of reply do they get? What happens if an engineer makes a mistake? Is the culture inviting the engineers of doing lessons learned or is it a culture of holding one engineer responsible?

Incorrect design leading to insufficient intact stability. The personnel and the organizational/management sub-system. One possibility could have been the peer review system, avoiding that only one engineer is responsible for the design. A control system could also have been made, where tests of the for example intact stability was made.

Lack of supervision from the supervision authority. Environmental context. Today, the supervision authority do not supervise companies building these types of boats(small rental boats). One control option could definitely be to supervise these companies. It is classified as an environmental context since it is assumed that the state of Norway need to put demands on the supervision authority if this control measure would be put into practice.

- *Risks owned by the company owning the vessel:*

The ship capsizing. Technical/engineering system. What happens if the boat capsizes? Which mitigating actions are necessary to make the consequences of the boat capsizing as small as possible?

The passengers not using the life and protection suits at all or not in a correct way. The personnel and the organizational/management sub-system. One mitigation action that can reduce the consequences that the passengers uses the protection and life suits correctly. Here, the company should have been able to recognize the importance of making sure that the passengers have this knowledge.

6.3.2 The accident with the RIB SFC-7153, Sweden

- *Risk owned by the company designing the vessel:*

The driver using the vessel while under the influence of alcohol. Technical/engineering system. To avoid that the driver is using the vessel while under the influence of alcohol, an interlock device could have been installed. Also systems warning the driver for driving the boat unstable and even an automatic system reducing the speed in a smooth way could be barriers hindering the driver under influence hurting him/her or passengers or other targets.

The passengers not using the designated passenger seats. Technical/engineering system. To ensure that the passengers are using the designated passengers seats it is important that they are so they are inviting and comfortable to sit in and feel safe is. Another aspect is to build away other areas where the passengers could sit in, but not supposed to.

- *Risk owned by the company operating the vessel*

The driver using the vessel while under the influence. The personnel and the organizational/management sub-system. See below.

The passengers not using the designated passenger seats. The personnel and the organizational/management sub-system. See below.

Deviating from the safety routines. The personnel and the organizational/management sub-system. To ensure that deviating from the safety routines are not possible, or recognized before an unwanted event happens is crucial. It is clear that the company deviated from their routines, but the reason of it is unknown. One could suspect that this deviation from

routines was not the first one, or the first time deviations was made. It is possible that the company during a period of time have deviated from their routines, but in many small steps which in themselves was hard to notice and not leading to any negative consequences, so called procedural drift. In the extension, procedural drifts can lead to accidents, like the one above. By doing many small deviations, that does not lead themselves to any negative consequences, will give the crew a false feeling of assurance that the routine is not that important and that nothing wrong can happen, SHK (2019:01).
To avoid this, an understanding of safety routines are vital. Does the crew and employees of the company understands why the safety routines are there? Is there a possibility of discuss the routines? To make the whole company both a part of creating routines and also understanding them, it is a possibility of increasing the willingness of following them.

6.3.2 The capsizing of the RF2 rescue boat, Denmark

- *Risk owned by the company designing the vessel:*

The boat not being self-righting. The personnel and the organizational/management sub-system. Designing a vessel is a difficult task, and a big responsibility. To reduce the risk of the calculations or test being not correct, a peer review system can be an option.

The windows not being intact. The personnel and the organizational/management sub-system. One example of an RCO to ensure the quality of the windows could have been by performing an intact test on the windows.

The tests not performed correctly. The personnel and the organizational/management sub-system. Due to the difficulties and many aspects of designing a vessel, having support by company routines on designing vessels and also by a supervisor authority can help controlling the characteristics of the vessel. It is though important that a false feeling of security is not created. The responsibility of the design and characteristics of the vessel needs to be shared, between the engineer designing it, the company where the vessel is designed, the supervisor authority controlling it, and the company buying it and also by the people using it.

- *Risks owned by the company operating the vessel:*

The boat not fulfilling the demands. The personnel and the organizational/management sub-system. Have a clear specification on which tests the boat must have passed and how these tests should be executed.

6.4 FSA step 4 and 5: Cost benefit assessment and Recommendations for decision-making

In the FSA step 4 and 5 the risk control options benefits and life cycle costs are evaluated and recommendations for implementing the RCO or not are given. In FSA step 4, the costs and effectiveness are presented. To decide whether to use the RCO or not, the ALARP method can be used, which is a method to measure risk levels. The ALARP method(As Low As Reasonably Practicable) divides risks into three areas; unacceptable risk, ALARP/tolerable and acceptable risks, see chapter 3.1.2.

In the ALARP method all risks listed in FSA step 1 are divided, with the help of a risk matrix, into the different levels in the ALARP diagram, see figure 3.

Which risks are unacceptable? Do these risks have a Risk Control Option connected to them? Does that Risk Control Option reduce the risk to a lower area in the ALARP method? By using the ALARP method it is possible for the company designing and using the vessel to sort out which risks that are necessary to reduce and which risks that are acceptable.

As mentioned above, all the risks analysed in this report was contributing factors to actual accidents and therefore most of them are evaluated as "unacceptable risks" that are in need of mitigation actions. When all the risks have been analysed with the ALARP method, and the costs of the mitigation actions are clear, a decision on whether the reduction of the risk is cost effective can be made. Here measures like Gross Cost of Averting a Fatality (Gross CAF) or Net Cost of Averting a Fatality (Net CAF) can be used.

7. Result

The background of this study is the aim of the International Maritime Organization to at larger extent build their work in relation to and around risk management. It has therefore been investigated how IMO standards comply with industry risk management processes. By doing a risk assessment, it can be possible to foresee different deviations from how a system, for example a vessel, is thought to be operated and used, and how designed functions connected to the system can be affected by unwanted deviations. If one is able to analyse these deviations, it is possible to prevent unwanted events or at least reduce the consequences of these unwanted events. By being aware of possible deviations and having a routine of performing risk analysis, both the company designing the vessel and the company operating it are prepared if an unwanted event occurs, both predicted but also unpredicted scenarios.

The IMO risk perspective used in this report is the Formal Safety Assessment which was created as a response to the accident at the oil platform Alpha Piper. The FSA can be used to evaluate and compare new regulations in regards to cost and administrative or legislative burden and is a risk management methodology, which goal is to improve maritime safety, and being proactive and dismantle hazards before an accident occurs. FSA uses risk analysis and cost benefit assessment, and covers both technical and operational issues, in relation to maritime safety.

Risk management can be divided into three steps; analysing the risks, evaluating the risks and controlling and reducing the risks. One can say that these steps together form the most general risk management process and is found in all risk management methods. This process can be found in the FSA as well. When doing the risk analysis, it is investigated which unwanted events that can occur, and the probabilities and the consequences of the event occurring. There are two ways of reducing the risk; either by reducing the probability of the unwanted event to occur or to reduce the consequences if the event occurs. To be able to evaluate the risks, an acceptance criteria must be defined.

The structure of risk management is the same in both general methods and in the FSA. To be able to manage, control and reduce the effects of risks, it is crucial to identify all potential risk. Similar methods are used within the FSA as in general risk management methods, both analytical and creative methods. When all the risks are identified, it is important to understand which risks that can affect the project the most, so the project management team knows which risks that is the most important to control and reduce. A risk analysis is performed, and no vital difference in methods used between the FSA and risk management in general is found.
After the risk analysis is performed, risk control measures are created and evaluated. The purpose is to find ways of reducing the probability of failure and also mitigate the consequences if a failure occurs. In general risk assessment, the method called Bowtie diagram is often used for this purpose. Prevention actions are created to prevent or reduce the probability of an unwanted event to occur. If the event however happens, mitigation actions are created barriers to stop or reduce the potential outcomes. In the FSA, the causal relationship is partly analysed in the probabilistic risk assessment, but the Bowtie diagram is not mentioned. Risk control measure and the Bowtie diagram can contribute with

suggestions of the barriers that prevent or reduces the unwanted event and the consequences of it. There is however no method proposing which risk control option that can be used to prevent or mitigate an unwanted event, neither if the control option will work.

A cost benefit assessment is made where the risk control options or mitigation actions are evaluated in a cost effective perspective. The method used in the FSA is the Life Cost Analysis, LCA. In both general risk management and in the FSA the importance of sharing the results of a risk analysis to their shareholders are emphasized. By using the ALARP method it is possible for the company designing and using the vessel to sort out which risks that are necessary to reduce and which risks that are acceptable.

In general, risk analysis can cover the whole project and product development , from the concept to the design phase and the operational phase. One could say that the FSA is a part of a whole risk analysis and for doing risk analysis for shipping project, one must add all other risk analysis parts, besides the operational perspective of the design phase and the operational phase.

In chapter 5 and 6, the practical use of the FSA was analysed by investigating three maritime accidents. The question was whether the accidents would have been able to prevent if the designers of the boat would have used the FSA. The accidents investigated was the capsizing of the fishing boat Viking 7 in northern Norway, the accident with a RIB boat in Stockholm archipelago and the capsizing of a rescue vessel outside Denmark.

The fishing boat, Viking 7, was taking in water through drain openings and flush hatches. The boat itself did not meet stability requirements and had production deviations that resulted in that spaces which was supposed to be filled up with foam was open. The systems that should detect and remove water did not work and the boat capsized, with the loss of one man. The RIB boat outside Djurö collided with a buoy when the driver showed the passengers the navigator plot. It was concluded that the accident was due to the fact that the driver was under the influence and that the passengers did not use designated passenger seats. Unfortunately, one man died. The rescue vessel outside Denmark suffered from insufficient stability, but one important factor of the accident was that the windows imploded when the vessel capsized, with the tragic loss of 6 men.

From the analysis of the accidents in chapter 6, it is concluded that performing a risk analysis is an important procedure to prevent accidents, and to make the design and operation of a vessel as good as possible. Further, it is also concluded from the analysis that many of the risks leading to the accidents could have been possible to detect if the companies designing and operating the vessels would have done a risk analysis.

The majority of the risks analysed in chapter 6 belonged to the personnel and organizational system, seen in figure 8. One example of such a risk is the deviation from safety routines, classified as one of the root causes leading to the RIB accident, and one reason for this was assumed to be small deviations from the routines over a long time, but without consequences. One way of avoiding this could be to increase the understanding of the routines and increasing the involvement of employees when creating the routines.

Many of the risks also belonged to the technical system. One example of this was in the accident with Viking 7, where the system detecting and removing water failed. Technical faults could be avoided by having a good company process when developing the technical system, in this case evaluating the consequences of these systems failing and as a result install two independent systems.

One risk belonged to the environmental context, the risk "lack of supervision from the supervision authority" which was one of the root causes in the fishing boat accident in Norway. This was classified as an environmental risks since it was concluded in the accident report that this was dependent on the decisions of the state of Norway.

Figure 8, Risks leading to the accidents analysed

One of the primary requirements for any risk analysis to be effective and capable of identifying and managing unforeseen events is the existence of a good corporate culture, including an open communication environment where the employees of the company are allowed and encouraged to freely share their concerns and thoughts regarding the design and use of the vessel. That the management group within the company is striving to ensure a good working environment and a good organizational culture is vital to reduce human errors, and also to reinforce and maintain the safety culture of a company. The responsibility to maintain the routines, rules and goals of the company is also shared between all employees in a company with a good corporate culture. This shared responsibility should lead to that more people recognize deviations from routines when such are made. To ensure that risks can be reduced and not replicated, it is crucial for the companies to develop safety management.

It is not given that a company by themselves have knowledge of what safety management is, and the importance of having it. It is therefore important that it is clearly stated in a risk management methodology the significance of such safety management. The largest deficiency of the FSA is hence the non-existing demands on safety management. It is mentioned in the FSA that risks in different areas shall be analysed and controlled, from the technical system, to working environment to passengers and crew and management culture, infrastructure and organizational regulations, but there are no demands on safety management. To ensure that the FSA can be used by a wide range of engineers and companies with variating knowledge in risk management and safety management, it is important that the FSA is clear on what safety management is and how it can be developed within a company. Without it, it is difficult for a company doing a risk assessment based on the FSA to comprehend all possible risk and control options necessary to reduce those risks.

8. Discussion

It lies in human nature to think that an accident will not occur, and especially not to oneself. It is hard to imagine the possible outcomes if standard routines are not followed, or if life suits are not used, and since accidents often are not due to just one reason, but rather as a result of a combination of many it makes it even harder. This makes people unprepared. The mindset that an accident will not happen to oneself, in combination with demands on profit, many and fast deliveries(number of boats rented out to tourists, number of charter trips etc.) can lead to an underestimation of risks of accidents even more. However, every company wants to reduce the risks of accidents, no company wants an accident to occur. But there could possibly be a conflict of what the company wants and aim for and what the company does and communicates to their employees through their leadership and company processes, standards and policies. If the company does not have routines where risk analysis are included, or if the workplace is not open or reward but instead put reprimands or silent personnel when raising concerns about detected risks, the possibility of having a proactive approach to risks decreases.

The attitudes of the companies and its employees will affect the outcome heavily, as well as the routines of the companies. A humble and careful attitude to one's own capability and the risks of unexpected events could reduce the risk of accidents. Another aspect that might make engineers designing the vessel distanced from the design choices is that a design of a vessel in the maritime industry are heavily controlled by either international, national or classification society standards. This could lead to a to a too high confidence in these standards, making the engineers not evaluating the risks of each design choice enough. The same risks lies in the use of available technique helping the crew use and convey the vessel in a safe manner, which definitely can be an asset, but it could also lead to excessively high reliance on the technique. Relying on available technique too much can make the crew not questioning the results generated by the technology or getting to reliant on it, leading to possible accidents.

Since it lies in our nature to think that accidents will not happen to you, and it is hard to connect one deviation from routines or design rules to an accident it is important that the companies designing and operating the vessel helps the engineers and crew with this. Ofcourse, these companies are also governed by humans. Strong management groups who works to ensure good working environment and a good organizational culture is vital to reduce human errors, and also to reinforce and maintain a safety culture within the organization. The main pillars in a safety culture is safety thinking, human behaviour and attitudes. To develop a safety culture, the employees must feel trust towards the company. An employee must for example feel safe to confess mistakes he or she has made in a design. If this is not the case, it is unlikely that an employee will voice his or her concern, and it is possible that the error or mistake is recognized too late. To help the companies with creating routines and make successful risk management assessments, standards like the FSA can be a good tool. But if the FSA is not clear on the importance of having safety management within the company, the risk of the companies not implementing it successfully or at all, and therefore not discovering and reducing potential risks exist.

9. Conclusions

The IMO risk perspective, here represented as the Formal Safety Assessment, does overall comply with industry risk management processes. Industry risk management processes focuses on all phases of a project, from the concept phase to operation phase but the FSA focuses mainly on the design phase and the operation phase.

It is seen when analysing three accidents that many of the risks leading to the accident was risks belonging to the personnel and management system, and that could have been discovered and maybe prevented by having and following good corporate processes.

A prerequisite for a risk management assessment to be effective is a good corporate culture, including safety management and this is found to be the largest deficiency of the FSA since there are no demands on safety management. Without a good corporate culture, the risk of both deviating from design requirements and standard routines increases, which increases the risk of accidents. If IMO is considering the FSA as their risk management method to be used, and to help design safe vessels and safe operation, it is important that requirements on safety management is added, to be the best support possible.

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