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A resilience assessment framework for shipping companies which learns from past accidents by using a Fuzzy Cognitive Maps-based approach

by

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Signed: *Beatriz Navas de Maya*

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This thesis is dedicated to the memory of my grandmother, Maria Dolores Santos Andres, who always believed I could achieve everything I wanted, and to Santi, Sensi, and Raquel, for their constant support and dedication.

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GLOSSARY

ADREP	Accident/Incident Data Reporting
AEB	Accident Evolution and Barrier Function
AHP	Analytic Hierarchy Process
ALARP	As Low As Reasonably Practicable
AmI	Ambient Intelligence
ATHEANA	Technique for Human Event Analysis
BN	Bayesian Network
CASMET	Casualty Analysis Methodology for Maritime Operations
CFA	Common Factor Analysis
CM	Cognitive Maps
CPC	Common Performance Condition
CREAM	Cognitive Reliability and Error Analysis Method
DCCS	Dimensional Change Card Sort
DEA	Data Envelopment Analysis
EMCIP	European Marine Casualty Information Platform
FCM	Fuzzy Cognitive Map
FLC	Fuzzy Logic Controller
FRAM	Functional Resonance Analysis Method
FSA	Formal Safety Assessment
GECNFCM	Genetically Evolved Certainty Neuron Fuzzy Cognitive Map
HEART	Human Error Assessment and Reduction Technique
HF	Human Factor
HFACS	Human Factors Analysis and Classification System

HRA	Human Reliability Analysis
HSQE	Health, Safety, Quality, and Environment
ICAO	International Civil Aviation Organization
IEA	International Ergonomics Association
IMO	International Maritime Organization
IRE	Integrated Resilience Engineering
ISM	International Safety Management
IT	Information Technology
JHEDI	Justification of Human Error Data Information
MAIB	Maritime Accident Investigation Branch
MALFCMs	Marine Accident Learning with Fuzzy Cognitive Maps
MORT	Management and Oversight Risk Tree
MTO	Man, Technology and Organisation
PACS	Pediatric Activity Card Sort
PSF	Performance Shaping Factors
RAQ	Resilience Assessment Questionnaire
SA	Situational Awareness
SCAT	Systematic Cause Analysis Technique
SMS	Safety Management Systems
SOAM	Systemic Occurrence Analysis Methodology
STAMP	Systems-Theoretic Accident Model and Processes
STCW	Standards of Training, Certification, and Watchkeeping
STEP	Sequential Timed Events Plotting
THERP	Technique for Human Error Rate Prediction

ABSTRACT

The maritime sector has strived to reduce accidents and their consequences since its beginning, by addressing safety as the priority from the design stage to decommissioning of any vessel. Previous accident studies are focused on identifying Human Factors (HFs) in past maritime accidents. However, these studies have failed to identify deeper relations amongst the aforementioned HFs. Then, there has been a lack of detailed technique, which is capable of modelling the complex interrelations between these factors. In addition, the maritime sector has traditionally presented a reactive approach to accidents, as regulations are generally developed to prevent reoccurrence rather than to avoid accident scenarios. However, a higher percentage of the time the system is safe, so it is possible to obtain additional useful information when focusing on the positive events and by learning from them.

The aim of this research study is to develop a theoretical understanding and a practical framework to describe how HFs in maritime accidents can more cleverly be identified and linked to the resilience engineering abilities, which will allow assessing the resilience level within a shipping company. Thus, by achieving the aforementioned aim, it is expected to improve overall safety within the maritime domain.

Therefore, in this research study, a new technique for Marine Accident Learning with Fuzzy Cognitive Maps (MALFCMs) is introduced and explained. The novelty of MALFCMs is the application of fuzzy cognitive maps (FCMs) to model the relationships of accident contributors by utilizing information directly from an accident database with the ability to combine expert opinion. Therefore, a key aspect to consider in this approach is the data selection, as a qualitative database will increase the success of the aforementioned MALFCMs technique. In addition, as each fuzzy cognitive map will be derived from real occurrences, the results can be considered more objective, and MALFCMs may overcome the main disadvantage of fuzzy cognitive maps by eliminating or controlling the subjectivity in results.

Moreover, in this research study, the resilience assessment framework that was developed in EU funded FP7 SEAHORSE project is modified to incorporate additional resilience abilities, and applied to a shipping company. The modified resilience assessment framework, which consists of six phases, is proposed with the aim to assess the resilience level in a shipping company, based on how the company performs on certain resilience abilities, which are linked to common human causes of accidents. Thus, the resilience assessment framework allows first

to measure the resilience level in a shipping company by providing a resilience score, which can be benchmarked with other shipping companies. Second, it allows identifying areas for improvement to increase the company resilience level. Finally, it provides a set of recommendations for resilience improvement that may serve the company for future research.

CONTENTS

1 INTRODUCTION

1.1 Overview

This chapter briefly introduces the background reasoning for the initiation and fulfilment of this research work.

1.2 General Perspectives

Traditionally, the maritime industry has been characterized by ship accidents, which result in significant consequences. For example, economic losses or social impact (Eliopoulou, Papanikolaou, & Voulgarellis, 2016). An accepted definition of the term “accident” was proposed by Kristiansen (2013), who defined accidents as “undesirable events that result in damage to humans, assets and/or the environment”. Hence, the aforementioned definition can be further extended and applied to the maritime and offshore domains, in which accidents are usually associated with injuries or fatalities, loss of goods, and loss of cargo, and defined as a source of damage for the environment (Luo & Shin, 2016; Wang, 2002). In addition, it is highly important to distinguish between the concepts of accident and incident within the maritime context. Henceforth, incidents are defined as “undesirable events that are detected, brought under control or neutralized before they result in accidental outcomes”. Thus, there is an average of three hundred incidents for every major accident (Kristiansen, 2013).

Figure 1.1 displays the trend in the evolution of total ship losses by year, where the accident data pertains to the years between 2007 and 2016 (inclusive). It is observed that shipping losses declined by 16% between 2015 and 2016. Moreover, the total amount of losses has declined by 50% over the past decade (Allianz Global Corporate & Specialty, 2017).

Although Figure 1.1 does not provide additional information (e.g. operational fleet per year, accident outcome, number of fatalities, etc.), its main purpose is to demonstrate that there is still an excessive amount of maritime accidents and ship losses per year (85 vessels were lost in 2016). Hence, maritime safety measures must be applied to reduce the rate of maritime accidents.

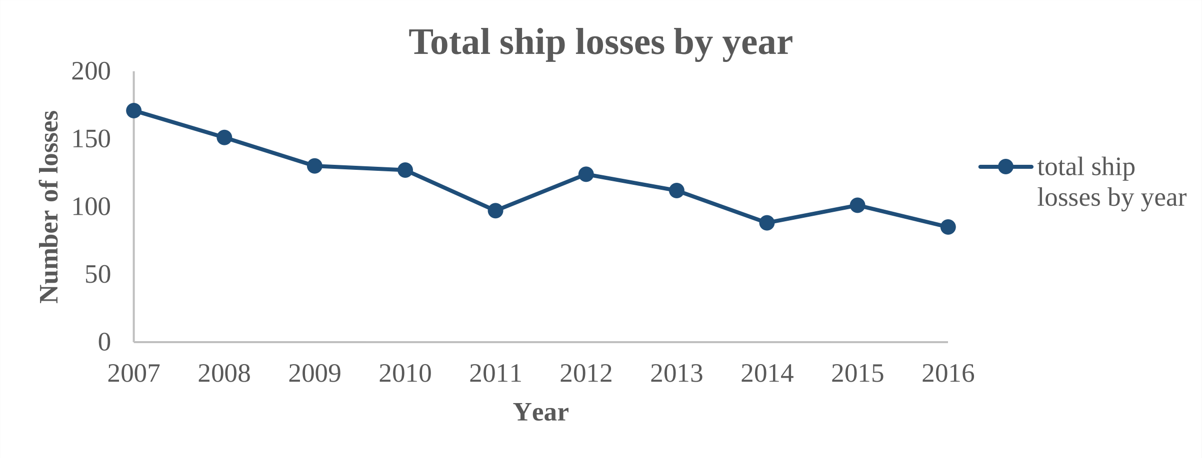


Figure 1.1. Evolution of total ship losses from 2007 to 2016. Adapted from Allianz Global Corporate & Specialty (2017)

In addition, when classifying the total number of shipping losses by vessel categories, five vessel types are identified as the major contributors to maritime losses, as shown in Figure 1.2. Thus, it is observed that cargo vessels have the highest losses for all the period being analysed.

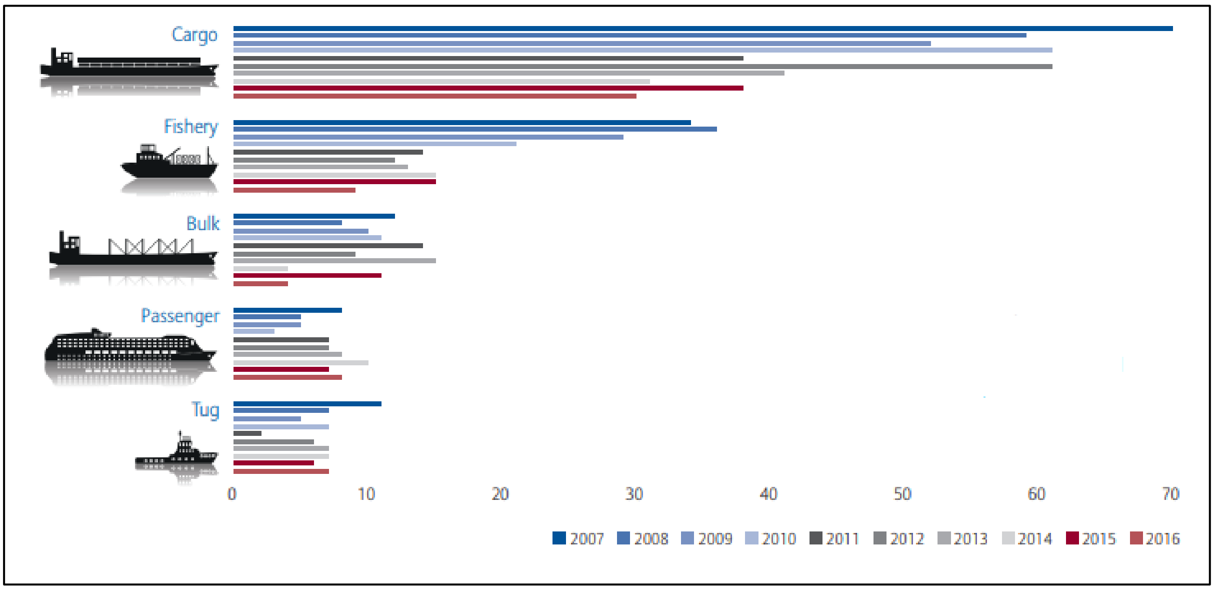


Figure 1.2. Total losses by type of vessel from 2007 to 2016 (Allianz Global Corporate & Specialty, 2017)

After illustrating that maritime accidents remain a major concern in our society, it is necessary to understand the nature and the reasons that contribute to maritime accidents, as a first attempt to reduce their rate. Hence, the following question arises:

Despite all the safety implementations that were introduced in the past decades, why maritime accidents are still happening?

There is no clear answer to the previous question, as accidents are complex processes, in which numerous factors, both human and technical, are involved. Therefore, commonly there is no simple solution for preventing maritime accidents from taking place. Hence, a new question arises that might be easier to understand and tackle:

Which are the main factors contributing to maritime accidents?

If accident contributors are identified and cleverly quantified, safety measures can be focused on addressing the aforementioned accident contributors, aiming to reduce the number of accidents and therefore, improve overall maritime safety.

1.3 Specific Issue of Human-Factors' Contribution to Accidents

Analysing the literature that is available, it becomes evident that humans have played a major role in past maritime accidents (Smith, Veitch, Khan, & Taylor, 2017). Statistical analyses on industrial causalities indicate that Human Factors (HFs) are the major causes of at least 66% of the accidents, and more than 90% of the incidents in various strategic industries such as aerospace (e.g. space shuttle challenger explosion) or nuclear (e.g. Three Mile Island, Chernobyl, etc.) (Ali Azadeh & Zarrin, 2016). For instance, between 70% and 80% of the accidents in both civil and military aviation are attributed to human errors (O'Hare, Wiggins, Batt, & Morrison, 1994). However, aviation is not an isolated sector. Within the scope of the maritime industry, different authors have researched extensively, to quantify the HF contribution to maritime accidents. For example, according to Rothblum (2000), between 75% and 96% of marine casualties are caused, at least partially, by some form of human error. In addition, Graziano, Teixeira, and Guedes Soares (2016) assert that HFs are implicated in around 80% of marine casualties. Furthermore, Turan et al. (2016) also suggest that human and/or organizational errors contribute to more than 80% of shipping accidents. Therefore, from the above-cited studies, it is plausible to assert that an average of 80% of the accidents in the shipping sector is attributed to HFs.

Nevertheless, despite the aforementioned extensive contribution of HFs into past accidents, the study of their contribution is relatively new, as HFs just became a widely recognized topic within the last decades. Historically, it was not until two main industrial accidents caused by human error took place (i.e. the ground collision between two air-crafts in Tenerife (1977) with 587 fatalities, and the nuclear accident at Three Miles Island (1979)), that the study of HFs contribution into accidents achieved a high priority in the psychological aspect (Chen et al., 2013). Within the scope of the shipping sector, it was only after the sink of the vessel Herald of Free Enterprise in 1987 that the International Maritime Organization (IMO) started considering HFs from a different perspective (J.U. Schröder-Hinrichs, Hollnagel, Baldauf, Hofmann, & Kataria, 2013). However, despite all the research that has been carried out in the past decades, there are still some difficulties when addressing the contribution of HFs into maritime accidents. First, there is a lack of a suitable technique to measure the contribution of each individual HF into maritime accidents. Second, the incorporation of HFs into safety analysis results in a complex task (Jeong et al., 2016). Thus, there is a gap in the literature regarding how to approach the human element in a systemic way when an accident occurs (J.U Schröder-Hinrichs, Praetorius, Graziano, Kataria, & Baldauf, 2015).

The maritime sector has been traditionally characterised by presenting a reactive approach to safety by mainly developing safety measures after catastrophic occurrences (e.g. Titanic, the Herald of Free Enterprise and Estonia). Therefore, this study will help towards changing the aforementioned traditional maritime approach by proactively measuring shipping companies' performance against common causes of accidents. By following such an approach, it will be possible to identify potential causes of failures that could develop an accident if additional safety measures in place fail. Hence, in this research study, it is considered vital to investigate HFs contribution to past maritime accidents in order to develop a resilience engineering approach to safety management. Thus, the aforementioned resilience approach will allow assessing the resilience level in a shipping company, based on how the company performs on certain resilience abilities, which are linked to common human causes of accidents.

1.4 The layout of the Research Study

This chapter has presented some background to the issue addressed in this thesis. Therefore, this research study will investigate the contribution of HFs into past maritime accidents, aiming to develop a resilience engineering approach to improve maritime safety. Figure 1.3 provides the overall layout of this research study. Thus, the structure of this thesis can be summarized as follows:

- **Chapter 1** outlines the background information and needs for conducting this research study. In addition, this chapter includes the main contributions and the novelties that this research has achieved, and the research outputs.
- **Chapter 2** conducts a critical review of available literature. Which is oriented to cover various areas of interest for the completion of this thesis. In addition, this chapter concludes by explaining the limitation of the traditional safety management approaches

and emphasizing the need for an approach to safety based on resilience engineering concepts and precepts, along with the identification of the research gaps.

- **Chapter 3** provides the motivations behind this research. It also defines the research questions that will be addressed, together with the aim and objectives that will be faced in this research.
- **Chapter 4** provides the approach and methodology proposed for this research study.
- **Chapter 5** examines various accident data sets, aiming to identify the most suitable historical accident database for this research study. Thus, it performs a set of descriptive statistical analyses to describe and analyse the content of the accident database that is selected. In addition, it includes a second set of statistical analyses, which aim to investigate the relationship between various variables from the database (e.g. the ship type and the accident outcome). Besides, it discusses the results of the statistical analyses. Finally, a data-driving approach is adopted to determine the most influential HFs from past maritime accidents.
- **Chapter 6** provides the current HF classification that is available within the Maritime Accident Investigation Branch (MAIB) accident database, highlighting the needs for a reduction and redefinition of the HFs contained in the MAIB database. In addition, the technique that is finally applied for the proposed HF reduction, the so-called card-sorting method, is introduced. Second, this chapter includes the results of an open card-sorting case study, and a hybrid card-sorting case study, which was launched to complete the results obtained from the open card-sorting session. Then, an initial proposal for an HF classification is included. Furthermore, experts in the area of HFs are asked to provide their insight into the initial classification proposed and the last amendments are made by incorporating their feedback. Lastly, this chapter concludes proposing a final HF classification, which will be applied through this research study.
- **Chapter 7** describes the overall framework of the Marine Accident Learning with Fuzzy Cognitive Maps (MALFCMs) method, which is proposed with the aim to establish weightings for accident contributors involved in past maritime accidents. Thus, the MALFCMs method is described in four major stages. The first stage of the MALFCMs method involves the construction of an individual interaction matrix and a state vector. The second stage of the MALFCMs approach is concerned with the construction of an individual interaction matrix and a state vector for each expert that agreed to participate in this research study. The third stage of the MALFCMs method

involves the construction of two dynamic FCMs. The first dynamic FCM is created from the interaction matrix and state vector, which were obtained from the historical accident database. Thus, the second dynamic FCM is obtained from the interaction matrix and state vector that resulted from the aggregation of experts' answers to the aforementioned questionnaire. Finally, the fourth stage includes the consolidation of the results by combining the findings from both FCMs.

- **Chapter 8** applies partially the MALFCMs method to a real case study to demonstrate that the MALFCMs method can be applied by only relying on historical accident data, without requiring additional expert participation. First, the case study specifications are highlighted. Second, the contributing factors from accidents in bulk carriers are calculated and ranked for each navigational accident (i.e. 1) Collision, 2) Grounding, 3) Contact) and 4) Fire and explosion). Finally, a discussion is provided to examine if the findings that are obtained are in line with previous studies in the literature, aiming to demonstrate that the MALFCMs method can produce reliable results.
- **Chapter 9** applies the overall framework of the MALFCMs method to a real case study. First, the four major stages of the MALFCMs approach are applied to the selected case study. Second, a discussion on the findings from this study is provided, aiming to explain the consistency of the results.
- **Chapter 10** describes the overall resilience assessment framework, which is proposed with the aim to assess the resilience level in a shipping company, based on how the company performs on certain resilience abilities, which are linked to common human causes of accidents.
- **Chapter 11** applies the overall resilience assessment framework to a real case study by assessing the resilience level in a shipping company. By comparing the resilience perspectives from crew members and shore personnel from a shipping company, it is possible to benchmark the results, identifying potential areas of resilience improvement for the shipping company under study.
- **Chapter 12** includes a summary of the main finding of this research study, a discussion of the limitations and recommendations for future research.
- **Chapter 13** comprises the conclusions extracted from this research study.

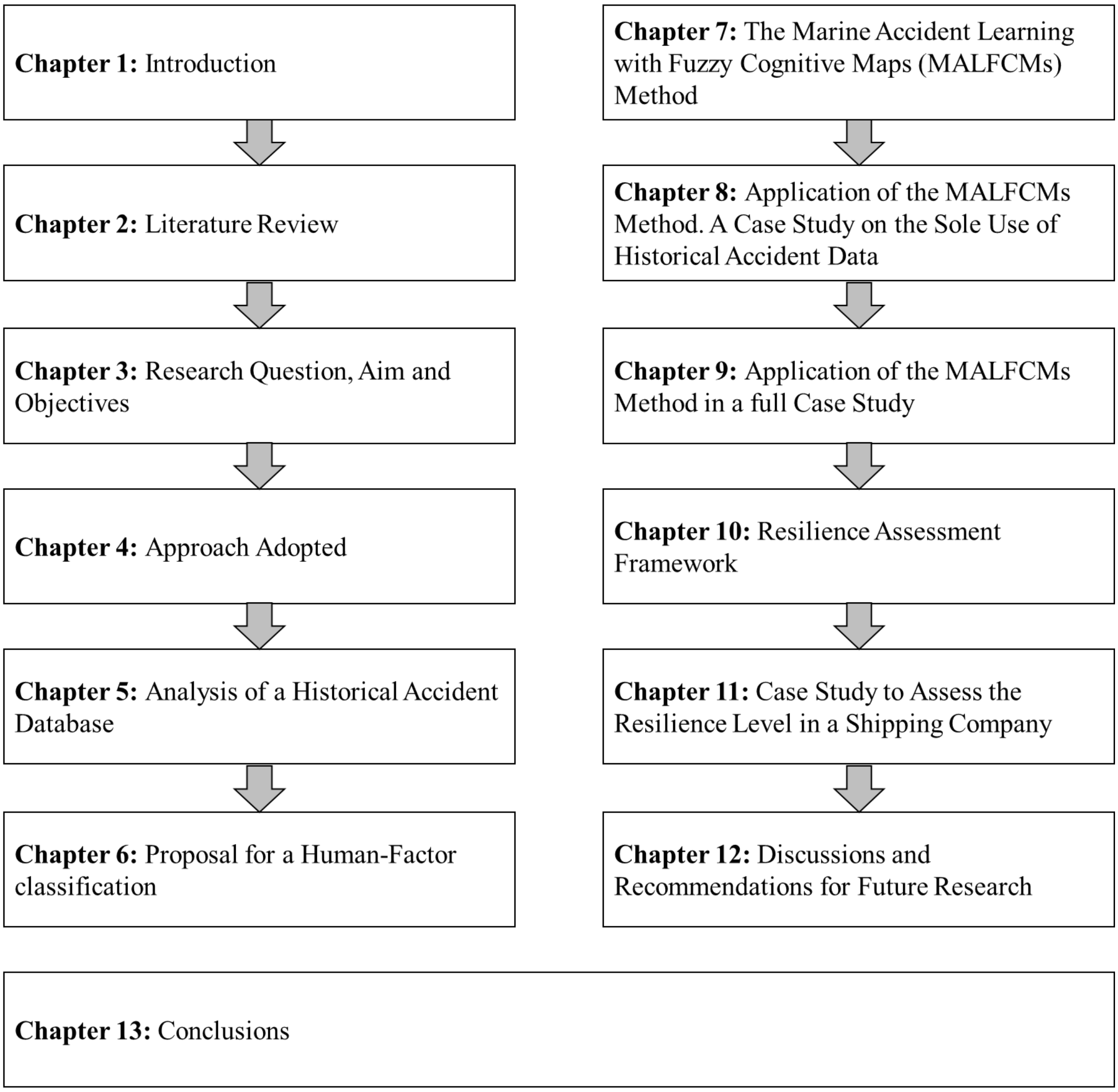


Figure 1.3. The layout of this research study

1.5 Main Contributions and Novelties of the Research Study

The contribution of HFs into accidents is difficult to quantify as there is a lack of an adequate technique that allows a systematic quantification of the importance of each contributing factor when accidents occur. This situation prevents researchers from integrating these factors into risk assessments design efficiently. Therefore, a new Fuzzy Cognitive Map (FCM)-based technique known as Marine Accident Learning with Fuzzy Cognitive Maps (MALFCMs) was developed and applied to various case studies to obtain the weighting of each contributing factor. To the best of the author's knowledge, such a comprehensive methodology has not been developed in the maritime sector yet. The novelty of the developed MALFCMs framework is the application of FCM concepts to model the relationships of accident contributors by combining information directly from historic accident data with expert opinion. The MALFCMs approach is capable of integrating information obtained from real occurrences, therefore, the results can be considered more objective, overcoming the main disadvantage of traditional FCMs by eliminating or controlling the subjectivity in results.

In addition, the maritime sector has always presented a reactive approach to accidents, as traditionally it has been characterized by developing reactive regulations to prevent accidents reoccurrence. Thus, the maritime sector lacks a proper resilience engineering strategy since the principles of safety are not well addressed within the industry, as lessons from past events are not integrated in a proactive way to avoid future accidents. Therefore, the resilience framework that was created through the EU funded FP7 SEAHORSE project has been modified to incorporate additional resilience abilities, and implemented in a shipping company for the first time. The aforementioned resilience assessment framework, which consists of six phases, is proposed with the aim to assess the resilience level in a shipping company, based on how the company performs on certain resilience abilities, which are linked to common human causes of accidents. Thus, the resilience assessment framework allows first to measure the resilience level in a shipping company by providing a resilience score, which can be benchmarked with other shipping companies. Second, it allows identifying areas for improvement to increase the company resilience level. Finally, it provides a set of recommendations for resilience improvement that may serve the company for future research.

1.6 Research Outputs

The following publications were generated throughout this research study.

1.6.1 Conference papers

- **Navas de Maya, B.**, Kurt, R. E., & Turan, O. (2018). Application of fuzzy cognitive maps to investigate the contributors of maritime collision accidents. Transport Research Arena (TRA), 2018, Vienna, 10 p.
- **Navas de Maya, B.**, & Kurt, R. E. (2018). Application of fuzzy cognitive maps to investigate the contributors of maritime grounding accidents. Human Factors: Royal Institution of Naval Architects, 2018, London, 8 p.
- **Navas de Maya, B.**, Babaleye, A. & Kurt, R. E. (2019). Marine accident learning with fuzzy cognitive maps (MALFCMs) and Bayesian networks: a case study on maritime accidents. 4th Workshop and Symposium on Safety and Integrity Management of Operations in Harsh Environments, 2019, St John’s, Canada, 9 p.

- **Navas de Maya, B.**, Ahn, S.I. & Kurt, R. E. (2019). Statistical analysis of MAIB database for the period 1990-2016. International Maritime Association of the Mediterranean (IMAM), Annual Congress, 2019, Varna.
- **Navas de Maya, B.**, Kurt, R. E. & Turan, O. (2019). Marine Accident Learning with Fuzzy Cognitive Maps (MALFCMs): A Case Study on Fishing Vessels. 29th European Safety and Reliability Conference (ESREL) 2019, Hannover.

1.6.2 Journal papers

- **de Maya, B. N.**, Babaleye, A. O. & Kurt, R. E. (2019). Marine accident learning with fuzzy cognitive maps (MALFCMs) and Bayesian networks. Safety in Extreme Environments, pp 1-10. https://doi.org/10.1007/s42797-019-00003-8.
- **Navas de Maya, B.,** Khalid, H. & Kurt, R. E. (2020). Application of card sorting approach to classify human factors of past maritime accidents. Maritime Policy & Management, 1-16. https://doi.org/10.1080/03088839.2020.1754481.
- **Navas de Maya, B.** & Kurt, R. E. (2020). Marine Accident Learning with Fuzzy Cognitive Maps (MALFCMs): A case study on bulk carrier's accident contributors. Ocean Engineering, 208, 107197. https://doi.org/10.1016/j.oceaneng.2020.107197.
- **Navas de Maya, B.** & Kurt, R. E. (2020). Marine Accident Learning with Fuzzy Cognitive Maps (MALFCMs). MethodsX. https://doi.org/10.1016/j.mex.2020.100940.
- Coraddu, A., Oneto, L., **Navas de Maya, B.** & Kurt, R. E. (2020). Determining the Most Influential Human Factors in Maritime Accidents: a Data-Driven Approach. Ocean Engineering. https://doi.org/10.1016/j.oceaneng.2020.107588.
- **Navas de Maya, B.** & Kurt, R. E. (2020). Marine Accident Learning with Fuzzy Cognitive Maps (MALFCMs): A method to model and weight human-related contributing factors into maritime accidents. Ships and Offshore Structures. (Revision submitted).
- **Navas de Maya, B.,** Arslan, O., Akyuz, E., Kurt, R. E. & Turan, O. (2020). Application of data-mining techniques to predict and rank maritime non-conformities in tanker shipping companies using accident inspection reports. Quality and Reliability Engineering International (Under Review).
- **Navas de Maya, B.** & Kurt, R. E. (2020). Statistical analysis and critical review of MAIB accidents for the period 1992-2016. (Under Internal Review).
- **Navas de Maya, B.** & Kurt, R. E. (2020). Resilience Assessment Framework. (Under Internal Review).

1.7 Chapter Summary

This chapter summarized the general reasons for pursuing this research study, including the identification of a gap regarding how to approach the human element in a systemic way into maritime accidents. It also summarised the layout of this thesis and provided a diagram in Figure 1.3, which allows a smoothly reading flow.

Chapter 2 is providing a critical literature review. Moreover, Chapter 2 also identifies the research gaps that will be addressed within this research study.

2 LITERATURE REVIEW

2.1 Overview

This chapter conducts a critical review of available literature, which is oriented to cover various areas of interest that were identified by the researcher for the completion of this thesis.

First, Section 2.2 provides an overview of the status of safety in the maritime sector. Second, Section 2.3 identifies different paths to analyse safety. In addition, Section 2.4 provides a more specific safety review, which is focused on how the maritime sector applies an adequate safety management, with special mention to the Formal Safety Assessment (FSA). Third, Section 2.5 provides a basic understanding of the resilience and resilience engineering concepts. Moreover, the characteristics and cornerstones of resilience are highlighted and explained, and the major resilience factors are identified and defined. Furthermore, this section also includes a description of how resilience is assessed in various strategic sectors. Fourth, Section 2.6 includes an overview of the accident phenomenon in the maritime sector together with a review of the major accident causation models. In addition, Section 2.7 review current methods to evaluate the contribution of HFs into past occurrences. Finally, in order to provide a basic understanding of the FCM method, Section 2.8 describes the historical evolution of FCMs from traditional Cognitive Map (CM). Moreover, it explains the mathematical representation of an FCM model. Thus, this section provides additional information regarding the processes that enable an FCM to be used as a dynamic model. Furthermore, an overview of numerous studies, which apply the FCM method in other fields, is provided, together with the main reasons for applying an FCM approach to the aforementioned previous studies.

Finally, this chapter concludes by explaining on Section 2.9 the key findings from the critical literature review, along with the identification of the research gaps on Section 2.10.

2.2 The Status of Safety in the Maritime Sector

When analysing the available literature, it is possible to find numerous definitions regarding the concept of safety. For instance, ICAO (2013) defines safety for the aviation domain as “the state in which the possibility of harm to persons or of property damage is reduced to, and maintained at or below, an acceptable level through a continuing process of hazard identification and safety risk management”. Therefore, this definition complies with the traditional idea of safety as “a condition where nothing goes wrong or where the number of things that go wrong is acceptably small” (Patriarca, Di Gravio, & Costantino, 2017). Within the maritime domain, it is possible to define safety as the tolerable risk level that is established and accepted by society.

Traditional safety management regime in the maritime sector had focused on accidents, developing reactive regulations to prevent reoccurrence, which resulted in more training, and increased automation since humans were considered as the cause of many accidents. The aforementioned approach is the so-called Safety I, in which the level of safety is measured by the absence of accidents and incidents. The safety-I approach considers that causalities happen because something goes wrong and ensures that the causes can be found and treated (Patriarca et al., 2017). Therefore, the focus on safety research has always been on unsafe behaviour rather than the safe operation. However, a higher percentage of the time the system is safe, so the additional useful information could be obtained by focusing on the positive events and by learning from them. Hence, within this new safety approach, the so-called Safety-II, the definition of safety shifts towards considering not only the adverse consequences but also the positive events, in order to succeed under varying conditions.

Table 2.1 shows the main differences between the above-mentioned safety approaches regarding how they approach safety management, which accident models they applied, how they address the human element, and how they assess systems' performance.

Table 2.1. Safety I versus Safety II approach, adapted from J.U Schröder-Hinrichs et al. (2015)

	Safety-I approach	**Safety-II approach**
Concept	Safety is achieved when the risk of accidents is as low as possible	Safety is achieved when as many things as possible go right
Safety management approach	Safety arises by eliminating the causes of failures. It is a reactive response	Safety arises by trying to anticipate future events focusing on what goes right. It is a proactive response
Accident models	Simple and complex linear accident models	Systemic accident models
Human operators view	Humans are sources of error	Humans provide flexibility to adapt quickly to unpredictable events
Performance variability	It should be eliminated or decreased	It should be monitored and managed as it is considered a source of flexibility

Additionally, Safety-I is often related to a traditional approach to safety based on a quantitative risk assessment, while Safety-II is associated with the theoretical concept of resilience and a qualitative assessment (Patriarca et al., 2017). Moreover, an important limitation of the Safety-I perspective seems to be that it focuses on one specific error that occurs under very specific conditions in a system. If things are mostly going right, then the Safety-I approach ignores the ability of the systems to compensate gaps and shortcomings during most of the cases. However, most of the times the system is safe and operations are completed successfully. So it is clear that additional useful information could be obtained by focusing on the positive events rather than only analysing the negative outcomes. Hence, this research will aim to develop an approach in line with the principles of the so-called Safety-II to enhance overall maritime safety.

2.3 Different paths to Analyse Safety

Safety is a concept in constant evolution, and diverse paths have been developed in the past decades to achieve the highest standards of safety. A study conducted by Harms-Ringdahl (2004) has already identified three main paths to achieve and improve safety: 1) methods for accident investigation, 2) risk analysis, and 3) Safety Management Systems (SMS).

An accident investigation can be defined as "the determination of the facts of an accident by inquiry, observation, and examination, and an analysis of these facts to establish the causes of the accident and the measures that must be adopted to prevent its recurrence" (Harms-Ringdahl, 2004). There are numerous methods for accident investigation that comply with the above definition. For example, Sklet (2004) conducted a comparison amongst various methods for accident investigation, including fault tree analysis, event tree analysis, barrier analysis, root cause analysis, events and causal factors charting and analysis, change analysis, influence diagram, Management and Oversight Risk Tree (MORT), Systematic Cause Analysis Technique (SCAT), Sequential Timed Events Plotting (STEP), Man, Technology and Organisation (MTO) analysis, the Accident Evolution and Barrier Function (AEB) method.

Nevertheless, despite the numerous methods that have been identified to perform accident investigations, the above-mentioned methods present some limitations, which can reduce their applicability to achieve safe operations. First, some of the aforementioned models require a specific level of expertise to be applied (i.e. learner, professional or expert). Hence, for those methods that require a high understanding, specific training needs to be provided to guarantee successful results. Second, to perform an accident investigation successfully, it is required to follow a different approach based on the method that is selected. For example, some of the identified methods require an inductive approach (e.g. event tree) while other methods are deductive methods (e.g. fault tree). Third, the aforementioned methods can be classified as primary or secondary. While primary methods imply a standalone technique, secondary methods might produce an input as a supplement to other methods, which could be used in a further investigation. Finally, each of the above-mentioned models is based on a different accident model. Hence, by selecting a specific accident model, the methods that can be applied are constricted. Hence, it is critical to consider all the above-mentioned factors prior to choose the most suitable method for a specific accident investigation.

In order to provide guidance for selecting the best technique based on the accident under consideration, Table 2.2 summarise the characteristics of the above-mentioned common accident investigation methods. In the expertise column, L stand for learner, P stands for professional, and E stands for expert. In addition, in the method column, P stands for primary while S stands for secondary.

Overall, the previous models are good for assessing a specific incident and the causal factors that led to the accidental outcome. However, the aforementioned methods fail to capture the most influential factors in a proactive way.

Table 2.2. Main characteristics of some traditional methods for accident investigation

AI Method	**Expertise**	**Approach**	**Method**	**Accident model**
Events and causal factors charting and analysis	P	Non-system oriented	P	Process models
Barrier analysis	L	Non-system oriented	S	Energy model
Change analysis	L	Non-system oriented	S	Process models
Root cause analysis	P	Non-system oriented	S	Causal-sequences models
Fault tree analysis	-	Deductive	P and S	Logical tree models
Influence diagram	-	Non-system oriented	S	-
Event tree analysis	P	Inductive	P and S	Logical tree models
MORT	E	Deductive	S	Logical tree models, management models
SCAT	P	Non-system oriented	S	Causal-sequences models, management models
STEP	L	Non-system oriented	P	Process models
MTO	P	Non-system oriented	P	Process models
AEB	P	Morphological	S	-

The second path that has been identified to analyse safety is to perform a risk analysis. However, within the field of risk and risk management, there is no agreed definition concerning the concept of risk (Aven, 2012). When analysing the literature, it is possible to find numerous references to this concept in terms of probability, undesirable events or uncertainties. For instance, ISO (2009) defines risk as “the effect of uncertainty on objectives”. Thus, Rosa (1998) considers risk as a “situation or event where something of human value (including humans themselves) is at stake and where the outcome is uncertain”. In addition, for Renn (2005), the concept of risk is “an uncertain consequence of an event or an activity with respect to something that humans value”. Moreover, Aven (2007) establishes that “risk is equal to the two-dimensional combination of events/consequences and associated uncertainties". On the other hand, risk analysis is defined by Harms-Ringdahl (2004) as "the systematic use of available information to identify hazards and to estimate the risk to individuals or populations, property or the environment".

Within the last decades, systematic risk methods have arisen to understand and analyse safety levels. Thus, risk methods have become a wide topic, providing decision support when addressing proactive safety policies. According to Luo and Shin (2016), some of the most important methods to conduct risk analysis are Bayesian Network (BN), Analytic Hierarchy Process (AHP), Fuzzy AHP (FAHP), and Formal Safety Assessment (FSA). Thus, as FSA has been successfully implemented within the maritime industry, it will be fully described later on in this chapter.

Finally, the last path to analyse safety is Safety Management System (SMS). A SMS comprises any set of strategies, procedures or functions related to safety. Thus, it is defined by Demichela, Piccinini, and Romano (2004) as "the adoption and implementation of procedures for systematically identifying major hazards arising from the normal and abnormal operation and the assessment of their likelihood and severity". Hence, an SMS is a complex mechanism inserted in society and organizations, which is designed with the purpose of controlling the operational hazards that could affect the health and safety of workers. Moreover, in order to be effective, the employees need to be involved in promoting a safety climate within the organization (Fernández-Muñiz, Montes-Peón, & Vázquez-Ordás, 2007). After analysing the literature, it is possible to find numerous studies regarding which requirements are needed to carry on an adequate safety management within a company, including risk assessment, accident analysis to emergency response, or near-missing reports (Basso et al., 2004; Kelly & Berger, 2006; Teo & Ling, 2006). However, the above-mentioned studies failed to achieve a consensus regarding the specific requirements needed in any SMS.

In addition, aiming to solve the above dispute, Fernández-Muñiz et al. (2007) conducted a study to identify specific requirements that any SMS should include. Thus, this study was key to identify specific aspects as incentives for employee participation, adequate training or a good communication system. These were very valuable requirements as the researcher believes that, by rewarding individuals when they are involved in the safety process, a company is promoting adequate safety. Thus, each company should also punish those individuals who do not follow safety behaviours within the workplace. In addition, an adequate training is indispensable at any organization, as it aims to provide individuals with the required skills and abilities to perform their job in a safe way. Also, by providing specific training programs in an organization, employees become more conscious about workplace safety, also accepting that safety is intrinsic related to a well-done job. Furthermore, any organization should adopt a good communication system, in which the information flows in both ways, from the company manager to the workers and vice-versa, favouring the motivation and participation of all members. From this study it was observed that companies with good safety performance demonstrate abilities to establish good practices, certain behaviours and aptitudes in the company to increase overall safety in a proactive manner.

2.4 Safety Management Systems in the Maritime Industry

When analysing maritime accidents, the focus of researchers has shifted over the last 50 years from design problems on the vessels to human error, with the ability to be expanded additionally into socio-economic factors. Hence, this may lead to multi-disciplinary research for future accidents considering not only the interaction between humans, the environment and technology but also the global conditions of the shipping market (Luo & Shin, 2016). However, when analysing an accident, two fundamental problems arise, the first problem is how to identify unsafe factors from accidents, while the second issue is how to represent relations between the unsafe factors once an accident takes place (Gong, Zhang, Tang, & Lu, 2014).

In terms of safety, the shipping sector has been traditionally defined by using reactive approaches to safety, focusing on design and equipment. Actually, maritime safety regulations have often been introduced as a response to an accident, as shown in Figure 2.1. For instance, after the loss of the Ro-Ro passenger ferry Herald of Free Enterprise, the International Maritime Organization (IMO) adopted the International Management Code for the Safe Operation of Ships and for Pollution Prevention (ISM Code) and the Stockholm Agreement (1995) was the response to the sinkage of the Ropax vessel, Estonia (Kristiansen, 2013; J.-U. Schröder-Hinrichs, Praetorius, G., Graziano, A., Kataria, A., & Baldauf, M. , 2015).

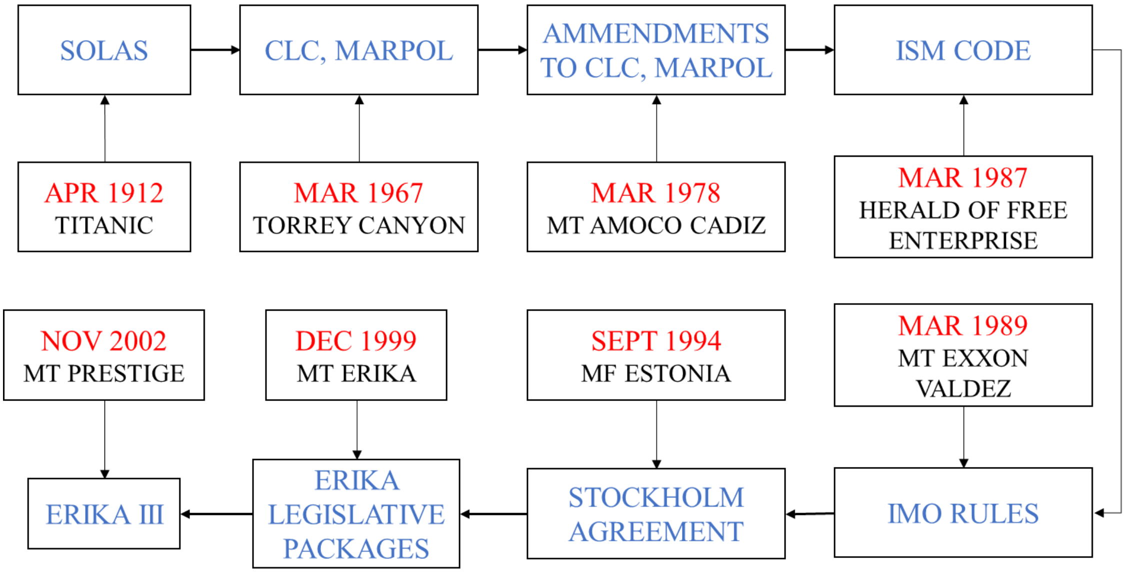


Figure 2.1. Impact of major maritime accidents in the development of safety international regulations

Furthermore, IMO has tried to address HFs by introducing the term “human element”, in order to encourage the development of a new and systemic approach to reducing human errors in the maritime sector (J.-U. Schröder-Hinrichs, Praetorius, G., Graziano, A., Kataria, A., & Baldauf, M. , 2015). Thus, IMO has introduced a risk analysis approach (i.e. FSA), which applies scientific methods reinforced by reliability techniques, probability theory and systems engineering (Kristiansen, 2013).

Kristiansen (2013) defines the FSA as “a rational and systematic process for assessing the risks associated with any sphere of activity, and for evaluating the costs and benefits of different options for reducing those risks”. FSA was originally developed as a response to the Piper Alpha accident (1988) in the North Sea, where 167 people lost their lives (Eliopoulou et al., 2016). Thus, it has been implemented and applied successfully in diverse sectors (e.g. nuclear or offshore).

After the Herald of Free Enterprise (1987) and Exxon Valdez (1989) accidents took place, a re-evaluation of the currents rules for maritime safety was necessary. While the safety regime in other industries was based on scientific methods (e.g. risk and cost-benefit analysis), the maritime sector was characterized by presenting an unfavourable regime (Kristiansen, 2013). Hence, in 1993 UK Marine Safety Agency proposed to apply the FSA to the maritime sector, aiming to provide a more proactive system for the IMO rule-making process. Therefore, FSA was defined as a five steps procedure for safety analysis, which was designed with two users in mind, IMO committees and individual maritime administrations (Kristiansen, 2013). Figure 2.2 shows the five steps required for conducting an adequate FSA.

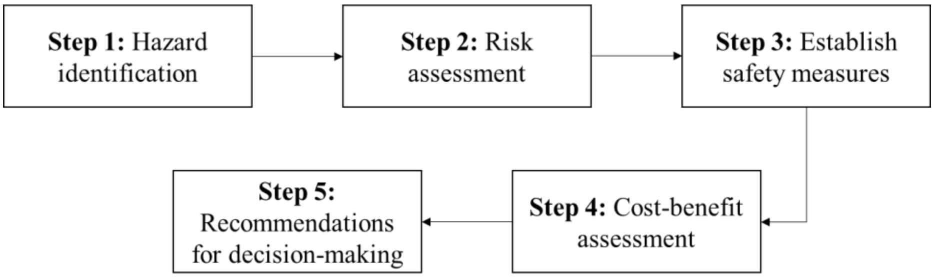


Figure 2.2. Five steps to perform a Formal Safety Assessment

The first step within the FSA process aims to identify the most relevant hazards within the system under consideration, such us undesirable accidental outcomes (e.g. injuries to personnel, damage to property or environmental impact). Thus, in order to perform a successful hazard identification, it is mandatory to define all the activities carried out within the system carefully, including boundary conditions. Within the second step of an FSA, a risk assessment is carried out to quantify the risks of undesirable outcomes, which were identified in the previous step. Thus, the aforementioned risk assessment might be qualitative, which includes a structured analysis of the defined hazards, or quantitative, aiming to establish the absolute and relative importance of the influencing causes in an accident. As a result of this step, high-risk activities are identified. The third step is focused on the above-mentioned high-risk activities. Thus, it includes considering new safety measures and assessing how risk management and regulation can reduce system hazards. Within the fourth step, a cost-benefit assessment is conducted. This is a crucial step as it decides if the suggested measures are suitable for implementation. Finally, the last step in an FSA includes proposing recommendations to the decision-makers regarding which risk control option should be adopted in order to make risks As Low As Reasonably Practicable (ALARP). Thus, the aforementioned recommendations are the final output of the FSA process.

Although FSA has been widely applied in the maritime sector, it was not designed to consider the contribution of HFs into maritime accidents. Hence, revised guidelines for FSA were published in June 2015, in which human factors were referred to as key factors to achieve and enhance operational safety. In addition, the guidelines above recognised that appropriate techniques for incorporating HFs into the risk process (i.e. step 2 of FSA) were required. Thus, revised guidelines recommended applying Human Reliability Analysis (HRA) techniques to incorporate the above-mentioned human element into risk assessments. Moreover, FSA specifically recommended applying the Technique for Human Error Rate Prediction (THERP) or the Human Error Assessment and Reduction Technique (HEART), as these methods have databases of human error probabilities. Although these probabilities were originally defined for the nuclear industry, they might be extrapolated to the maritime domain.

2.5 Resilience and Resilience Engineering

The concept “resilience” was introduced in the early 1970s, as an ecological system’s ability to achieve equilibrium over time in a dynamic and changing environment. (J.-U. Schröder-Hinrichs, Praetorius, G., Graziano, A., Kataria, A., & Baldauf, M. , 2015). Ever since that first definition, the word “resilience” has been used in many disciplines (e.g. material science, psychology or computer networks) to denote entirely different concepts (Erol, Sauser, & Mansouri, 2010; Mansouri, Mostashari, & Nilchiani, 2009). For instance, material science explains the concept of resilience as the capacity of a material for recovering its initial shape after suffering a deformation. However, in psychology, resilience is introduced as a completely different concept, as it is defined as the positive capacity of a person to deal with stressful events and their level of tolerance for future negative events (Erol et al., 2010). Thus, within the resilience engineering domain, E. Hollnagel (2006) defines resilience as the “ability of a system or an organization to react and recover from disturbances at an early stage, with minimal effects on its dynamic stability”. Hence, a system will be classified as resilient if it is able to respond and adapt to unexpected changes or disturbances (Erol et al., 2010). As the science of resilience engineering is a new discipline, which has emerged recently, there is no clear agreement regarding how to define the term “resilience”. Thus, each discipline provides its own definition. As it would not be possible to include all the available definitions for the terms “resilience” and “resilience engineering”, Table 2.3 comprises the major definitions that are available in the literature. Nevertheless, most sources agree to define resilience engineering as 1) the ability to prevent something bad from happening, 2) the ability to prevent something bad from becoming even worse, or 3) the ability to recover from something bad before it becomes even worse than before (Jackson, 2009).

A common interpretation of the aforementioned definitions is that resilience engineering can be understood as the response of a system to unforeseen or unexpected changes or disturbances, with the ability to adapt and respond while being into the above-mentioned unforeseen circumstances (Erol et al., 2010). This interpretation emphasizes two characteristics, which are common for any resilient system: First, during adverse conditions, a resilient system not only tries to react and recover but it also changes its function to achieve its final purpose. Second, a resilient system must be always prepared to deal with disturbances or diverse conditions of functioning (Erik Hollnagel & Fujita, 2013). The aim of resilience engineering is to increase robustness and flexibility (Ali Azadeh & Zarrin, 2016). Hence, since the first Symposium in 2004, resilience engineering has become widely recognized in various strategic fields (e.g. air traffic management, offshore production or health care) (Erik Hollnagel & Fujita, 2013). Therefore, resilience engineering has emerged not only to prevent accidents but also to prevent accident outcomes from evolving into more catastrophic events.

Table 2.3. Major definitions for the resilience and resilience engineering concepts

Author	**Definition**
Holling (1973)	**Resilience:** Ability of a system to absorb changes without dramatic alterations.
Grotberg (1996)	**Resilience:** Capacity that allows a person, group or community to prevent, minimize or overcome the damaging effects of adversity.
Christopher and Peck (2004)	**Resilience:** Ability of a system to return to its original state or move to a new, more desirable state after being disturbed.
Erik Hollnagel, Woods, and Leveson (2007)	**Resilience:** Ability of a system to keep (or recover quickly into) a stable state, allowing it to continue operations during and after a major mishap.
Miller and Xiao (2007), Gomes, Woods, Carvalho, Huber, and Borges (2009)	**Resilience:** Ability to keep the system within its functional limits.
Erol et al. (2010)	**Resilience:** Capacity of a material for recovering its initial shape after suffering a deformation.
Erol et al. (2010)	**Resilience:** Positive capacity of persons to deal with stressful events.
de Carvalho (2011)	**Resilience:** Ability of a system to recognize and act accordingly when variability in its performance is unanticipated.
Furniss, Back, Blandford, Hildebrandt, and Broberg (2011)	**Resilience:** Ability to recover and avoid accidents in poor circumstances.
Carmeli, Friedman, and Tishler (2013)	**Resilience:** Proactive approach to safety management that recognizes the complexity and ever-changing environment.
J.U Schröder-Hinrichs et al. (2015)	**Resilience:** Ecological system's ability to arrive at an equilibrium, or stable state, over time in a dynamic and changing environment.
A. Azadeh, Salmanzadeh-Meydani, and Motevali-Haghighi (2017)	**Resilience:** Capability of an organization to respond or "bounce back" untoward, surprising or disruptive incidents.
E. Hollnagel (2006)	**R. Engineering**: Ability of a system or an organization to react and recover from disturbances at an early stage, with minimal effects on dynamic stability.
Fairbanks, Wears, Woods, Hollnagel, and Plsek (2012)	**R. Engineering**: Deliberate design and construction of systems that have the capacity of resilience.
J. Anderson, Ross, and Jaye (2013)	**R. Engineering**: Shift in safety towards a proactive approach that addresses the need for adapting to changes in the environment.
A. Azadeh et al. (2017)	**R. Engineering**: Paradigm for safety management that concentrates on how to help people deal with complexity under stress to access success.
Smith et al. (2017)	**R. Engineering**: Study of why systems or objects work in the face of adversity, and how to achieve robust and flexible designs.

2.5.1 **Modelling Resilience & Resilience Engineering**

In order to assess the resilience level in a system, Hosseini, Barker, and Ramirez-Marquez (2016) have established two different methods. First, qualitative approaches, which tend to assess a system's resilience without numerical descriptors. Thus, the above-mentioned qualitative approaches may comprise a conceptual framework to offer best resilience practices, or they may include semi-quantitative indices that offer expert assessment of diverse qualitative aspects of resilience. Second, quantitative approaches, which aim to quantify a system's resilience. In addition, quantitative methods may include general resilience approaches, which offer measures to quantify resilience across application, or they may include structural-based modelling methods, which aim to model domain-specific representation of the components of resilience.

Within the resilience engineering domain, qualitative approaches are commonly applied to assess and improve resilience while quantitative resilience approaches are still under development (Stroeve & Everdij, 2017). A well-known qualitative method is the Functional Resonance Analysis Method (FRAM) (Erik Hollnagel, 2012b), which will be further reviewed later on in this chapter. Nevertheless, it is still challenging to apply resilience engineering principles productively for understanding everyday actions and outcomes, such as encouraged in the Safety-II perspective (Stroeve & Everdij, 2017).

2.5.2 **Review of Factors and/or Abilities to Assess Resilience**

In order to become resilient, a system must be able to perform four major actions. First, a system must be able to respond without hesitation in both expected and unexpected conditions. Thus, it must be able to sustain its response until the situation is brought under control. Second, a system must monitor every possible change or disturbance in the near term, covering what happens in both, the system and the environment. Third, a system must anticipate threats and opportunities in the future, for example, potential changes or increased demands. Finally, a system must learn the right lessons from the right experiences, including both successes and failures (Erik Hollnagel & Fujita, 2013). Aforementioned actions (i.e. responding, monitoring, anticipating and learning) represents the so-called four major abilities or cornerstones of resilience, which are used as indicators to analyse system performance in both normal operations and disturbances (J.-U. Schröder-Hinrichs, Praetorius, G., Graziano, A., Kataria, A., & Baldauf, M. , 2015).

Responding is defined as the ability to behave and respond when an unfolding event takes place (Lundberg & Johansson, 2015). There are different approaches to enhance response, e.g. by developing flexibility within an organization. Thus, flexibility can be achieved through training programs, which are designed to keep specific skills active within the organization's members (E. Lay, Branlat, & Woods, 2015). On the other hand, monitoring is based on the ability to detect unexpected events and respond in consequence (Lundberg & Johansson, 2015).

According to E. Lay et al. (2015), an enhancement on monitoring might be achieved by training members to be alert and notice when some expressions are recorded within an organization, which are indicators of potential risks For example, “I’ve never seen this before” or “This is the first time that…”. In addition, anticipating is defined as the ability to predict a future outcome, developing measures to prevent it (Lundberg & Johansson, 2015). There are numerous strategies to improve the anticipation level within an organization. For instance, E. Lay et al. (2015) propose to record stories with both unexpected problems that occurred in the past and cases which worked well. Finally, learning is a resilience ability which aims to receive knowledge from past events, particularly the right lessons from the right experiences (Erik Hollnagel & Fujita, 2013). As memory retention is lower when a non-narrative informing style is applied (Denning, 2006), storytelling is commonly used as a source of lessons and knowledge, (E. Lay et al., 2015).

The above-described abilities have been widely recognized as the major resilience abilities. Nevertheless, numerous authors have extensively applied additional indicators when addressing resilience engineering. Thus, in order to be resilient, a system must comply with a required number of resilience factors, which vary between studies. Table 2.4 includes a summary of numerous studies that apply various resilience factors to assess an organization’s resilience. In addition, a description of each resilience factor is provided below as follows:

- Factor 1 - Management commitment. It is defined as the top management’s ability to recognize and evaluate human performance concerns (A. Azadeh, Salehi, Ashjari, & Saberi, 2014; Erik Hollnagel et al., 2007). A top management commitment implies that safety is the target to achieve at all levels within an organization (Costella, Saurin, & de Macedo Guimarães, 2009).
- Factor 2 – Reporting culture: It is defined as a resilience ability that involves reporting the company issues up through the organization. Thus, establishing a reporting culture in an organization assures that both, operators and managers make an effort to find solutions for keeping the organization in a robust state. Without an appropriate reporting culture, the willingness to mention the problems inside an organization will be decreased, which will limit the ability of an organization to learn about weaknesses that could be used for preventing accidents (Erik Hollnagel et al., 2007).
- Factor 3 – Awareness: It is defined as a resilience ability that makes a company insightful about all the aspects within the organization. Thus, both staff and managers

should be aware of their current state, the current state of the defences in the company, and boundaries in systems (Erik Hollnagel et al., 2007; Saurin & Júnior, 2011).

- Factor 4 – Flexibility: It is defined as the ability of an organization to adjust when immediate changes appear in the environment. While uncertainty is a serious threat for many organizations, a high level of flexibility can change this threat into new opportunities. However, it requires that members of the organization make important decisions rapidly, without having to wait for confirmation from the managers (Erik Hollnagel et al., 2007).
- Factor 5 – Teamwork: It is defined as the ability of various members with complementary skills to complete a common target, while all the members are still responsible for completing the aforementioned target successfully. In addition, when an organization is coping with a crisis or a high workload, teamwork can reduce both personal and organizational pressure through mutual support, increasing the reliability of the organization (A. Azadeh et al., 2017). Thus, teamwork has a significant role in improving safety in high-risk industries such as aviation or nuclear (Burtscher & Manser, 2012).
- Factor 6 – Redundancy: It is defined as the ability to have an alternative route from supply to demand or an extra capacity to be used when components are not available (A. Azadeh et al., 2017). Thus, as mentioned by Clarke (2005), redundancy is "a key design characteristic of organizations or systems capable of very high standards of safety performance".
- Factor 7 – Fault-tolerance: It is defined as the ability that enables an organization to continue operating in the event of a crisis. In addition, making an organization fault-tolerant is one of the most promising ways to increase both safety and reliability (A. Azadeh et al., 2017).

Table 2.4. Summary of additional resilience factors and/or abilities

Author	F1	F2	F3	F4	F5	F6	F7
Woods (2003)	✓	✓	✓				
P. V. Carvalho, dos Santos, Gomes, and Borges (2008)	✓	✓	✓				✓
Huber, van Wijgerden, de Witt, and Dekker (2009)	✓	✓	✓	✓			
Gomes et al. (2009)		✓					
Costella et al. (2009)	✓	✓	✓	✓			
Hansson, Herrera, Kongsvik, and Solberg (2009)		✓	✓	✓			
Morel, Amalberti, and Chauvin (2009)	✓	✓	✓	✓			
Saurin and Júnior (2011)	✓	✓	✓	✓			
G. A. Shirali, Mohammadfam, and Ebrahimipour (2013)	✓	✓	✓	✓			
A Azadeh and Salehi (2014)	✓	✓	✓	✓	✓	✓	✓
A. Azadeh, Salehi, Arvan, and Dolatkhah (2014)	✓	✓	✓	✓	✓	✓	✓
Ali Azadeh and Zarrin (2016)	✓	✓	✓	✓	✓	✓	✓

2.5.3 **Resilience Engineering Studies in Various Sectors**

Numerous authors have developed models based on resilience engineering principles. For example, Komatsubara (2011) proposed a safety management model that identified those situations in which resilience is required in an organization, providing also a set of actions and recommendations at an organizational level to address the aforementioned lack of resilience. The developed safety model was also tested in various organizations in Japan. One of them was an aviation company, in which a positive attitude with safety first is strongly required. As a result of this study, it was recommended that the flight crew must not just obey operational manuals when they feel some anxiety but they must also assert the situation and behave from the safety view. Pflanz and Levis (2012) presented guidelines to measure organizational resilience in terms of specific parameters, for example, error-tolerance, the capacity of responding to unexpected events or the level of connectivity between the system's elements. Siegel and Schraagen (2014). Thus the above-mentioned model consisted of three boundaries putting pressure on the operating state named safety, performance (capacity and punctuality), and workload. In addition, to model the pressure, an additional dimension was added. The model was able to differentiate between internal changes that keep the system in a resilient state or move it towards brittleness. Moreover, Costella et al. (2009) developed a method for the assessment of health and safety management systems, which aimed to emphasize the resilience engineering perspective on health and safety by taking into consideration four major resilience principles (flexibility, learning, awareness, and top management commitment). Such principles underlined seven major assessment criteria, which were further divided into items and statements. Thus, the aforementioned items and statements were assessed based on interviews, analysis of documents and direct observations to obtain a score on a scale of compliance ranging from 0% to 100%. In addition, Øien, Utne, Tinmannsvik, and Massaiu (2011) established a method that considered warning indicators to develop resilience. From the previous studies, it was observed that authors tend to address resilience engineering with a different approach depending on their field of study.

For instance, within the aviation domain, various studies have researched how innovative safety indicators can be supported from a resilience engineering perspective (I. Herrera & Hovden, 2008; I. A. Herrera & Tinmannsvik, 2006). In addition, Cabon et al. (2008) performed a study to measure the risks of flight crews' fatigue through resilience engineering principles to identify both, contributing factors and risk control measures. Moreover, Gomes et al. (2009) carried out a study on the offshore helicopter transportation system in Brazil, which aimed to understand the resilience and brittleness of the system under workload demands and economic pressure. Furthermore, Saurin and Junior (2012) conducted a case study, which was designed to identify and analyse the sources of resilience and brittleness on two air taxi carriers.

Within the scope of the chemical sector, there are also studies that have applied a resilience-engineering approach. For example, Elizabeth Lay and Branlat (2013) performed a risk assessment in a manufacturing plant to identify alternative solutions to increase resilience. Moreover, Abech, Berg, Delis, Guimaraes, and Woods (2006) carried out an analysis of opportunities and challenges to improve resilience in an oil distribution plant. Furthermore, a study performed by G. Shirali, Motamedzade, Mohammadfam, Ebrahimipour, and Moghimbeigi (2012) collected interviews and on-site observations to identify the challenges in the procedure of building resilience engineering in a chemical plant. Thus, some of the challenges that the aforementioned study identified were a lack of reporting systems, a lack of experience about resilience engineering, or inadequate procedures and manuals. Finally, A. Azadeh, Salehi, Ashjari, et al. (2014) defined additional resilience abilities for assessing resilience engineering (e.g. teamwork, redundancy or fault tolerance), creating a new concept known as Integrated Resilience Engineering (IRE). Hence, the purpose of the above-mentioned study was to evaluate a petrochemical plant and to make a comparison between the application of traditional resilience engineering and IRE by analysing data from questionnaires and by utilising a data envelopment analysis (DEA) approach. The aforementioned study revealed that although there is a strong direct correlation between the DEA results in both frameworks, the mean scores of efficiency in IRE is slightly higher than RE. In addition, the superiority of IRE was shown through robust statistical analysis.

On the other hand, within the health and safety management domains, S. Anderson et al. (2011) developed a classification of socio-technical risks that jeopardize resilience in healthcare. Besides, Costella et al. (2009) defined a new method for assessing health and safety management systems, which is based on the application of flexibility, learning, awareness, and top management commitment abilities, in order to emphasize the resilience engineering perspective. Besides, Ross et al. (2014) performed a study to assess how diabetes care is delivered and how resilience is created, identifying quality improvements.

Finally, within the scope of the maritime sector, Zavitsas, Zis, and Bell (2018) carried out a study to establish a link between environmental and network resilience performance for supply chains, by applying operational cost and SO_x emissions cost metrics. Moreover, Lam and Bai (2016) performed a study to develop an original quality function deployment approach to enhance resilience on maritime supply chains. Thus, the aforementioned study aimed to identify first, the major customer requirements, second, common risks that would affect the satisfaction of customers, and third, resilience measures to mitigate those risks.

When compared to other sectors, it seems that the maturity level of the application of resilience engineering concepts in the maritime sector is still at infant stage. There are limited attempts to implement resilience engineering principles and to develop a complete resilience framework that could enhance maritime safety. A European project known as the FP7 SEAHORSE project was conducted, aiming to improve safety in maritime transport by addressing human and organizational factors through a transfer of practices and methodologies from air transport. Hence, the above-mentioned project was the first attempt to introduce the principles of resilience engineering in an integrated framework to create a multi-level resilience assessment for the maritime domain (Turan et al., 2016), which was focused on the traditional resilience abilities (i.e. learning, monitoring, anticipating and responding). However, as it was mentioned before, the study conducted by A. Azadeh, Salehi, Ashjari, et al. (2014) identified additional resilience abilities for assessing resilience engineering (e.g. teamwork, redundancy or fault tolerance), creating a new concept known as Integrated Resilience Engineering (IRE), and demonstrating its superiority when compared with the traditional resilience engineering abilities. Therefore, although SEAHORSE project set the foundation for the creation of a resilience assessment framework in the maritime domain, the output was less robust than the IRE framework.

In addition, Badokhon (2018) developed a new approach to barrier management concerning the operation of the navigation bridge system in a framework that incorporates the principles of resilience engineering to enhance shipping safety. The aforementioned study was the first attempt to apply the outputs from the SEAHORSE project to minimise the errors of the bridge operator by addressing the traditional resilience abilities. Nevertheless, the downside of this approach was the limitation on the amount of resilience abilities utilised, as it only incorporated the traditional resilience abilities (i.e. anticipation, monitoring, learning, and responding) without investigation the potential utilisation of additional resilience abilities that were and still are available in the literature. In addition, this study was focusing on assessing resilience at a functional level, in other words, in a specific operations rather than assessing resilience for the entire organization.

2.6 Historic Evolution of Accident Causation Models

This section aims to review the major accident causation models that are available within the literature. The maritime sector has been traditionally characterized by ship accidents, which usually involve significant economic consequences and social impact (Eliopoulou et al., 2016). Thus, within the last decade, a significant improvement has been reached by understanding how these accidents are developed. Nevertheless, there is still a gap in terms of understanding how risk could be reduced or how safety could be upgraded by properly addressing maritime accidents. Thus, a level has been reached, in which safety is considered hard to improve mainly due to the following reasons (Kristiansen, 2013):

- Short memory: Maritime workers start relaxing on their daily requirements when “things go right”, and there are no accidents.
- Focus on consequences: Accident analysis tends to focus on the consequences of an accident instead of the accident contributing factors.
- Complexity: There are numerous factors that influence safety. Thus, under relations between elements are not always easy to understand due to the complexity of the system. Therefore, this situation makes safety improvements more challenging to be identified and conducted.
- Unwillingness to change: It is in human nature trying to avoid changes in behaviours and acts.

- Selective focus: Current safety assessment approaches aim to perform efficient control of risks. However, current approach has certain weaknesses such as studying the system in a simplified way, which results in underestimating certain aspects and not properly addressing all the factors involved (e.g. human element).

Accidents within the maritime sector are usually complex processes, in which there is no single factor solely responsible for the accident outcome. Hence, the value of having an accident model has been recognized for many years (Erik Hollnagel et al., 2007). According to Erik Hollnagel et al. (2007), an accident model is defined as “different perceptions of the accident phenomenon”. Thus, the choice of an adequate accident model is a crucial step, as it will not only determine the analyst's perspective, guiding the conclusions of an investigation, but it will also lead to the development of a set of preventive measures to comply with aforementioned conclusions (Chauvin, Lardjane, Morel, Clostermann, & Langard, 2013).

2.6.1 Accident Causation Models and their Evolution

According to the literature available, accident models have evolved within the last century, allowing to establish three main archetypes (Erik Hollnagel et al., 2007) as follows:

- Single-factor models, e.g. the simple linear model.
- Complex linear causation models, e.g. the Swiss cheese model.
- Systemic or functional models, e.g. STAMP or FRAM methods.

The main representation of a simple linear model is Heinrich’s Domino model (1931), which defines an accident as “a linear propagation of a chain of causes and effects” (Erik Hollnagel et al., 2007). Hence, this model considers an accident as a disruption in a stable system. Although this model was the first attempt to provide a proper understanding of an accident event, its weaknesses are first; the misinterpretation that there is a root cause, which leads into accidents, and second; that it is possible to find this root searching back from the accident to the chain of events. Thus, within this model, safety is achieved by interrupting the linear sequence of events, which can be accomplished by removing a piece or by spacing the domino pieces (Erik Hollnagel et al., 2007). Figure 2.3 provides an example of the most representative simple linear model (i.e. Heinrich’s Domino model).

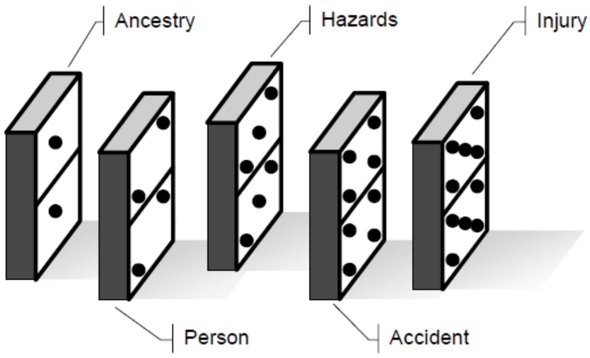


Figure 2.3. Example of a simple linear accident model (Hollnagel, Woods et al. 2007)

On the other hand, the main representation of a complex model is the Swiss cheese model, which was elaborated by Reason in 1990 (Reason, 1990). Thus, the aforementioned model defines an accident "as the result of the interrelation between real-time unsafe acts by front-line operators, and latent conditions (e.g. weakened barriers or defences), which are represented by the holes in the slices of cheese" (Erik Hollnagel et al., 2007). Within the Swiss cheese model, active failures and latent conditions are clearly distinguished. Active failures are the unsafe acts committed by the end of the system (e.g. pilots or crew members), which have a direct and immediate impact on the global safety of the system. Hence, active failures are seen as the consequences of deeper causes or latent conditions. (Chauvin et al., 2013). Furthermore, the Swiss cheese model is more complex than the above-mentioned simple linear models since the focus remains on individual components and the function associated with them instead of the functions of the overall system. However, within the scope of the Swiss cheese model, an accident is still the result of a chain of events. Thus, the Swiss cheese model thinks that one individual barrier cannot be the reason of a loss or an accident. It is the chain of the events collectively responsible. Figure 2.4 provides an example of the most representative complex linear model (i.e. the Swiss cheese model).

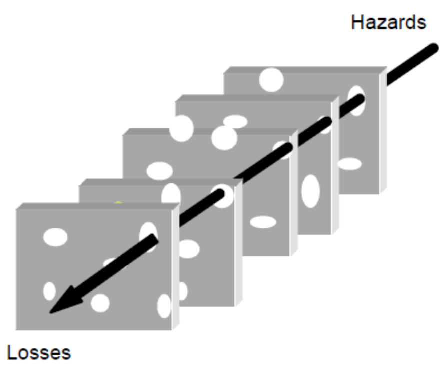


Figure 2.4. Example of a complex linear accident model (Hollnagel, Woods et al. 2007)

Nevertheless, maritime accidents have become extremely complex events to be understood by applying simple or complex linear accident models (J.-U. Schröder-Hinrichs, Praetorius, G., Graziano, A., Kataria, A., & Baldauf, M. , 2015). Hence, there is a challenge to develop a resilience model, which defines resilience as an independent concept, without simply making it a synonym for other existing definitions such as robustness or flexibility (Lundberg & Johansson, 2015). Thus, to develop a model, which complies with the previous statement, it is necessary to understand the core functions of any resilient system and the relationships that exist between the aforementioned core functions. Therefore, these ideas have been researched in many studies over the last decade (Lundberg & Johansson, 2006; Lundberg & Johansson, 2015; Lundberg & Rankin, 2014; Lundberg, Törnqvist, & Nadjm–Tehrani, 2012; Rankin, Lundberg, & Woltjer, 2011). Thus, as a result of the aforementioned studies, new resilience models have been published. One of these models, which is widely recognized, is the Hollnagel systemic model, which is based on the application of resilience engineering concepts and precepts. The main characteristics of the systemic model could be summarized as follows (Erik Hollnagel et al., 2007):

- Both normal performance and failures cannot be explained as the consequence of a malfunction of a specific component. Thus, normal performance occurs as a required response for adapting to an unpredictable environment, and it is not the performance defined within the regulations.
- The outcome of a specific action may differ from what was expected. However, when this occurs, it is often attributed to changes in performance conditions rather than component failures.
- Efficiency is a consequence of the adaptability of human work. Variability in people's reactions under changes allows success in normal action performance. Thus, it allows people to be proactive, saving resources in the process. However, the above-mentioned adaptability may also lead to failures, as the human response is often based on a partial analysis of the work conditions.

Overall, the main goal of the aforementioned new resilience models is to understand systems performance in order to design them more resilient, instead of searching for accident causation. Nevertheless, most accident analysis methods assume that accidents are the result of a series of events, occurring in a specific order. Within this way of thinking, the concern is the belief that accidents could be prevented by finding and eliminating possible causes, hence, safety is ensured by improving the ability of an organization to respond and looking for failure probabilities (de Carvalho, 2011).

Resilience engineering is still an approach under development; hence, there is a need to complete the gap between practice and theory. In order to achieve this target, there is a requirement to develop new tools for complementing the existing models. Currently, there are two major accident causation models based on resilience engineering concepts, which can be applied in addition to risk assessment methods. These methods are the Systems-Theoretic Accident Model and Processes (STAMP) and the Functional Resonance Analysis Method (FRAM) (Erik Hollnagel et al., 2007).

2.6.2 **Systems-Theoretic Accident Model and Processes (STAMP)**

The Systems-Theoretic Accident Model and Processes (STAMP) method was developed in the Massachusetts Institute of Technology (MIT) for the aviation and space industries by Nancy Leveson's book “Engineering a Safer World” (Leveson, 2011) and it has been successfully implemented in numerous scenarios. For instance, STAMP method was applied in safety modelling to represent; an aircraft rapid decompression event (Allison, Revell, Sears, & Stanton, 2017); in small drone operations (Chatzimichailidou, Karanikas, & Plioutsias, 2017); or on safety analysis regarding unmanned protective vehicles (Bagschik, Stolte, & Maurer, 2017).

The STAMP method is based on system process dynamics and not only events and human actions individually (Alvarenga, e Melo, & Fonseca, 2014). Thus, the STAMP method is a combination of two models, Rasmussen and Svedung’s model (Rasmussen & Suedung, 2000) and Forrester’s model (Ameziane, 2016). Rasmussen (1997) proposed a model for socio-technical systems, in which the accident was viewed as a complex process with several hierarchical control levels. In addition, Rasmussen and Svedung applied Sasmussen model to risk management. Thus, Forrester developed in 1961 a mathematical model of socio-technical systems by using concepts of process control systems theory. Therefore, the STAMP method combines the structure from the Rasmussen and Svedung’s model with Forrester's mathematical model for system dynamics to describe the process occurring in each hierarchical control level (Alvarenga et al., 2014). STAMP method represents a new way of thinking about accidents, which integrates all the aspects related to risk, including both, organizational and social aspects. Thus, this method has the potential to be applied as a new approach for accident investigation and analysis, accident prevention, risk assessment, risk management, and performance monitoring (Erik Hollnagel et al., 2007).

According to Erik Hollnagel et al. (2007), the STAMP method views systems as components that are interrelated in a state of dynamic equilibrium. Within this method, accidents are the result of errors from interaction among people, organizational structures, engineering activities, and systems components. Hence, an accident occurs when an adaptive feedback function fails to maintain safety and performance over time. In addition, the STAMP method treats safety and resilience as control problems, in which accidents occur when component failures, external disturbances or interaction between system components are not adequately addressed. For instance, an example of a control problem was the accident of the Space Shuttle Challenger, in which the O-rings did not control properly the propellant gas released by sealing a minor gap in the field joint.

STAMP is designed around three major areas, in which each area allows classifying certain controlling errors that could lead to an accident. Thus, these areas have been defined by Erik Hollnagel et al. (2007) as follows:

- Constrains: Systems are described as classified structures, in which each level imposes constraints on the level below it. Therefore, constraints (or the lack of them) from a higher level may control the behaviour at lower levels. Hence, an accident is considered as the result of interactions between components that interrupt the system safety constraints, which differs from the traditional approach of considering accidents as the result of a root cause in a sequence of events that lead to a loss.
- Hierarchical level of control: A ranked level of control is necessary in order to prevent accidents from happening. Each model can have one or more hierarchical levels of control, in which effective communication is required for both, providing the essential information to add constraints to the levels below and offering feedback related to how effective the constraints were imposed.
- Process models: Any controller must contain a model of the system under control. In order to achieve effective control, three aspects are required: the current state of the system under control, the relation between the variables within the system, and the different ways the system can change to another state.

Finally, the STAMP method involves creating a model of the organizational safety structure. This model can be applied to investigate incidents or accidents, aiming to establish the role played by any components regarding the safety control structure. Thus, the above-mentioned model can also be utilized to learn how to prevent a future accident from happening, to perform hazard analysis and reduce risks, or to create and support a risk management program in which risk can be controlled and monitored (Erik Hollnagel et al., 2007). STAMP is a very adequate method for analysing an accident in any technical system. However, it is not a valid method to analyse HFs, as the required software will not be able to predict the behaviour of the system (Ameziane, 2016).

2.6.3 **Functional Resonance Analysis Method (FRAM)**

The Functional Resonance Analysis Method (FRAM) was originally proposed as a risk assessment and accident analysis method (Erik Hollnagel, 2012b). Hence, it has been successfully applied for addressing the re-interpretation of major accidents in different domains. For example, de Carvalho (2011) utilized this method in a mid-air collision between a commercial aircraft Boeing and an executive jet EMBRAER E-145. Moreover, Woltjer (2008) analysed the Alaska Airlines flight 261 accident; and Praetorius, Lundh, and Lützhöft (2011) re-analysed the accident of the vessel MV Herald of Free Enterprise.

The objective of the FRAM method is to identify and model the required function to carry out a specific activity (Erik Hollnagel & Fujita, 2013). Therefore, each function is described in terms of six different aspects as follows: Input (I), what starts the function, Output (O), the result of the function, Precondition (P), conditions that must exist prior carrying out the function, Resource (R), supplies that the function needs to produce the output, Control (C), what controls and monitors the function, and finally Time (T), constraints of the function in terms of duration (Patriarca et al., 2017). As it was established in the previous section, resilience engineering is characterized by presenting four major abilities or cornerstones: responding (What we need to do?), monitoring (What we need to look for?), anticipating (Do we know what to expect?) and learning (Do we know what has happened?) (Pęciłło, 2016). These four abilities characterize resilience; nevertheless, they are not independent. Hence, in order to understand how a system can be resilient, it is necessary to describe the ways in which these abilities depend on each other (Erik Hollnagel & Fujita, 2013). The major interdependencies are shown in Figure 2.5, in which the four hexagons that represent the aforementioned abilities are connected. For example, the output from the "Learning" hexagon is considered as the input for the "Anticipation" hexagon. Thus, it is also used by the "Monitoring" hexagon for both control and time, and finally, it is used as a resource for the "Responding" hexagon.

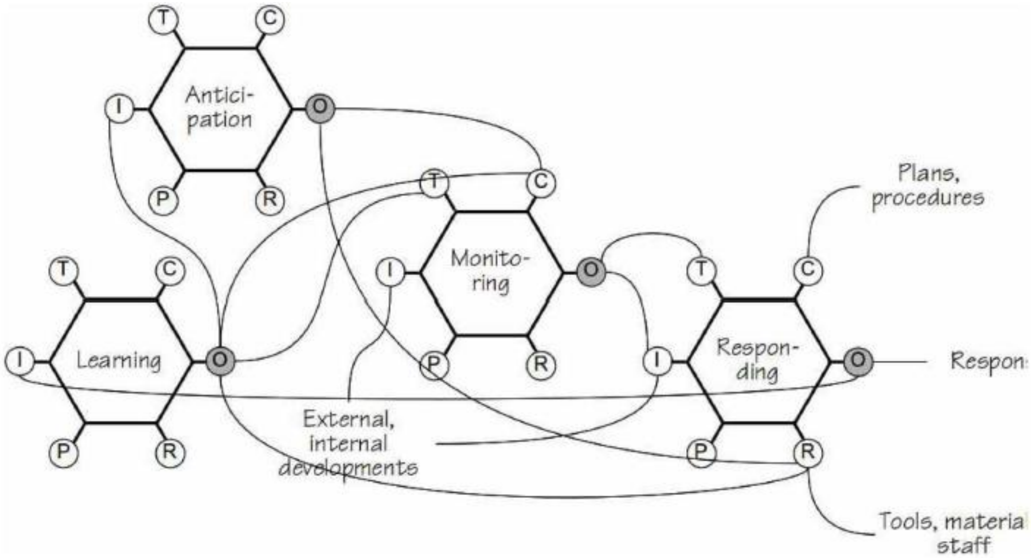


Figure 2.5. Major dependencies among Resilience's Capabilities (Hollnagel and Fujita 2013)

FRAM principles are based on a non-linear accident model, assuming that accidents occur as the result of unexpected combinations of normal performance variability. Then, according to this interpretation, accidents could be prevented by monitoring and damping variability among system functions, and safety may be achieved through the constant ability to anticipate future events (de Carvalho, 2011). FRAM consists of four major principles (Ameziane, 2016; de Carvalho, 2011; Erik Hollnagel, 2012a; Smith et al., 2017) as follows:

- Principle of equivalence of successes and failures: Failures and successes are equivalent, understanding that there is a common reason for them to happen. In other words, it could be said that things go wrong for the same reason that they go right. This principle is based on the idea that failures represent the other side of the adaptations, which are necessary in a complex world, rather than a failure due to normal system performance. Hence, achieving success depends on the ability of organizations and individuals to anticipate critical situations in time and to respond appropriately when a failure occurs.
- Principle of approximate adjustments: Work situations are unpredictable due to the complexity in nowadays systems. Just a few, if any, tasks can be carried out in an optimum way unless procedures, tools, and measures are adapted to the situation to meet multiple and even conflicting goals. Therefore, the daily performance of socio-technical systems (including humans) is adjusted to match the system conditions in both normal and necessary.

- Principle of emergence: The variability of normal performance is rarely enough for causing accidents, but multiple functions may combine in unexpected ways with unpredictable major consequences, producing a non-linear effect. Hence, both successes and failures are emergent rather than resultant, as they cannot be explained by merely looking at the performance of system components.
- Principle of functional resonance: The variability of a number of functions may resonate in some occasions, causing an accident as a consequence. FRAM emphasizes the dynamics, nonlinearity, and non-randomness of this resonance, hence, FRAM aims to support the analysis and prediction of functional resonance in order to understand and avoid accidents.

In addition, the FRAM promotes a systemic view for accident analysis, aiming to understand the characteristics of system functions. There are four elementary steps, which may be iterated, to perform an accident analysis by applying the FRAM. These steps can be summarized as follows (Ameziane, 2016; de Carvalho, 2011; Erik Hollnagel, 2012a; Smith et al., 2017):

- Step 1: To identify essential system functions, characterizing each function by six basic parameters. These parameters were identified before as input (I, that which the function uses), output (O, that which the function produces), preconditions (P, conditions that must be fulfilled prior to perform a function), resources (R, that which the function needs prior to start), time (T, that which affects time availability), and control (C, that which supervises the function).
- Step 2: To characterize the potential variability through Common Performance Conditions (CPCs). Within the FRAM, Eleven CPCs are identified to be used, which combine human, technological and organizational aspects for each function as follows: availability of personnel and equipment; training, preparation, competence; communication quality; human-machine interaction, operational support; availability of procedures; work conditions; goals, number, and conflicts; available time; circadian rhythm, stress; team collaboration; and organizational quality. In addition, after identifying the CPCs, the variability needs to be determined qualitatively in terms of stability, predictability, sufficiency, and boundaries of performance.
- Step 3: To define the functional resonance based on possible dependencies/couplings among functions and the potential for functional variability. Within this step, instantiations, which are defined as sets of coupling among functions for specific time

intervals, are identified, defining the potential links among the functions, which are used to specify the different impacts.

- Step 4: To identify barriers for variability (i.e. damping factors) and to specify required performance monitoring. Thus, these barriers may either prevent an unwanted event from occurring or may protect against the consequences of an unwanted event. Moreover, the aforementioned barriers may enhance the capabilities, allowing the system to continue its operation. In addition, barriers can be described in terms of barrier systems (i.e. the structure of the barrier) or barrier functions (i.e. how the barrier achieves its purpose).

In conclusion, FRAM provides a framework that allows understanding the human interaction in the system in a clear way, by describing each required function to carry out a specific activity. Within a FRAM model, the human element is essential in order to achieve successful operations, and it needs to be considered as more than a component that can only succeed or fail. FRAM aims to understand why an accident happened.

2.7 Methods to Evaluate the Contribution of Human Factors into Past Occurrences

Human Factors (HFs) were first introduced during World War I and World War II, as a result of the development and posterior use of airplanes (Ameziane, 2016). However, within the maritime domain, and especially when discussing HFs that are related to shipping operations, there are two key concepts that are often misused as synonyms. First, HFs, in which the relation between the requirements on board and human capacity is a key aspect to be taken into consideration, and second, ergonomics, in which more emphasis is given to the design of controls and workplace. Thus, according to the International Ergonomics Association (IEA), ergonomics may be defined as “the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and methods to design in order to optimize human well-being and overall system performance”(IEA, 2017).

Nowadays, HF is a term commonly used, as it has been established as solid discipline in the last decades. Nevertheless, the study of the contribution of HFs to accidents only achieved a high priority after the occurrence of two major industrial disasters, the ground collision between two aircraft in Tenerife (1977) and Three Miles Island nuclear accident (1979) (Chen et al., 2013).

In recent years, various authors have conducted numerous studies with the aim to identify and successfully evaluate the contribution of HFs into past accidents. By analysing the aforementioned studies, it is possible to identify three major paths regarding the analysis of HFs into past accidents. First, one of the most applied techniques to analyse and classify HFs is the Human Factor Analysis and Classification System (HFACS) method, which aims to identify latent human errors. Thus, it has been successfully applied for accident analysis in numerous fields (Luo & Shin, 2016). Second, human reliability assessments (HRAs), which aim to predict human errors, allowing the adoption of the human element within the risk framework (Kirwan, 1996; Smith et al., 2017). Third, statistical analysis.

2.7.1 Human Factors Analysis and Classification System (HFACS)

The well-known HFACS method was originally designed for military aviation with two purposes. First, to facilitate HFs accident investigation and secondly, to underline the causes of human error and analyse them. Thus, HFACS was successfully expanded to other strategic industries as civil aviation, railway, mining (Chauvin et al., 2013) or maritime (Luo & Shin, 2016). As HFACS is a well-established method for the analysis of HFs and it has been implemented in numerous studies within the shipping sector. For instance, Chauvin et al. (2013) analysed maritime accidents by applying the HFACS method, identifying Situational Awareness (SA) and a deficit of attention as significant HFs leading to collision accidents. Yıldırım, Başar, and Uğurlu (2017) assessed grounding accidents by applying HFACS, highlighting that insufficient communication or a lack of procedures are HFs highly related to grounding accidents. In addition, HFACS-based techniques have been developed and applied to specific accident-scenarios in the maritime sector. For example, Chen et al. (2013) developed and applied an HFACS-based method specifically designed for the maritime sector (i.e. HFACS-MA), which follows the ideas used in both HFACS and Systemic Occurrence Analysis Methodology (SOAM). The aforementioned HFACS-MA was applied to past maritime accidents in order to analyse both human and organizational factors. Moreover, Celik and Cebi (2009) proposed to create an HFACS based on a fuzzy analytical hierarchy process, and Jens U Schröder-Hinrichs, Baldauf, and Ghirxi (2011) adapted HFACS for the machinery spaces on ships (i.e. HFACS-MSS). However, although HFACS has a strong theoretical foundation (i.e. it is based on Reason's ideas and theory), it presents some limitations. First, HFACS have industry restrictions. As it was designed to analyse the causes of aviation accidents, some categories within this model are not applicable to other sectors. Hence, HFACS presents a remarkable lack of versatility. Thus, although psychological factors can be identified by interviewing relevant personnel when applying HFACS, these psychological factors will be limited due to the subjectivity of interview results (Fu, Cao, Zhou, & Xiang, 2017). Moreover, by applying HFACS, the scope of the investigation is limited to the predefined taxonomy and organization level; hence, it will be altered in each accident outcome or scenario being modelled.

2.7.2 **Human Reliability Assessments**

It is possible to establish two different generations regarding Human Reliability Assessments (HRAs). Within the first generation, the concept of human error is associated with people's deficiencies. In this first category, some representatives HRAs are the "Technique for Human Error Rate Prediction (THERP)", the "Human Error Assessment and Reduction Technique (HEART)" or the "Justification of Human Error Data Information (JHEDI)". On the other hand, the second generation of HRAs is characterized by approaching human behaviour to risk analysis, presenting a more complex and integrating model validation and Performance Shaping Factors (PSFs). In this category, some representative HRA methods are "A Technique for Human Event Analysis (ATHEANA)" or the "Cognitive Reliability and Error Analysis Method (CREAM)" (Z. L. Yang, Bonsall, Wall, Wang, & Usman, 2013). Thus, the second generation of HRAs aims to incorporate expert judgments to deliver quantitative human failure analysis results.

The aforementioned methods have been applied in numerous case studies. For instance, K. Yang, Tao, and Bai (2014) assessed flight crew errors by applying the THERP method. In the aforementioned case study, the take-off task was analysed, the human error modes and consequences were identified, and the failure probability of take-off task was calculated. Although the application of the THERP method seems a suitable approach, the researcher has specific concerns regarding the objectivity of the results when applying this technique. Firstly, the interdependence among subtasks is a determinant factor, as it may influence significantly on the conditional human error probability. Hence, it is critical to select adequate experts to perform this task, which is always a very subjective decision. In addition, the analysis of a different scenario will lead to different conclusions. Thus, the decision of how many scenarios needs to be considered is a notable problem to the system designers.

In addition, Maniram Kumar, Rajakarunakaran, and Arumuga Prabhu (2017) developed a Fuzzy-HEART approach to quantify human error probabilities in LPG refuelling stations, in which the HEART technique was applied to analyse the tasks. Moreover, an expert weighing approach along with a structured expert-elicitation approach was employed to increase the fidelity of the HEART technique. Furthermore, the JHEDI technique has been also applied in the literature. For instance, it was utilised to evaluate human reliability in a nuclear chemical plant (Kirwan, 1997).

Within the scope of the maritime sector, it seems that the CREAM method is the HRAs that has been more widely applied. For instance, Zhou et al. (2017) applied an enhanced CREAM method by incorporating stakeholders-graded protocols for tanker shipping safety. Ung (2015) developed a weighted CREAM model to perform analysis on maritime human reliability. In addition, Zhang, He, Chen, Chu, and Fan (2019) applied a Predictive Mean Vote (PMV)-CREAM to perform a dynamic human reliability assessment to manned submersibles. Thus, Ung (2019) applied fault tree analysis and modified fuzzy Bayesian Network-based CREAM to evaluate the human error contribution to oil tankers. However, the CREAM method present certain limitation that reduce its applicability for human error or human reliability. First, in order to apply the CREAM method, a higher understanding and previous knowledge in the method is required. Hence, to the novice analyst, the method appears complicated and daunting. Second, the application of CREAM is larger and more resource intensive than observed in other methods due to the exhaustiveness of the classification scheme that exist within the CREAM method. Third, due to the aforementioned complexity of this method, it is understandable that the training and application time would be considerable higher than other methods. Thus, it would require previous knowledge of human factors.

Overall, it seems that the majority of the above HRAs apply some sort of expert judgment, as the contribution of the human element to an accident is difficult to quantify numerically. However, by incorporating expert judgment, the results are highly influenced by each expert own knowledge, hence, the results become subjective. In addition, HRAs are designed for a specific sector or scenario and normally applied for specific tasks. This limitation does not allow creating a generic model, which could be easily applied to any maritime accident. Hence, the need to model a new scenario for each case study is time and cost consuming. As a result, it was identified that the aforementioned HRAs will not be useful for establishing a high level organizational approach to assess reliability and resilience of shipping operations at a practical level.

2.7.3 **Statistical Analysis**

Statistical analyses have been extensively performed to identify accident contributing-factors (Bye & Aalberg, 2018; Eliopoulou et al., 2016; A Papanikolaou, Bitha, Eliopoulou, Ventikos, & Engineering, 2014; N. Ventikos, Papanikolaou, Louzis, & Koimtzoglou, 2018; Yıldırım et al., 2017). For instance, A Papanikolaou et al. (2014) carried out a systematic analysis of marine accidents to evaluate the level of safety considering the majority of ship subtypes in the world merchant fleet. Moreover, Yıldırım et al. (2017) assessed the frequency and distribution of collision and grounding accidents by combining the HFACS technique with statistical methods, such as the Chi-Square Test of Compliance and Independence and the Simple Correspondence Analysis. In addition, Bye and Aalberg (2018) conducted an exploratory statistical analysis utilizing AIS data from Norwegian waters and the results of maritime accident reports, concluding that certain vessel types (e.g. dry cargo, bulk, tanker or fishing boats) are more prone to lead into a navigational accident. Furthermore, Eliopoulou et al. (2016) performed a set of statistical analyses of ship accidents, including a deeper study to calculate if an interrelation exists between the vessels' age and the accident rates. Thus, they also reviewed the safety level of various ship types. Besides, Schlögl, Stütz, Laaha, and Melcher (2019) provided a comparison amongst various statistical learning methods with respect to their predictive performance, finding out that there is a trade-off amongst sensitivity and accuracy in the imbalanced dataset. In addition, N. Ventikos et al. (2018) statistically analysed navigational accidents in adverse weather conditions, aiming to assist the IMO regulatory framework with their findings. Table 2.5 displays a summary of previous statistical analyses that have been conducted for the maritime domain. The above-mentioned summary indicates for each publication (1) the period under analysis, (2) the data source, and (3) the major contribution.

Table 2.5. Summary of existing statistical analysis for the maritime domain

Authors	Period	Data Source	Contribution
Jin and Thunberg (2005)	1981-2000	Coast Guard	Analysis of fishing vessel accidents in the northeastern United States
Eliopoulou, Papanikolaou, and Technology (2007)	1978-2003	Lloyd’s	Casualty analysis of large tankers
Kujala, Hänninen, Arola, and Ylitalo (2009)	1997-2006	DAMA database	Analysis of marine traffic safety in the Gulf of Finland
Tzannatos and Kokotos (2009)	1993-2006	Reports of the Hellenic Coast Guard	Analysis of accidents in Greek shipping during the pre- and post-ISM period
Chauvin et al. (2013)	1998-2012	MAIB database and the Transportation Safety Board (Canada)	Analysis of collisions at sea using the HFACS
Apostolos Papanikolaou, Eliopoulou, Hamann, and Golyshev (2013)	1990-2012	Germanischer Lloyd	Casualty analysis of cellular type container ships
N. Ventikos, Koimtzoglou, Louzis, Eliopoulou, and Engineering (2014)	1990-2013	IHS Sea-web® database, IMO, GISIS	Statistics for marine accidents in adverse weather conditions
A Papanikolaou et al. (2014)	1990-2012	IHS Sea-web® database	Statistical analysis of ship accidents and assessment of safety level on ship types
Ntanos, Chalikias, Milioris, and Sidiropoulos (2015)	1974-2010	Database created from data of the Ministry of Shipping and the Aegean Directorate of Ship Safety	Statistical analysis of maritime accidents over 1000 GRT on Greece
Kum and Sahin (2015)	1993-2011	MAIB database	Root cause analysis for Arctic Marine accidents
Pagiaziti, Maliaga, Eliopoulou, Zaraphonitis, and Hamann (2015)	1990-2012	IHS Sea-web® database, GISIS	Statistics of passenger and container ships
Stornes (2015)	1981-2014	Norwegian Database	Exploratory statistical analysis
Banda, Goerlandt, Montewka, Kujala, and Prevention (2015)	2009-2012	Finnish Maritime Administration and the Finnish Transport Safety Agency	Risk analysis of winter navigation in Finnish sea
Eliopoulou et al. (2016)	2000-2012	IHS Sea-web® database	Statistical analysis of ship accidents and review of safety level
Goerlandt et al. (2017)	2007-2013	North BAceD database	Analysis of wintertime navigational accidents in the Northern Baltic Sea
N. P. Ventikos, Stavrou, Andritsopoulos, and Technology (2017)	1999-2009	IMIS database	Studying the marine accidents of the Aegean Sea
N. Ventikos et al. (2018)	1990-2013	IHS Sea-web® database, IMO, GISIS	Statistical analysis and critical review of navigational accidents in adverse weather conditions
Bye and Aalberg (2018)	2010-2016	AIS data and accident reports	Exploratory statistical analysis
B Navas de Maya, Ahn, and Kurt (2019)	1990-2016	MAIB database	Statistical analysis of the MAIB database

Despite the available research in terms of statistical analysis of maritime accidents, efforts of statistically modelling the relationship between contributors and accidental outcomes have been difficult due to the type of data and inconsistency in data collection.

2.8 Fuzzy Cognitive Maps (FCMs)

When analysing a complex scenario, the classification of the factors implicated appears to be one of the main issues (Wolpert, 1992). The problem associated with how to select the best classification technique has been addressed in the literature (Aggarwal, 2014), identifying amongst others Bayesian Networks (BNs), decision trees methods or rule-based techniques. However, although these techniques provide excellent performance, there is no representative technique that could be selected as the best method for all datasets (Fernández-Delgado, Cernadas, Barro, & Amorim, 2014). One of these models, which has been used for classification of new data, and has been applied to numerous fields in the last years, is the Fuzzy Cognitive Map (FCM) method. Despite the fact that it is not as well-known as other methods (Papakostas, Boutalis, Koulouriotis, & Mertzios, 2008; Papakostas, Koulouriotis, Polydoros, & Tourassis, 2012), it has been successfully applied as a classification tool in different fields, e.g. in medicine (Kannappan, Tamilarasi, & Papageorgiou, 2011; E. I. Papageorgiou & Kannappan, 2012; E. I. Papageorgiou, Oikonomou, & Kannappan, 2012) or information technology (Büyüközkan & Vardaloğlu, 2012). Thus, recent studies have proven that FCMs are very promising and worth for further investigation and development (Vergini & Groumpos, 2016), as they present a set of advantages. First, FCMs are suitable for modelling causal relationships between accident variables (Kardaras & Karakostas, 1999; M. Khan, Quaddus, & Intrapairot, 2001). Second, by modelling an FCM, it is possible to represent hazy degrees of causality relations between components (Lee & Han, 2000). Third, FCMs are able to model systems that cannot be explained entirely by applying mathematical models (Stylios & Groumpos, 1999). Finally, vector-matrix operations allow an FCM model to become a dynamic system (M. Khan et al., 2001; B Kosko, 1994). Hence, changes over time might be considered in the system under study.

2.8.1 **Evolution of Fuzzy Cognitive Maps**

One of the first appearances of Cognitive Maps (CMs) in the literature was in 1948, in a paper entitled "*Cognitive maps in rats and men*" (Tolman, 1948), which intended to create a model for the psychology domain. Since it was first mentioned, several authors have represented a collection of nodes linked by arcs. However, there was not a standard meaning for these nodes and arcs (Marchant, 1999). In the last decades, numerous authors have tried to address CMs from different perspectives, for instance, in the 1970s Axelrod (1976) proposed CMs to develop a social and scientific knowledge in the field of decision-making for the politic domain (Bertolini, 2007; Dodurka, Yesil, & Urbas, 2017). Also, Eden, Ackermann, and Cropper (1992) suggested a method that could be applied within the field of management. In addition, Wellman (1994) provided a solid semantic foundation to CMs, in which nodes were considered as random variables and arcs as evidence of probabilistic dependence.

By definition, CMs are signed digraphs characterized by the opinions of experts in a particular area of knowledge (Dodurka et al., 2017). According to, Axelrod (1976) there are two types of cognitive maps, a first type representing the belief system of a person and a second type aiming to weigh cognitive maps. A CM is composed of two primary elements, known as concepts and causal beliefs. The concepts variables, C_x (x=1, 2, …), are represented as nodes linked by arcs within the CM structure. Moreover, the concepts represented at the origin of an arc are known as causal variables, while the concepts located at the end of the same arc are known as effect variables. Thus, the aforementioned concept variables are interrelated through causal beliefs (Rodriguez-Repiso, Setchi, & Salmeron, 2007). Besides, the interrelation between concept variables can be defined with positive or negative signs (Dodurka et al., 2017).

Traditional CMs presented two main limitations (M. Khan et al., 2001). First, the above-mentioned interrelation between concepts could be established as positive or negative. However, the strength of the internal relation amongst concepts remains unknown. Second, a CM was not able to represent a dynamic system (i.e. the system could not evolve with time), ignoring that the effect of a change in a node might affect other nodes in the process. Therefore, in order to overcome CMs drawbacks, Bart Kosko (1986) developed FCMs, as an extension of cognitive maps in which the concepts were weighted with fuzzy numbers.

FCMs have been defined countless times in the literature. For instance, Bart Kosko (1986) defined FCMs as cognitive maps in which the concepts are weighted with fuzzy numbers. Dickerson and Kosko (1994) described FCMs as a computing tool resulting from the combination of fuzzy logic and neural network based on expert knowledge. In addition, for Xirogiannis and Glykas (2004), an FCM was a description of the behaviour of a system through concepts, in which each concept represents an entity, a state, or a characteristic of the system. Thus, a generic definition commonly accepted is that FCMs are extensions of cognitive maps (Axelrod, 1976; Eden, 1988; Tolman, 1948), which aim to model complex chains of casual relationships.

In order to build a traditional FCM, experts with a specific background develop a model based on their own experience in a process composed of three stages. First, key concepts are identified within a determined area. Second, interrelationships are proposed between these concepts, by also identifying if these relations are positive or negative. Third, experts estimate the causal relationship´s strength between each pair of factors (E. I. Papageorgiou, 2010; Zare Ravasan & Mansouri, 2016). In order to identify the aforementioned strength amongst concepts, various approaches are available. For instance, a common suggestion is to request each expert to assign a value to the interrelation between two factors within the interval [0, 1]. Then, expert responses are combined, and an average value is calculated (Dodurka et al., 2017). Nevertheless, it is extremely challenging for some experts to assign numeric values, so an alternative solution is to apply linguistic variables (e.g. *weak* < *moderate* < *strong*) to define the interrelation amongst concepts (Bart Kosko, 1986). Thus, a linguistic weight is obtained by combining all expert answers, which is transformed into numerical values by means of diverse techniques (e.g. Centre of Gravity method (E. I. Papageorgiou, 2010), or a linguistic-numerical conversion (Tsadiras, Kouskouvelis, & Margaritis, 2001)). According to Markinos, Papageorgiou, Stylios, and Gemtos (2007), the seven variables that are used frequently depending on the problem characteristics are: *very very low* < *very low* < *low* < *medium* < *high* < *very high* < *very very high*.

In terms of decision support, there are two methods to analyse an FCM, which represents a given domain. The first method consists of performing a static analysis of the model, which is based on studying the characteristics of the weighted directed graph that represent the model, using graph theory techniques. The most important feature that should be studied on static analysis is the feedback cycles that exist in the graph (Tsadiras et al., 2001). Thus, often this kind of analysis is carried out to observe the relative importance of concepts, and the causal effects between nodes (Axelrod, 1976; M. S. Khan & Quaddus, 2004). In addition, the second method consists of performing a dynamic analysis of the model to explore the impact on the decision process with time. Within this approach, given an interaction matrix and an initial state vector, the final resulting state can provide information regarding any impacts or changes made to the system. Furthermore, by executing a dynamic analysis, it is possible to study the system from a "what-if" perspective (M. S. Khan & Quaddus, 2004).

2.8.2 Mathematical Representation and Dynamic Process of Fuzzy Cognitive Maps

A simple FCM representation is illustrated in Figure 2.6, in which each concept is used to represent an entity, a variable, or a characteristic of the system (Xirogiannis & Glykas, 2004). An FCM is mainly characterized by three components: the characteristics of the system and signed and weighted arcs representing the interrelations within the different elements. The main target in an FCM is to define the relationships between the different concepts represented in the map, understanding the global structure and the dynamics of the system (A. Azadeh, Salehi, Arvan, et al., 2014).

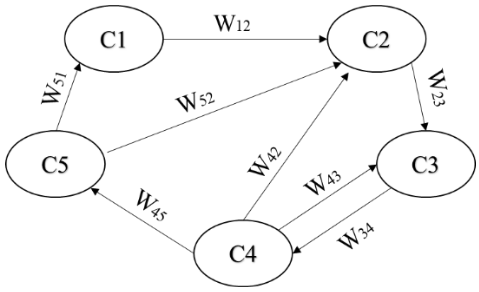


Figure 2.6. A simple representation of an FCM (Beatriz Navas de Maya, Kurt, & Turan, 2018)

In addition, in an FCM, each of the concepts is represented by a number, Ai, that provides the value of each concept, C_i, within the interval [0,1] (León, Rodriguez, García, Bello, & Vanhoof, 2010). Thus, it is possible to identify three different connections between the concepts modelled within an FCM that represents the nature of their respective influence (A. Azadeh, Salehi, Arvan, et al., 2014; León et al., 2010). First, the weight between concepts C_i and C_j may be positive ($W_{ij}>0$), which indicates that an increase or decrease in the first concept will cause the same reaction in the second concept, and vice versa. Second, the weight between concepts C_i and C_j may be negative ($W_{ij}<0$), which shows that an increase or decrease in the first concept will cause the opposite reaction in the second concept, and vice versa. Third, there is no relation between concepts C_i and C_j ($W_{ij}=0$) (Bart Kosko, 1986). In addition, a traditional formula to calculate the values of the concepts in an FCM is shown in Equation 2.1 (Bart Kosko, 1986).

$$A_i^{(t+1)} = f\left(A_i^{(t)} + \sum_{j=1, j\neq 1}^{n} W_{ji}\, A_j^{(t)}\right)$$

Equation 2.1. Traditional formula to calculate the values of the concepts represented in an FCM over time.

Where $A_i^{(t+1)}$ represents the value of C_i at the step t+1, f is the threshold function which assures that the concept's value is limited within the interval [0, 1], W_{ji} represents the weight between both concepts C_i and C_j, and $A_j^{(t)}$ is the value of the concept C_j at step t.

Thus, in order to successfully create an FCM, it is necessary to establish three components. First, an interaction matrix with dimension n x n (where n indicates the number of concepts being modelled in the FCM). In addition, zero elements in the matrix indicate that a relationship does not exist between those two particular elements, while non-zero elements show not only the relation between two elements but also the strength or weight of that relation. Second, an initial state vector, which provides the initial value of the concepts in the scenario being modelled at any point in time (t) before applying the threshold function. Finally, a threshold function, which aims to reduce unbounded inputs to a strict range, to maintain the stability of the qualitative model (Mohr, 1997).

Numerous threshold functions are available for performing an FCM. The bivalent threshold function, the trivalent threshold function, and the logistic signal function are considered significant, according to Mohr (1997). Thus, other authors have also included the hyperbolic tangent function and the linear threshold function (Wu, Liu, & Chi, 2017). Nevertheless, the logistic signal function, also known as the Sigmoid function, provides any possible value within the interval [0,1] (A. Azadeh, Salehi, Arvan, et al., 2014; Xiao, Chen, & Li, 2012) and it has been proven that using this function provides greater benefits (Bueno & Salmeron, 2009). Therefore, Equation 2.2 shows the Sigmoid function.

$$A_i^{(t+1)} = \frac{1}{1 + e^{-x}}$$

Equation 2.2. Sigmoid function.

Where $A_i^{(t+1)}$ represents the value of C_i at the step t+1.

A dynamic analysis of the model may be performed to observe how the model under study evolves with time. Thus, the values of the concepts at each time step (i.e. step 1, step 2, etc.) will be obtained by applying Equation 2.1 until the process ends, which may occur in three different scenarios (M. Khan et al., 2001; B Kosko, 1994; Xiao et al., 2012):

- The FCM reaches equilibrium, which occurs when after two consecutive steps, the state vector remains identical. Hence, the simulation ends, and the FCM is considered to be steady.
- The FCM does not produce a stable state vector, which occurs when the state vector keeps cycling between a set of values, without producing identical results. This situation is known as the “limit cycle”, and it results from a certain combination of weight values when applying an FCM, which drive the map away from reaching equilibrium (Wierzchon, 1995). Nevertheless, a limit cycle might be corrected by means of alternative approaches. For instance, Mateou and Andreou (2006) propose a new methodology for eliminating the limit cycle phenomenon through the application of a hybrid system comprising both FCMs and genetic algorithms.
- The last scenario occurs when the FCM does not reach identical values, producing different state vectors for each step. This scenario is known as “chaos”, and it may occur in complex scenarios, where the model needs to be re-defined.

2.8.3 **Application of Fuzzy Cognitive Maps in Other Fields**

Several studies have addressed the application of FCMs as a classification tool in different fields in recent years, proving that FCM is not only a well-validated classification tool but also its effectiveness. FCMs have been mainly applied in terms of planning and decision making (Dodurka et al., 2017). Nevertheless, the interest from both researcher and industry is increasing, and FCMs have been widely applied to diverse areas as medicine, engineering, resilience or social sciences amongst others.

Within the health field, numerous studies have applied FCMs for the last decade. For example, Kannappan et al. (2011), E. I. Papageorgiou and Kannappan (2012), and E. I. Papageorgiou et al. (2012) applied FCMs successfully in diagnosing autistic disorders, in which the initial weights were determined through expert opinion. In addition, Nápoles, Grau, Bello, and Grau (2014) applied FCMs for the prediction of the degree of resistance of HIV proteins, determining the threshold function from clinical assays. Thus, Froelich (2017) identified historical relics using FCMs as a classification system. Furthermore, E. Papageorgiou, P. Spyridonos, et al. (2008) and Papakostas et al. (2012) also addressed FCM without the requirement of expert opinion. In addition, FCMs have been extensively applied for medical diagnosis and decision support, in radiotherapy (EI Papageorgiou, Stylios, & Groumpos, 2008), brain tumour characterization models (E. I. Papageorgiou, Spyridonos, et al., 2006), a model for the management of urinary tract infections (E. I. Papageorgiou, Papadimitriou, & Karkanis, 2009), and a specific language model aims for impairment (Georgopoulos, Malandraki, & Stylios, 2003). Thus, additional studies have been conducted by Papakostas et al. (2008), who proposed the use of an FCM model for pattern recognition task, Rodin et al. (2009), who modelled cell behaviour in systems through the intracellular biochemical pathway, and Froelich and Wakulicz-Deja (2009), who developed an approach for mining temporal medical data based on FCMs.

Within the engineering domain, a special mention is given to the areas of control and prediction (E. I. Papageorgiou, 2011b). For example, Stylios and Groumpos (2004) modelled complex systems by using FCMs. Thus, non-linear Hebbian rules to train FCMs for modelling industrial process control problems were implemented by E. I. Papageorgiou, Stylios, and Groumpos (2006). Furthermore, the recent integration of a cognitive map and a fuzzy inference engine was developed in which the FCM differs from previous approaches in its hieratical architecture. Within this approach, the FCM, the available plant, and the accessible data were used to generate a complete Fuzzy Logic Controller (FLC) architecture and parameter description

(Gonzalez, Aguilar, & Castillo, 2009). Within the maritime field, Soner, Asan, and Celik (2015) proposed a proactive model that combines FCMs and Human Factors Analysis and Classification System (HFACS) in order to predict and eliminate the root causes of a fire-related deficiency onboard ships. The limitation of their work was the identification of the causal relationships between concepts by collecting expert knowledge in a questionnaire format. Hence, although this approach allows transcribing an expert's opinion, it can equally encode the expert's lack of knowledge.

For the resilience domain, A. Azadeh, Salehi, Arvan, et al. (2014) assessed the factors affecting the resilient level of a petrochemical plant using data from both an FCM and questionnaires, proposing a model which was able to be expanded to other industries. Thus, Jamshidi, Rahimi, Ruiz, Ait-kadi, and Rebaiaia (2016) proposed to apply FCMs for risk assessment of complex and dynamic systems in order to predict the impact of each risk on both, additional risks and the outcome of the project over time. The aforementioned approach could also support the management of risks associated with complex systems in a more effective and precise way, offering extended risk mitigation solutions.

In addition, FCMs can be successfully applied for modelling political and strategic issues to support the decision-making process for an imminent crisis. Andreou, Mateou, and Zombanakis (2003) proposed a variation of FCMs by using Genetically Evolved Certainty Neuron Fuzzy Cognitive Map (GECNFCM) in order to overwhelm the main weaknesses in the recalculation of the weights for each concept for any new strategy adopted. The main advantage of this approach was the capacity to offer an optimal solution once the requirements were defined, with no need for a problem-solving strategy. The benefits of this method were demonstrated in two cases, firstly, in a model analysing the political/strategic complexity of the Cyprus issue, and secondly, in an evolutionary FCMs for crisis management regarding the political problem of Cyprus (Andreou et al., 2003; E. I. Papageorgiou, 2011b). Furthermore, Acampora and Loia (2009) introduced a new methodology based on Ambient Intelligence (AmI) systems. An AmI is a distributed cognitive framework composed of a group of intelligent entities, which are able to modify their own behaviours by considering the user’s cognitive status at a certain selected time. Hence, Acampora and Loia (2009) combined AmI and FCMs for creating a selection of dynamical intelligent agents, which use cognitive computing in order to define patterns of action to maximize environmental parameters. Finally, J. P. Carvalho (2010) discussed the structure, semantics, and use of FCMs when simulating complex economic, social and political systems.

For the business domain, FCMs are valuable in the fields of product planning, analysis, and decision support. For instance, Jetter (2006) applied the concepts of FCMs for ideation, concept development and concept evaluation of new products, creating a systematic method to deal with managers' problems by using FCMs. Furthermore, FCMs were used by Yaman and Polat (2009) as a procedure for supporting decision making in effect based planning. In the aforementioned study, adequate consideration of the problem features and constraints were taking into account to develop an FCM to model effect-based operations in a scenario involving military planning. Moreover, Wei, Lu, and Yanchun (2008) applied FCMs for modelling and evaluating trust dynamics in the virtual enterprises, Bueno and Salmeron (2008) modelled enterprise resource planning selection, and Salmeron (2009) applied FCMs for modelling critical success factor. In addition, a hybrid quantitative and qualitative approach was presented by Kim, Kim, Hong, and Kwon (2008) in order to evaluate the forward and backward analysis of supply chains. Moreover, Trappey, Trappey, and Wu (2011) applied FCMs for reverting logistic operation. This study provided a method for allowing the prediction of future logistics operation states, and it allowed constructing a decision support model to manage system performance based on the forecast. It is known that in many cases, FCM can include subjective factors involved in the determination of FCM weights. Therefore, the research group of Baykasoglu, Durmusoglu, and Kaplanoglu (2011) applied an Extended Great Deluge Algorithm (EGDA) as a training algorithm for FCMs . This study helped to verify the useful application of FCM where interrelated variables and uncontrollable variables were used by reducing the subjectivity of the inference in the results.

Furthermore, different studies addressed the use of FCMs in ecology and environmental management. For instance, Tan and Özesmi (2006) modelled a generic shallow lake ecosystem by augmenting individual cognitive maps. Thus, Isaac, Dawoe, and Sieciechowicz (2009) assessed local knowledge use in agroforestry management, Ramsey and Norbury (2009) developed a model of interactions among sustainability components of an agro-system through local knowledge, and Markinos et al. (2007) applied FCMs for decision making in precision agriculture. In addition, Rajaram and Das (2010) predicted a dryland ecosystem in New Zealand in order to anticipate pest management outcomes, van Vliet, Kok, and Veldkamp (2010) applied FCMs for a semi-quantitative scenario located on Brazil, and Kafetzis, McRoberts, and Mouratiadou (2010) investigated water use and water use policy through fuzzy logic.

Finally, within the Information Technology field (IT), FCMs are significantly valuable, particularly for project management. Modern approaches regarding IT have some limitations, as the identification, classification, and evaluation of the indicators of success (E. I. Papageorgiou, 2011b), which could be overcome by applying FCMs for mapping success, modelling Critical Success Factors (CSFs) and their interrelationships (Rodriguez-Repiso et al., 2007). Some case studies addressing the application of FCMs include the analysis and summary of common software's usability quality character system for identifying malfunction problems (Lai, Zhou, & Zhang, 2009), the analysis of remotely collected data through planetary exploration (Furfaro, Kargel, Lunine, Fink, & Bishop, 2010) or the application of FCMs for distributed wireless P2P networks (Li, Ji, Zheng, Li, & Yu, 2009).

2.8.4 **Reasons for Adopting a Fuzzy Cognitive Map Approach in Previous Studies**

An FCM can be adopted as a research approach for different purposes, including the following (Codara, 1998):

- Explanatory function: To understand the reasons behind an expert or a given agent behaviour when taking decisions, highlighting the limits in their representation of the situation.
- Prediction function: An FCM can predict future actions and decisions from expert judgment to justify new occurrences.
- Reflective function: To help experts when they are representing and assessing the concepts of a given situation in order to validate its adequacy.
- Strategic function: An FCM can also help to generate a more accurate description of a situation and the concepts involved in it.

The main reasons why FCM approach was adopted and used in previous studies could be summarised as follows:

1) Results are easy to obtain and replicate.

2) Flexibility in representation, as an FCM allows representing unlimited concepts and their interactions.

3) Low time performing. When the concepts are established and their relationships defined, the mathematical calculations that are required can be obtained with no extra cost (van Vliet et al., 2010).

4) The process is comprehensible to non-experts in FCM theory (Rodriguez-Repiso et al., 2007).

In addition, individual FCMs from a particular field can be combined together (Dubois, Prade, & Yager, 2014; Bart Kosko, 1986), allowing different experts' viewpoints to be incorporated (Stach, Kurgan, & Pedrycz, 2010). Furthermore, FCMs are able to combine information from numerous sources to create a rich body of knowledge within a certain domain (Elpiniki Papageorgiou, Stylios, & Groumpos, 2007; E. I. Papageorgiou, 2011a; E. I. Papageorgiou, Papandrianos, Apostolopoulos, & Vassilakos, 2008). Finally, the vector-matrix structure presented in an FCM allows to model dynamic systems (Bertolini & Bevilacqua, 2010; Bart Kosko, 1986), which facilitate the capture of the dynamic aspect of system's behaviour (E. I. Papageorgiou, 2011b). For all aforementioned reasons, FCMs have gained considerable research interest in recent years, and they have been accepted as a suitable methodology in diverse scientific fields (E. I. Papageorgiou, 2011b).

2.8.5 Benefits and Limitation of traditional Fuzzy Cognitive Maps

One of the main benefits of applying FCMs is that they are not only a suitable technique for modelling causal relationships between variables (Kardaras & Karakostas, 1999; M. Khan et al., 2001) but also its fuzzy quality allows representing unclear degrees of causality relations between components (Lee & Han, 2000). FCMs are a powerful tool for modelling systems that cannot be explained entirely mathematically for two reasons (Stylios & Groumpos, 1999). First, the fuzzy degrees of causality can be expressed in both ways, quantitatively or qualitatively (B Kosko, 1994), and second, FCMs are not limited by model identification problems (Craiger & Coovert, 1994). In addition, due to their graph structure, FCMs also allow systematic propagation (Lee & Han, 2000). Furthermore, vector-matrix operations let an FCM model become a dynamic system (M. Khan et al., 2001; B Kosko, 1994), which allows the system to evolve with time.

The main limitation of a traditional FCM is that, although it allows transcribing an expert's opinion, it can equally encode the expert's lack of knowledge. Thus, some experts may be more credible due to their own experiences or position. Hence, it is possible to weight each expert with a different credibility weight (Kandasamy & Smarandache, 2003).

2.9 Conclusions from the Critical Review

2.9.1 **Limitation of the Traditional Safety Management Approach and the Need for a Resilience Engineering Approach**

As systems are evolving and developing into structures that are more complex, the traditional approach to safety management seems to present limitations to cope with these new and advanced systems. The above-mentioned conventional safety management approach is based on the application of risk assessment techniques, which can deal only with a single failure at a time. However, accidents are usually the outcome of complex processes, not the result of a single event. Therefore, numerous authors have extensively justified the need for a resilience approach to safety. For example, Brooker (2010) states that quantitative risk assessments are unable to deal with the actual level of complexity, and he proposes to look at the resilience of the system in addition to its safety. Besides, Andersen and Mostue (2012) explain the need for a resilience approach based on the complexity of the events when an accident occurs. Thus, Costella et al. (2009) also justify the need for a resilience engineering approach as it is challenging to adequately address complex, dynamic and unstable systems within current safety management approaches.

Evidently, safety can be enhanced to reduce the number of maritime accidents. However, it should be recognized that no system is totally safe. Currently, there is a new approach called resilience engineering, that was defined by E. Hollnagel (2006) as the "ability of a system or an organization to react and recover from disturbances at an early stage, with minimal effects on dynamic stability". Hence, approaching resilience engineering concepts in order to increase the success in a changing environment can prevent a further catastrophe as it was demonstrated for the Fukushima nuclear accident (Yoshizawa, Oba, & Kitamura, 2016).

However, the maturity level of the application of resilience engineering concepts in the maritime sector is still questionable, as there are only few records of attempts to implement resilience engineering concepts and precepts. One of the aforementioned first records was the SEAHORSE project, which developed a multi-level resilience assessment for the maritime domain, which was focused on the traditional resilience abilities (i.e. learning, monitoring, anticipating and responding). Thus, Badokhon (2018) also applied in his thesis the SEAHORSE resilience assessment tool for the first time into a shipping company.

Both of the previous attempts represent the first steps into the development of a resilience assessment framework for the maritime domain. However, there is a clear need to develop a more robust resilience framework for the maritime sector based on the Integrated Resilience Engineering (IRE) concept. Which can be utilised to better enhance safety levels.

2.9.2 Need for Adopting Fuzzy Cognitive Maps as a Modelling Approach

Within the maritime domain, shipping accidents are often characterized as complex processes in which usually there is no simple solution to prevent them, as it is not easy to model the accident development, analyse the data and identify key areas of improvement. In addition, often, the accident investigation processes lack quality in terms of human factor assessments. Hence there is limited data availability which leaves unclear parts in these accident investigations. Therefore an approach that can deal with this fuzziness and utilise expertise, like the FCM method, can be promising to be employed.

Thus, this research study is first related to modelling the various combinations of HFs, and the extent to which these factors influence accidents within the maritime sector, and FCMs allow modelling such causal fuzzy relationships between variables as indicated by the literature. In addition, this research study is particularly concerned with modelling the HFs and any influential relationship amongst these contributing factors that exist on maritime accidents, as perceived by the relevant stakeholders, whose views and opinions are considered important and consequential. Therefore, traditional statistical techniques, in which causal relationships are determined and based on strict quantitative measures, are not considered appropriate for this study. Thus, the maritime environment includes numerous stakeholder groups, each with a different perception of the accident phenomenon. In this aspect, FCMs have been considered an ideal mechanism for incorporating different stakeholder views and for combining their knowledge using different weights for their opinions according to their level of expertise.

Furthermore, the maritime environment pertaining to this study problem is a social and complex domain, which involves numerous human aspects, and would need to be modelled accordingly. Numerous studies have indicated that FCMs can model systems in domains which cannot be explained quantitatively, or which need to represent both qualitative and quantitative information and model both tangible and intangible issues. Therefore, in comparison to traditional quantitative modelling methods, FCMs can be considered appropriate for modelling the problem under investigation in this research study.

Finally, a dynamic model will make it possible to explore the resulting effect of a proposed change on the model, to examine different investment strategies, and/or to simply help to identify crucial factors which have higher importance on all the maritime accidents, so that resources can be directed accordingly. Therefore, as FCMs have been used successfully as dynamic models, it is again a strong argument for justifying the adoption of FCMs in this thesis.

2.10 Research Gaps

As illustrated in the previous chapter, it becomes evident that human errors have played a major role in past accidents by leading into an average of 80% of maritime accidents (Graziano et al., 2016; Rothblum, 2000; Turan et al., 2016). Although the IMO acknowledges the need to address the human element contribution into maritime accidents (J.U Schröder-Hinrichs et al., 2015), there is still a gap in the literature in terms of guidance in how to approach this multifaceted issue in a systemic way. Therefore, the first focus of this research study will be to develop a strategy that would allow identifying and quantifying the above-mentioned HF contribution into past maritime accidents, covering the gap that currently exists in the literature.

In addition, the current safety management approach in the maritime industry present certain limitations, which were discussed in the previous section, and there is a second gap in terms of developing a maritime approach that complies with the principles highlighted in the so-called Safety-II perspective. As maritime systems are complex, it is difficult to model and ensure safety levels are maintained by following traditional approaches. Therefore, there is a need for a resilience approach to deal with the current level of systems' complexity in order to guarantee maritime safety. The SEAHORSE project set the foundations for a resilience assessment framework. However, it was limited only to the four traditional resilience abilities. As it was previously discussed, there is a clear benefit in developing a more robust resilience framework for the maritime sector based on the Integrated Resilience Engineering (IRE) concept.

To enhance maritime safety, the mere identification and quantification of HF contribution into past maritime occurrences become only the first step, and a more robust resilience engineering strategy needs to be defined. Therefore, this research study will aim to fill two different gaps from the literature as follows:

- First, this research study will develop a strategy that allow identifying and quantifying the HF contribution into past maritime accidents (i.e. the MALFCMs method introduced in Chapter 7).
- Second, this research study will extend the SEAHORSE resilience assessment framework to capture additional resilience abilities, creating an enhanced resilience assessment framework. Then, the aforementioned enhanced framework will be utilised

to assess the resilience level in a shipping company, based on how the company performs on certain resilience abilities, which are linked to the common human causes of accidents identified with the strategy that has been developed in the first place. Thus, by assessing the resilience level, it will be possible to identify weaknesses in the organization, which must be addressed in order to enhance overall safety.

2.11 Chapter Summary

This chapter conducts a critical review of available literature, which was oriented to cover various areas of interest. In addition, the key findings from the critical literature review were highlighted, and the research gaps were identified.

Chapter 3 is outlining the research questions, aim and objectives of this research study.

3 RESEARCH QUESTION, AIM AND OBJECTIVES

3.1 Overview

For the successful development of this research study, it is crucial to identify the problems that will be solved within this research together with the objectives, which will be used as milestones to achieve the overall aim of this research. The motivations behind this work, together with the research questions that will be addressed, will be presented in Section 3.2. In addition, Section 3.3 outlines the overall aim and objectives this research.

3.2 Motivations behind this Work and Research Questions

As indicated in previous chapters, the literature review on HFs revealed that human errors are responsible for the majority of accidents not only in safety-critical sectors such as nuclear and aviation (Ali Azadeh & Zarrin, 2016; O'Hare et al., 1994) but also in the maritime sector (de Maya, Babaleye, & Kurt, 2019; B. Navas de Maya & Kurt, 2018; Turan et al., 2016). Nevertheless, the contribution of HFs into accidents is difficult to quantify as there is a lack of an adequate technique that allows measuring the importance of each contributing factor in accidents. Although maritime sector can be described to be reactive, which means mainly learning from experienced bad incidents, it is very easy to argue that aforementioned "learning" is limited to reacting individual events only. Hence we are still not able to effectively analyse and learn from bigger data, (i.e. from a database of accidents) in order to identify human factor related shortcomings. Thus, the maritime sector is more reactive and lacking ability to learn effectively from past incidents and which results in a reduced ability to anticipate unexpected conditions which may lead to accidents. Hence, implementing resilience engineering principles can enhance current safety levels and influence the way safety is managed at shipping companies. In this way, lessons learnt from past events can be integrated with safety management strategies in a proactive way to avoid future accidents, and abilities required in a resilient system can be developed, implemented and monitored to enhance operational safety.

Therefore, there is a need for a proactive approach that can:

- Identify and measure the common HF related causes in maritime accidents,
- Link identified common HF causes with resilience abilities that could help to prevent them,

- Assess the resilience level of a company by using an IRE framework, which is practical and systematic, and not limited to the traditional four resilience cornerstones but extended with additional abilities from the literature to represent different aspects of a system.
- Monitor the performance of a company amongst those resilience abilities with the aim to estimate the company's ability to anticipate and prevent accidents. In other words, predict the resilience level of a company, so the company can implement proactive measures to enhance safety and prevent accidents.

Such a comprehensive framework does not exist in the maritime sector. Hence, this research study will be focused on addressing two main research questions, which may be put together as:

1. *How could we understand the contribution of human element in maritime accidents in a systematic and effective way?*
2. *Is it possible to link common human factors causes in maritime accidents with resilienceabilities, aiming to proactively measure the resilience levels within a shipping company?*

3.3 Aim and Objectives

The development of resilient operational abilities in shipping companies has a huge potential to innovate and improve the way safety is managed in maritime operations. Therefore, the aim of this research study is to develop a theoretical understanding of how HFs can more cleverly be addressed and second, to link the above-mentioned HFs and resilience abilities, which will allow assessing the resilience level within a shipping company. Thus, by achieving the aforementioned aim, it is expected that the approach of traditional, compliance-driven safety management in shipping will be changed with a proactive and resilient style which will improve overall safety within the maritime domain.

The framework that will be developed within this research study is focused on fulfilling the aforementioned aim. Therefore, the final output of this research will be a framework that will allow assessing the resilience level within a shipping company, based on how the company performs on certain resilience abilities, which are linked to common human causes of accidents. By assessing the resilience level, it will be possible to identify weaknesses in the system and propose a set of measures to overcome these weaknesses and increase the overall safety level.

In order to achieve the aforementioned overall aim, this research study will adopt the following specific objectives:

- To critically review the literature relevant to the current maritime safety regime and resilience engineering theory in order to identify the shortcomings of the current research and available methods.
- To capture developed resilience models that could be applied to increase safety within the maritime sector.
- To identify, modify or develop a suitable method that can cleverly measure the HFs contribution to maritime accidents.
- To collect historical-accident data and to perform statistical analyses, aiming to identify the main data features (e.g. the number of accidents per ship type or vessel categories that are more prone to developing an accident).
- To perform additional analyses on the historical-accident data in order to define a set of specific HFs that are contributing to maritime accidents.
- To conduct activities to collect more information and complete gaps in HF accident data (e.g. organise workshops to capture expert judgment).
- To apply the above-mentioned method, which can cleverly measure the HFs contribution to maritime accidents.
- To identify a specific strategy that allows linking together resilience abilities and HFs.
- To utilise the SEAHORSE resilience assessment framework as the initial concept to develop a more robust framework to assess resilience level of a company.
- To conduct a case study in order to test the developed framework in a real shipping company.
- To identify limitations and future research opportunities.

3.4 Chapter Summary

This chapter has introduced the research questions along with the aim and objectives of this research study.

Chapter 4 will outline the approach adopted for this research.

4 APPROACH ADOPTED

4.1 Overview

This chapter presents the approach adopted in order to fulfil the aim and objectives of this research study (Chapter 3). The approach for this research could be summarised as follows: (1) Literature Review (Chapter 2). (2) Analysis of historical accident data to identify the main data features (Chapter 5). (3) Additional analysis of the historical accident data, aiming to define a set of specific human contributing factors into maritime accidents (Chapter 6). (4) Development of the Marine Accident Learning with Fuzzy Cognitive Maps (MALFCMs) method to overcome the limitation of traditional Fuzzy Cognitive Map (FCM) (Chapter 7). (5) Application of the MALFCMs method through two case studies. The first case study demonstrates the ability to utilize MALFCMs by only relying on historical accident data (Chapter 8). The second case study demonstrates the overall framework of the MALFCMs method through a complete case study (Chapter 9). (6) Development of a resilience assessment framework, which will allow measuring the resilience level in a shipping company, based on how the company performs on certain resilience abilities, which are linked to common human causes of accidents (Chapter 10). (7) Application of the resilience assessment framework to a real case study, assessing the resilience level in a shipping company and allowing the identification of potential areas for resilience improvement (Chapter 11).

4.2 Mind Map of Approach Adopted

After conducting a detailed review of the literature regarding the areas of safety management, resilience engineering, accident models, HFs and Fuzzy Cognitive Maps (FCMs), it is imperative to define a clear strategy for achieving the aim and objectives of this research study (Chapter 3). Hence, a simplified mind map of the approach adopted in this research is presented in Figure 4.1. It can be observed from the figure that the overall process comprised of several phases and/or steps that are briefly discussed in the following sections. Thus, each phase and/or step shown in the mind map is representing a different phase in this research study.

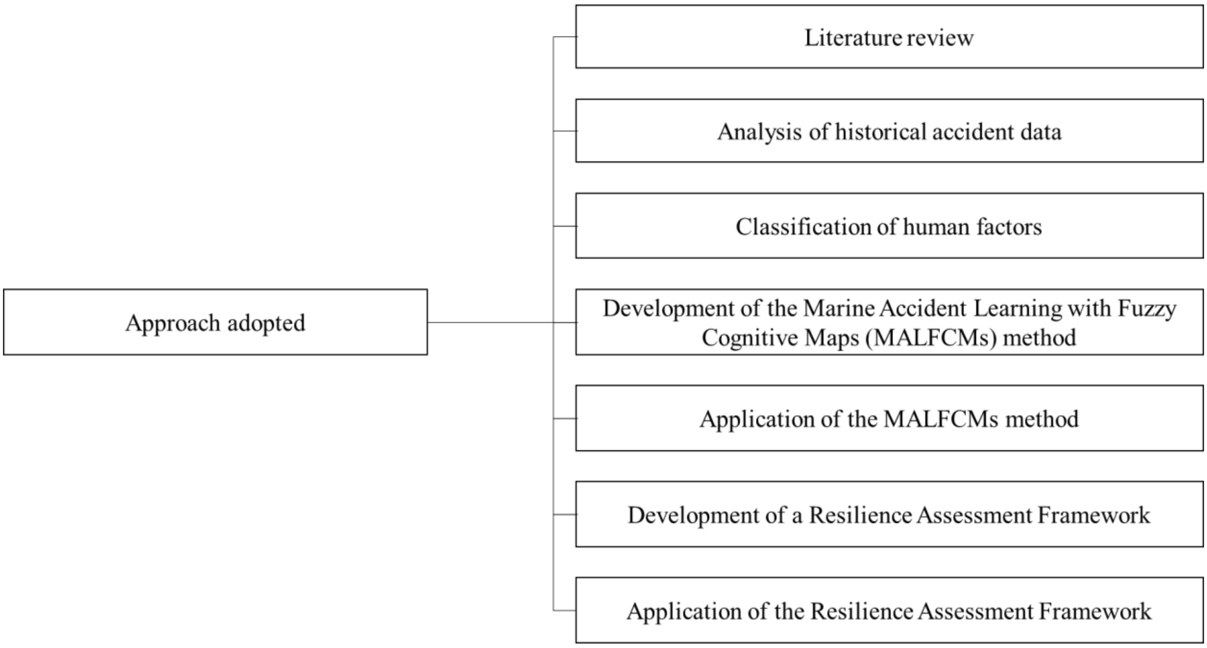


Figure 4.1. Mind map of the approach adopted

In addition, a more detailed and descriptive framework is displayed in Figure 4.2, which aims to provide a better understanding of how all the steps and outcomes of this research study are connected and inter-related. Thus, Figure 4.2 provides a detailed description of the contents of Chapter 6 (in green), Chapter 7 (in blue) and Chapter 10 (in orange).

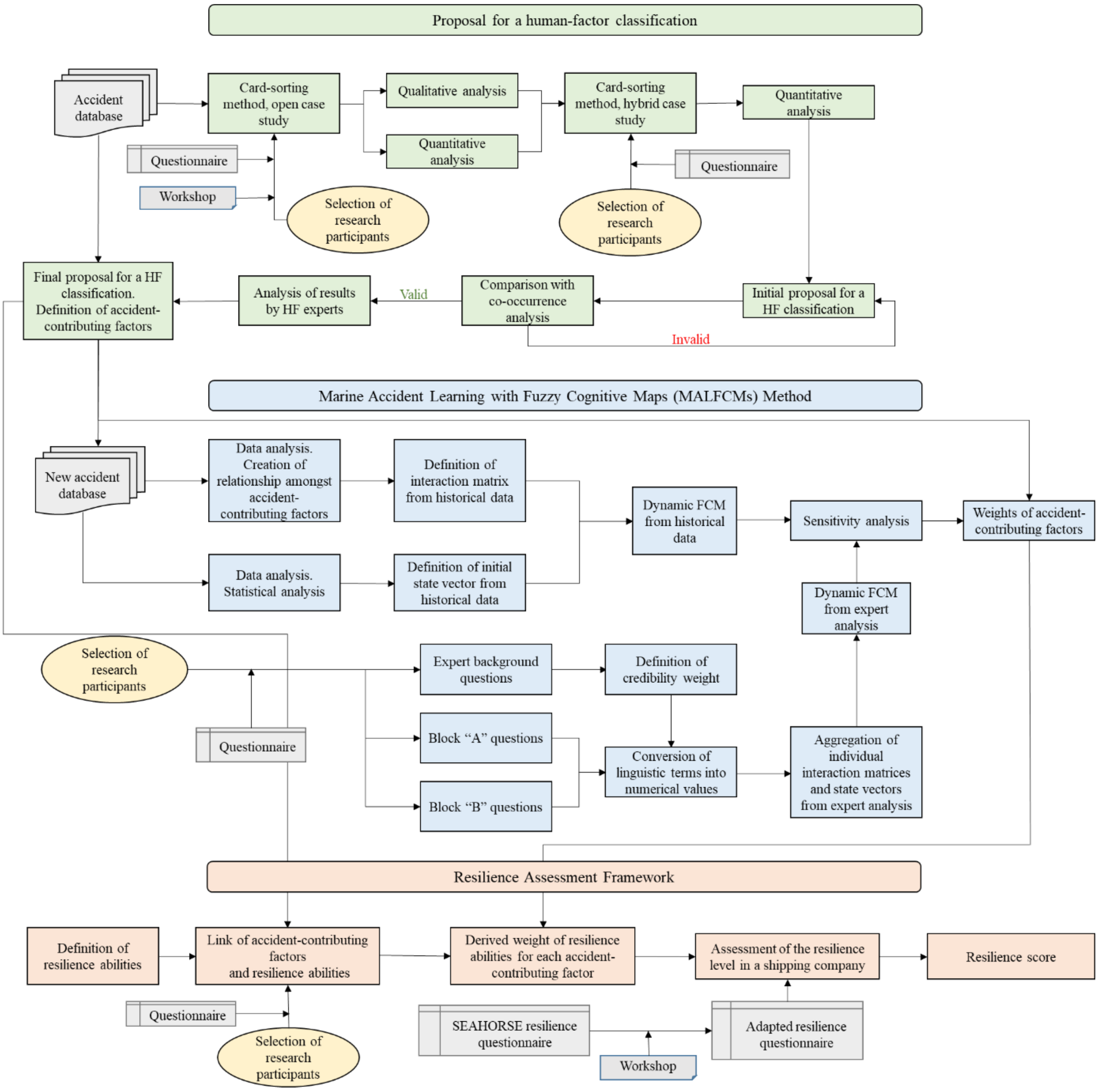


Figure 4.2. Framework in more detail

4.3 Literature Review

Before proceeding with the development of a method that allows measuring the human contribution into accidents, and the creation of a resilience engineering framework to assess the resilience level in a shipping company, it was important to conduct a detailed literature review.

A critical review was presenting in Chapter 2, starting with an overview of the status of safety in the maritime sector in Section 2.2. Thus, different paths to analyse safety were identified in Section 2.3, including methods for accident investigation, risk analysis, and Safety Management Systems (SMS). Moreover, the previous section was followed by a more specific review on Section 2.4, which was focused on how the maritime sector applies safety management, with special mention of the Formal Safety Assessment (FSA). Moreover, Section 2.5 provided a basic understanding of the resilience and resilience engineering concepts, which was followed by a more concise explanation regarding how to model resilience and resilience engineering. Moreover, the characteristics and cornerstones of resilience engineering were highlighted and explained, and the major resilience engineering factors were identified and defined. Furthermore, this section also included a description of how resilience engineering is assessed in various strategic sectors. For the specific context of the maritime sector, two main contributions were identified. First, the SEAHORSE project, which was the first attempt to introduce the principles of resilience engineering in an integrated framework to create a multi-level resilience assessment for the maritime domain (Turan et al., 2016). And second, the research conducted by Badokhon (2018), which was the first attempt to apply the outputs from the SEAHORSE project in a shipping company, aiming to minimise the errors of the bridge operator by addressing the traditional resilience abilities.

In addition, Section 2.6 included an overview of the accident phenomenon in the maritime sector, together with a review of the major accident causation models, which comprised simple linear models (Heinrich's Domino model, 1931), complex models (Reason's Swiss cheese model, 1990), and non-linear or systemic models. Moreover, two specific accident models based on resilience engineering precepts, i.e. the Systems-Theoretic Accident Model and Processes (STAMP) and the Functional Resonance Analysis Method (FRAM), were included and explained. Moreover, Section 2.7 provided a review of methods to evaluate the contribution of HFs into past accidents. Thus, a review of the Human Factors Analysis and Classification System (HFACS) method, the main Human Reliability Analysis (HRAs), and statistical analysis was carried out within this section.

Furthermore, in order to provide a basic understanding of the FCM method, Section 2.8 described the historical evolution of FCMs from traditional Cognitive Maps (CMs), as a new tool for modelling complex chain of casual relationships. Moreover, the mathematical representation within an FCM and the processes involved, which enable the FCM to be used as a dynamic model, were explained. Furthermore, an overview of numerous studies, which apply the FCM method in other fields, was provided, together with the main reasons for applying an FCM approach to the aforementioned previous studies. Finally, this section included the advantages and/or disadvantages associated with the FCM method. Finally, the literature review section concluded by explaining on Section 2.9 the key findings from the critical literature review, along with the identification of the research gaps on Section 2.10.

4.4 Analysis of Historical Accident Data by Means of Statistical Analysis and a Data-Driven Approach

After a detailed literature review was provided, the next logical step was to obtain historical accident data to conduct this research study. Hence, first, a comparison was provided on Section 5.2 amongst various accident databases (i.e. IMO, Casualty Analysis Methodology for Maritime Operations (CASMET) and Maritime Accident Investigation Branch (MAIB) databases), which aimed to select the most suitable historical accident database for the purposes of this research study. After conducting the aforementioned comparison, the MAIB database was selected first because it possesses a public right of access, as recognized by the Freedom of Information Act 2000 (c.36) of the Parliament of the United Kingdom. In addition, within the MAIB database, historical data is recorded at a national level, as it investigates marine accidents involving UK vessels worldwide and all vessels operating in UK territorial waters. By focusing on a national level, it is possible to identify specific accident contributing factors, and therefore, efforts may be focused on addressing those factors. Thus, according to the literature, the MAIB database is the more reliable and complete database in terms of HFs involved in past maritime accidents (Gil de Egea, Calvo Holgado, Garcia Suarez, & Camblor Magadan, 2003). Finally, the MAIB database applies the same accident nomenclature that the European Marine Casualty Information Platform (EMCIP). Therefore, it would be possible to replicate this research study within another European country and compare the results.

Once the aforementioned MAIB database was selected for pursuing this research study, a set of descriptive statistical analyses was performed on Section 5.3 to describe and analyse the contents of the MAIB database, also discussing the validity of the statistical analysis results that were obtained. Thus, the descriptive statistical analyses performed were concerned with the following areas: (1) Descriptive analysis related to vessel specifications, (2) Descriptive analysis related to the accident consequences, (3) Descriptive analysis related to the accident location, and (4) Descriptive analysis related to the environmental conditions.

In addition, the second set of statistical analyses was performed on Section 5.4, aiming to test the various null hypothesis. For example, the ship type and the accident outcome are related; the number of fatalities and injuries are related to the ship type and accident outcome; the accident location is related to the ship type and accident outcome; and the environmental conditions are related to the accident outcome.

In addition, a discussion on both sets of statistical analysis results was provided in Section 5.5. Finally, a data-driving approach was adopted and presented in Section 5.6 to determine the most influential HFs from past maritime accidents

4.5 Classification of Human Factors by Applying a Card-Sorting Method

After the MAIB accident database was selected, and its content was statistically described, the next step included observing the current HFs classification that is available within the aforementioned MAIB database. Thus, amongst the 129 accidents that MAIB has recorded that include HFs information; 94 different HFs were identified as directly responsible for maritime accidents, as indicates in Section 6.2. These factors were carefully analysed, and a decision was made in Section 6.3 to redefine and reduce the total number of HFs by grouping similar HFs together.

Therefore, potential alternatives were investigated in Section 6.4 to reduce the aforementioned number of HFs. These alternatives included factor analysis, the application of the k-means method, and expert judgment. Thus, the limitations of the above-mentioned alternatives were also highlighted, and finally, it was decided to apply a technique known as the card-sorting method, which was described in Section 6.5. The so-called card-sorting technique was selected as it is very intuitive and easy to understand and utilize. Then, the aforementioned card-sorting method was first applied to an open case study on Section 6.6, in which participants were asked to sort a set of cards (i.e. HFs cards) into different groups based on their own interpretation. Four sets of answers were collected from this open case study (Group1 to Group4), which was organized in two phases as follows:

The next step included the qualitative analysis (i.e. group normalisation and expert opinion) and the quantitative analysis (i.e. statistical analysis) of the results obtained from the above-explained open card-sorting case study, which were conducted on Section 6.7. In addition, this analysis allowed sorting 78 out of the initial 94 HFs from the original accident database. Furthermore, in order to complete the aforementioned classification and obtain results that are more reliable, a new hybrid card-sorting case study was created with the remaining unsorted HFs and displayed in Section 0. Thus, results from the aforementioned hybrid card-sorting case study were further analysed by means of statistical analysis and included in Section 6.9.

Moreover, an initial proposal for an HF classification was suggested in Section 6.10, which was amended and validated by performing a co-occurrence analysis in Section 6.11. In addition, in Section 6.12, experts in the area of HFs were asked to provide their insight into the proposed HF classification, after the findings from the co-occurrence analysis were incorporated. Finally, the last amendments were made by incorporating the experts' feedback, and a final proposal for an HF classification was defined and proposed in Section 6.13.

4.6 Development of the Marine Accident Learning with Fuzzy Cognitive Maps (MALFCMs) Method by Combining Historical Accidental Data and Expert Judgement

After a new classification of HFs was provided, the next step included developing the first output of this research study, the so-called MALFCMs method. The MALFCMs method was described in four major stages. Section 7.2 described the first stage of the MALFCMs development, which involved the construction of an individual interaction matrix and a state vector, which are the required components to create an FCM as discussed in Chapter 2. Thus, the above-mentioned interaction matrix and state vector was based on the data gathered from a historical accident database. Section 7.3 discussed the second stage of the MALFCMs approach, which was concerned with the construction of an individual interaction matrix and a state vector for each expert, and their posterior aggregation. Thus, this section also included the data collection and analysis procedures, the description of the experts that participated in this research study, and the criteria that were adopted to determine the credibility weightings of each expert. Section 7.4 explained the third stage of the MALFCMs method, which involved the construction of two dynamic FCMs. The first dynamic FCM was created from the interaction matrix and state vector obtained from the historical accident database. Thus, the second dynamic FCM was obtained from the aggregated individual interaction matrix and state vector. Finally, Section 7.5 included the consolidation of the results by combining the findings from both FCMs, which was achieved through a sensitivity analysis of the weightings that were obtained from both FCMs.

4.7 Application of the Marine Accident Learning with Fuzzy Cognitive Maps (MALFCMs) Method on Case Studies

After providing a full description of the MALFCMs method, the next step included first, a partial application of the MALFCMs approach to a real case study, aiming to demonstrate that the MALFCMs method can be utilized by purely relying on historical accident data. And second, a full demonstration of the overall MALFCMs framework, which was achieved by applying the MALFCMs approach to a real case study.

Therefore, Chapter 8 aimed to demonstrate how it is possible to apply the MALFCMs method by only relying on historical data. First, Section 8.2 provided the case study specifications. Second, Section 8.3 calculated and ranked the contributing factors from collision accidents in bulk carriers. Similarly, Section 8.4 obtained and ranked the contributing factors from grounding accidents and Section 8.5 established and ranked the contributing factors from contact accidents for the same vessel category. Third, Section 8.6 calculated and ranked the contributing factors from fire and explosion accidents in bulk carriers, aiming to demonstrate the differences that exist amongst navigational accidents (i.e. collision, grounding, and contact) and fire and explosion accidents. Finally, Section 8.7 discussed the validity of the results obtained in the previous sections by comparing the results from this case study with the findings from similar studies in the literature.

On the other hand, Chapter 9 aimed to demonstrate the overall MALFCMs framework by combining historical data and expert opinion. First, Section 9.2 included the case study specifications. Second, Section 9.3 applied the first stage of the MALFCMs method to the selected case study. Third, Section 9.4 applied the second stage of the MALFCMs method. In addition, Section 9.5 performed two dynamic FCMs. The first FCM included the data pertinent to the historical accident database while the second FCM incorporated the findings obtained from a questionnaire, which was filled by a group of experts in the areas of HFs, ship operations and accident investigations. Thus, Section 9.6 combined the findings from the previous section by means of a sensitivity analysis. Finally, Section 9.7 discussed the results obtained in the previous sections, aiming to validate and explain the consistency of the results from this case study.

4.8 Development of a Resilience Assessment Framework by Linking Human Factors and Resilience Abilities

After applying the MALFCMs method to two case studies, the next step included developing the second output of this research study, the resilience assessment framework, which was proposed with the aim to assess the resilience level in a shipping company, based on how a company performs on certain resilience abilities, which are linked to common human causes of accidents. To success in this task, the resilience assessment framework that was developed through the SEAHORSE project will be combined with additional resilience abilities in order to create a more robust resilience assessment framework, which will be based on the IRE concept.

First, Section 10.2 provided the context and the objective for developing a resilience assessment framework, which consists of six major phases. In addition, Section □ described the first phase of the above-mentioned resilience assessment framework, in which the aforementioned MALFCMs method is applied to identify and quantify the importance of those accident contributors that could adversely affect the performance and safety in a shipping company. Thus, the output of this phase was a weighted list of HF threats.

Section 10.4 explained the second phase, which includes the identification of major resilience abilities. Section 10.5 analysed the third phase of the resilience assessment framework, which aimed to establish a link between HF threats and resilience abilities. In addition, this section included the criteria for the selection of participants, the design of a questionnaire for data collection, and the criteria and the criteria to analys and aggregate the data collected.

Section 10.6 described the fourth phase, which is related to the procedure of establishing weightings for all resilience abilities. First, an initial analysis was carried out to determine the most influential resilience abilities for each HF threat. Second, as each expert has a different credibility weight, a more detailed analysis was performed to aggregate the expert data collected. Third, after the most influential resilience abilities for each HF threat were identified, the next step included to derive the weighing for each resilience ability associated with each HF threat. Finally, the final weight for each resilience ability was obtained by totalling all partial resilience values from each HF threat for that specific ability.

Moreover, Section 10.7 analysed the fifth phase, which included the development and distribution of a Resilience Assessment Questionnaire (RAQ). Finally, Section 10.8 explained the sixth phase, which comprised the analysis of the RAQ results, the establishment of a resilience score, and recommendation for resilience improvement.

4.9 Application of the Resilience Assessment Framework on a Shipping Company

After providing a full description of the resilience assessment framework, the final step included applying the overall resilience assessment framework to a real case study by assessing the resilience level in a shipping company. First, Section 11.2 provided the customization and quantification of the HFs threats by performing a full MALFCMs case study (i.e. phase-I). Section 11.3 identified and listed the resilience abilities that were considered for this case study (i.e. phase-II). In addition, Section 11.4 created a link between HF threats and resilience abilities (i.e. phase-III). Section 11.5 obtained the weightings for each resilience ability that was included in this case study (i.e. phase-IV). Moreover, Section 11.6 provided the objectives, the criteria, and the distribution of the RAQ (i.e. phase-V). Finally, Section 11.7 included an exhaustive analysis of the RAQ results, the resilience score, and a set of recommendations for resilience improvement in the shipping company under study (i.e. phase-VI).

4.10 Chapter Summary

This chapter presented the approach that was adopted for this research study.

Chapter 5 will perform a set of statistical analysis in a historical accident database, aiming to identify the main data features.

5 ANALYSIS OF A HISTORICAL ACCIDENT DATABASE

5.1 Overview

Transportation of goods and people existed for over a hundred countries. This sector is not likely to disappear, in fact due to increased need the worldwide maritime fleet is under expansion continuously (Eyring et al., 2010; Parola & Veenstra, 2008). Aforementioned large global merchant fleet and associated operations is serving to match the needs of today´s increased global trade for sure but also, by nature includes extensive list of risks which may lead to maritime accidents (Kececi & Arslan, 2017). Hence, in order to reduce the operational risks, and therefore, improve maritime safety, one of the most common approaches is "learning from accidents" through investigating accidents by experts, and by extension, the communication of the accident outcomes to the authorities, which is established in the major legislations. For instance, the United Nations Convention on the Law of the Sea (UNCLOS) defines in article 94, paragraph 7, the mission of a flag state when addressing accidents. Moreover, other legislation also encourage this procedure, i.e. Safety of Life at Sea (SOLAS) on regulation I/21 and regulation XI-1/6, the International Convention for the Prevention of Pollution from Ships (MARPOL) on articles 8 and 12, the Load Lines Convention on article 23, the International Labour Organization's (ILO) Convention No. 134 on articles 2 and 3, the ILO Convention No. 152 on articles 36 and 39, or the Standards of Training, Certification, and Watchkeeping (STCW) regulation I/4 (Kececi & Arslan, 2017). However, despite the available legislation, there is still a lack of consensus between the numerous organizations in charge of collecting accidental data, as each organization possesses and applies a specific nomenclature to identify accident contributing factors, especially HFs. Moreover, HF related knowledge and expertise is not enough amongst accident investigators which significantly affects the quality of collected information.

The main aim of this chapter is to analyse and demonstrate the dataset which is used in this PhD research. This chapter first examines various accident data-sets in Section 5.2, aiming to identify the most suitable historical accident database for the purpose of this research study. Second, Section 5.3 performs a set of descriptive statistical analysis to describe and analyse the content of the accident database that is selected. Third, Section 5.4 includes a second set of statistical analyses, which aim to investigate the relationship between various variables from the database (e.g. the ship type and the accident outcome). Moreover, a discussion on the statistical analysis results is provided in Section 6.5. Finally, a data driven approach is presented in Section 5.6[1] to determine the most influential HFs from past maritime accidents.

5.2 Selection of the Most Suitable Historical Accident Database for this Research Study

In order to analyse an accident successfully, it is mandatory to ensure that the information regarding the sequence of events, and the HFs involved in the accident outcome are available. One of the most complete and comprehensive databases is the Accident/Incident Data Reporting (ADREP) system, which is maintained by the International Civil Aviation Organization (ICAO) and applied in the aviation sector. In addition, also the nuclear and chemical sectors have improved considerably when addressing HFs. Unfortunately, historical accident databases for the maritime domain are not the most developed when addressing HFs involved in past maritime accidents. Despite the fact that there is lack of quality regarding HF information stored in maritime accident databases, it is still important to study and understand the causes of past accidents, identify the common HF concerns and potential ways for improvement.

Numerous historical accident databases are available within the maritime sector. For instance, the International Maritime Organization (IMO) accident database is one of the closest databases to be considered a standard classification system at an international level. However, within the IMO taxonomy, it is not possible to indicate in a clear way which underlying factor led to the accident, for example, if it was caused by a deviation from the standard procedures or by a communication problem. Moreover, IMO taxonomy only allows to log an accident as a crew member. This means that accidents that have been caused from non-crew members (e.g. contractors, stevedores, etc.) cannot be registered into current IMO taxonomy.

In addition, there are accident databases, which record information at a national level. One example of an accident database operating at a national level is the Maritime Accident Investigation Branch (MAIB) database. Thus, the MAIB database registers marine accidents involving UK vessels worldwide and all vessels operating in UK territorial waters. Within the MAIB database structure, it is only possible to appoint one underlying HF as responsible for the accidents. Hence, if during the accident investigation more factors are found as contributing

[1] The data driven approach to identify the most important human factors from past maritime accidents was performed in collaboration with machine learning experts. This section has been already converted to a journal paper and published in Ocean Engineering (Coraddu, Oneto, Navas de Maya, & Kurt, 2020).

directly to the accident, it is necessary to introduce a new entry in the database for each additional HF. For example, if there were six factors involved in an accident, the database will contain six entries for the same ID event, duplicating the data and increasing the complexity of the process when running accident comparisons and statistical analysis of the data is not filtered correctly.

Finally, there are additional accident databases, which were developed collaboratively through involving multinational experts. An example of the above-mentioned databases is the Casualty Analysis Methodology for Maritime Operations (CASMET) accident database, which was developed under a European Project. Although the CASMET (Caridis, 1999) database supplies an extensive amount of information, it is required to define all the factors contributing to the accident event, otherwise, each accident investigator could understand each factor from a different perspective. Moreover, within the CASMET database, the identification of accident contributing factors is personal, hence, subject to the perceptions of each investigator, which results in additional problems when analysing the data. Thus, the CASMET database has not been fully applied operationally.

Although it is acknowledged that there are numerous accident databases available, and it would make difference if more databases are obtained and consolidated and analysed all together to draw more accurate conclusions. However such data is generally not accessible by researchers especially if there is no policy forcing administrations to share the data with public. As the aim of this PhD study is not to come up with a new accident taxonomy but to develop a better framework for managing human factors through learning from past accidents, such comparative study was not performed. Hence, the MAIB database is selected to perform this research study due to the following reasons:

- The Freedom of Information Act 2000 (c.36) of the Parliament of the United Kingdom creates a public “right of access” to information held by public authorities. Therefore, the MAIB accident database was accessible for this research study.
- MAIB records historical accident data at a national level, as it investigates marine accidents involving UK vessels worldwide and all vessels operating in UK territorial waters. Considering the fact that there is not a uniform approach established for accident investigation worldwide, choosing an international database may brought additional uncertainty in terms of the types of human factors observed. For example, some countries may completely fail to collect human factor information from the

accidents and this may create the illusion that HF did not play a role in those accidents. Though focussing on one accident database which followed a homogenous approach when investigating accidents may help removing the uncertainties involved. As a result, MAIB accident database was identified as the best option that focuses on one country while containing enough data to facilitate conducting the research intended in this study.

- According to the literature, the MAIB database is not only more reliable when compared with other accident databases, but it is also one of the most complete databases concerning HFs involved in maritime accidents (Gil de Egea et al., 2003).
- MAIB has recently changed its internal nomenclature in order to comply with the European Marine Casualty Information Platform (EMCIP) nomenclature. Therefore, it will be possible to replicate the results of this research study within those countries that share the same accident database nomenclature.

5.3 Descriptive Statistical analysis on MAIB database for the period 1992-2016

This section performs systematic statistical analysis of ship accidents in recent years for the majority of vessel categories. Thus, the ultimate goal of this section is to identify those vessel categories that are more prone to maritime accidents, possible historical trends, and geographical areas, where accidents are more likely to occur.

Therefore, this section starts by conducting an initial screening of the accidental information. Second, a set of descriptive analysis is performed in order to have an overview of the main accident data. Numerous past studies have emphasized the importance of accident statistics in risk quantification as a statistical analysis of past experiences may demonstrate the trends for certain accidents. The descriptive analysis that is presented in this section may be classified as follows: 1) Initial descriptive analysis related to vessel specifications, which comprises an overview of the total number of accidents per ship type, accident outcome, and vessel age. 2) Descriptive analysis related to accident consequences, in which the number of injuries and fatalities are presented for each ship type and accident outcome. 3) Descriptive analysis related to the accident location. 4) Descriptive analysis related to the environmental conditions, in which the number of accidents is determined for various sea state, visibility and wind force conditions.

5.3.1 **Initial Screening of the Accidental Information of Interest**

The data that is considered for this study is obtained from the Marine Accident Investigation Branch (MAIB) accident database. The aforementioned accident records were extracted according to the definitions comprising the generic vessel categories as defined by the European Marine Casualty Information Platform (EMCIP) (EMSA, 2014). Hence, the following vessel categories, as specified in above-mentioned EMCIP taxonomy, were included in the analysis carried out in this study:

- Fishing vessels: Vessels equipped or used commercially for catching fish or other living resources of the sea.
- Cargo ships: Ships designed for the carriage of various types of cargo, goods or products and up to a maximum of twelve passengers, for commercial gain.
- Passenger ships: Ships designed to transport more than twelve passengers.
- Service ships: Ships designed to transport more than twelve passengers.
- Recreational crafts: Boats of any type, regardless of the means of propulsion, intended for sports or leisure purposes.
- Inland waterway vessels: Vessels intended solely or mainly for navigation on inland waterways.
- Navy ships: Ships operating under a navy or other military organization.

The initial sampling plan (N=38028) was filtered to remove accident records in which information was out of the scope of this study. In addition, specific inclusion criteria for this study are displayed in Table 5.1.

Table 5.1. Criteria for initial inclusion in the analysis

Criterion	**Value**
Period	1992-2016
Ship type	Fishing vessels, Cargo ships, Passenger ships, Service ships, Recreational crafts, Inland waterway vessels, and Navy vessels
Accident outcome	Collision, Grounding/stranding, Contact, Fire/explosion, Flooding/foundering, Capsizing/listing, Hull failure, Loss of control
Vessel age	This study includes from new vessels to vessels ≥ 20 years
Fatalities	Number of fatalities (crew, passenger, other and total)
Injuries	Number of injuries (crew, passenger, other and total)
Accidents included	Marine accidents involving UK vessels worldwide and all vessels operating in UK territorial waters
Accident location	Internal waters, Inland waters, Open sea
More detailed accident location	Port area, River, Channel, Within EEZ, Outside EEZ, Lake
Weather conditions included	Accidents distributing by sea state, visibility, and wind force

Cases that are excluded from this study are the result of the application of four specific constraints to the database. First, incidents that were not defined in the accident database as accidental events (i.e. non-accidental events). Second, cases in which the accident only resulted in damage to the ship and/or equipment. Third, accidents that did not occur during ship operation (i.e. accidents in the shipyard). Fourth, cases where no data were available (i.e. missing data). After the aforementioned screening process was performed, the accident database under the scope of this study contained N=2533 samples, as shown in Table 5.2.

Table 5.2. Number of accidents by ship type considered in this study after each constraint

Ship type	Initial Number	Remained accidents after each constraint					Retained	
		1st	2nd	3rd	4th	Total excluded	No	%
Fishing vessels	12164	12162	12074	12074	359	11805	359	2.95%
Cargo ships	7273	7272	7112	7111	1030	6243	1030	14.16%
Passenger ships	9398	9397	9258	9255	522	8876	522	5.55%
Service ships	5124	5122	5003	5003	405	4719	405	7.90%
Recreational crafts	3025	3024	2977	2977	117	2908	117	3.87%
Inland waterway vessels	944	944	931	931	94	850	94	9.96%
Navy ships	100	100	100	100	6	94	6	6.00%
Total	**38028**	**38021**	**37455**	**37451**	**2533**	**35495**	**2533**	

The difference that exists between the total number of entries within the database (i.e. 38028) and the accidents analysed within this chapter (i.e. 2533) is due to two main reasons. First, the well-known problem of under-reporting, which currently exists in maritime accident investigation. Therefore, as a result of the aforementioned under-reporting, there is a lack of collected information affecting many entries in the database (i.e. empty entries). Second, due to the current MAIB database structure, it is only possible to appoint one underlying factor as responsible for each accident. Hence, if more factors are found responsible during the accident investigation (e.g. environmental factors or HFs), it is necessary to introduce a new entry in the database for each factor involved as discussed in the previous section. Thus, the structure of the MAIB database duplicates the data and increases the complexity of the process when performing statistical analysis when the data is not filtered correctly. Therefore, the original database had to be filtered to cope with the aforementioned MAIB structure concerns.

It addition, it can be noted from Table 5.2 that cargo vessels are the ship type with the highest number of accidents retained for this study (14.16%), along with inland waterway vessels (9.96%) and service ships (7.90%). Moreover, Figure 5.1 provides a snapshot of the geographical accident location that comprises the MAIB database.

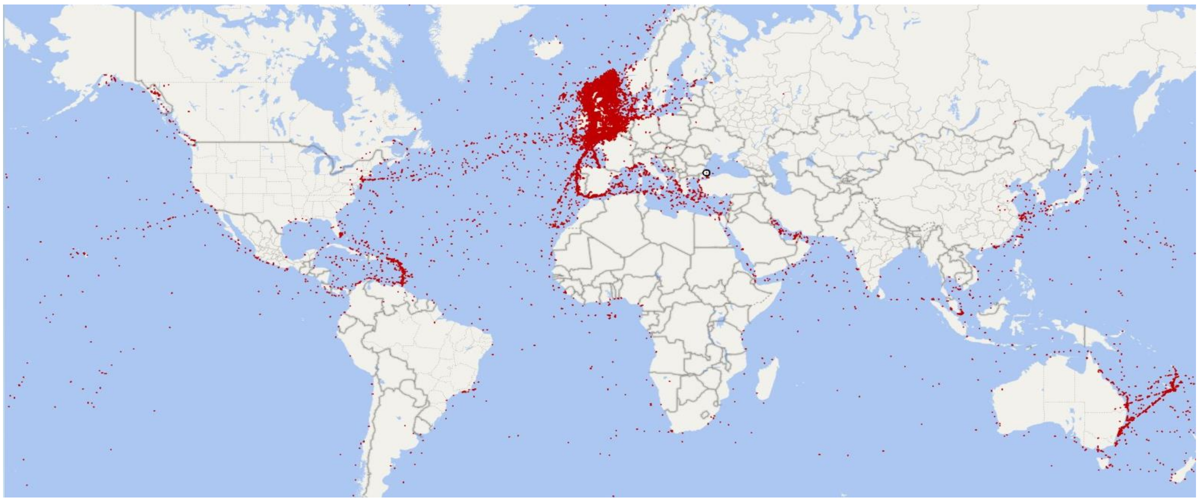


Figure 5.1. Geographical accident location. Period 1992-2016

5.3.2 Descriptive Analysis Related to Vessel Specifications

The following is an initial statistical description of the accident sample. As it was mentioned above, the MAIB accident database includes accident information regarding seven ship types as follows: (1) Fishing vessels, (2) Cargo ships, (3) Passenger ships, (4) Service ships, (5) Recreational crafts, (6) Inland waterway vessels, and (7) Navy vessels. The distribution of accidents per vessel category is provided in Figure 5.2. It indicates that over 90% of the accidents involved cargo ships (40.66%), passenger ships (20.61%), service ships (15.99%) and fishing vessels (14.17%).

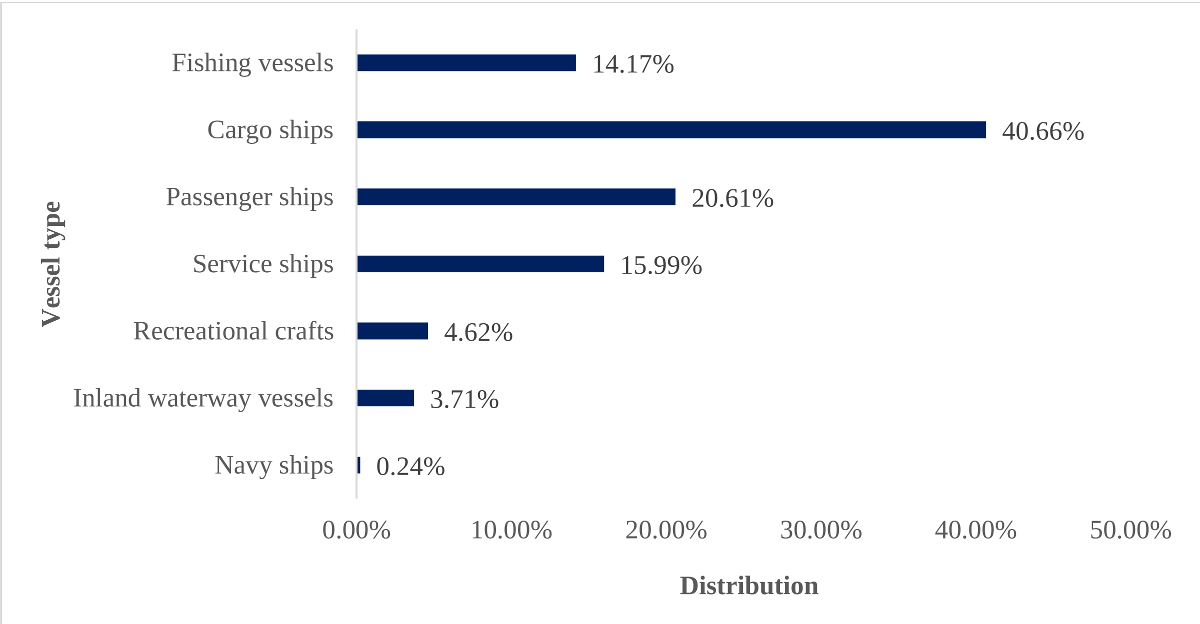


Figure 5.2. Number of accidents per vessel type for the period 1992-2016 (N=2533)

Regarding the accident type, Figure 5.3 shows that navigational accidents (i.e. collision, contact and grounding/stranding) and loss of control account for more than 85% of the total accidents.

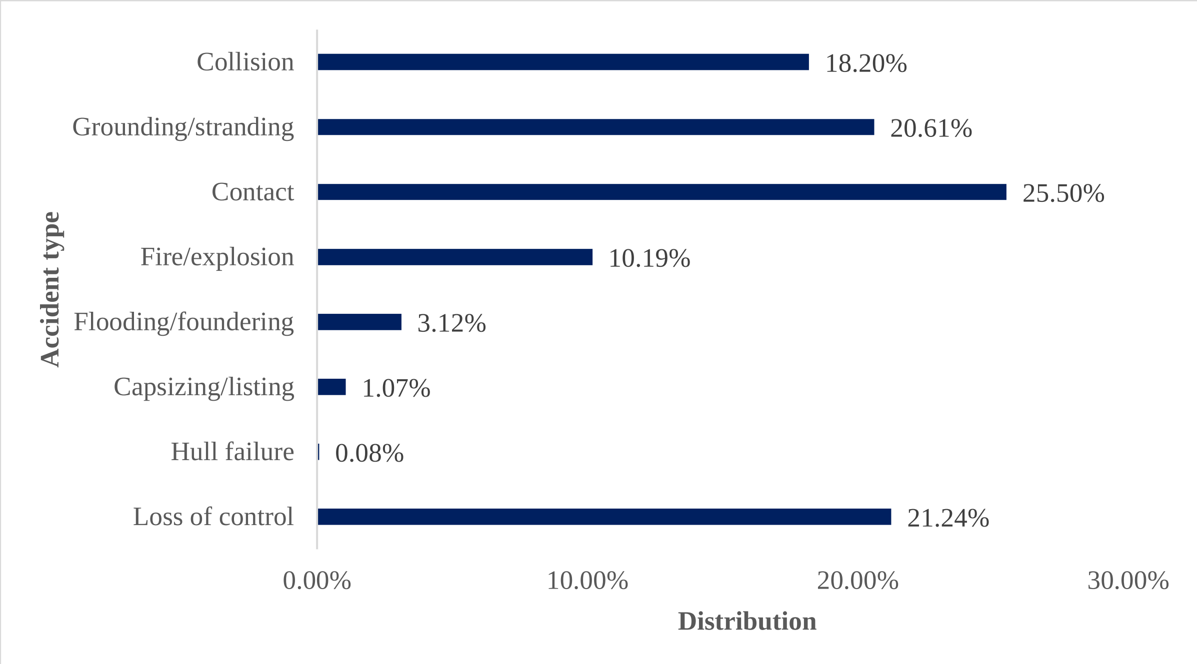


Figure 5.3. Number of accidents per accident type for the period 1992-2016 (N=2533)

In order to compare if older ships are more likely to have an accident, Figure 5.4 provides the relation between the total number of accidents and the vessel age. It is possible to observe that there is a steady accident distribution for vessels under 20 years. However, for vessels above 20 years, the number of accidents almost triplicates the previous periods.

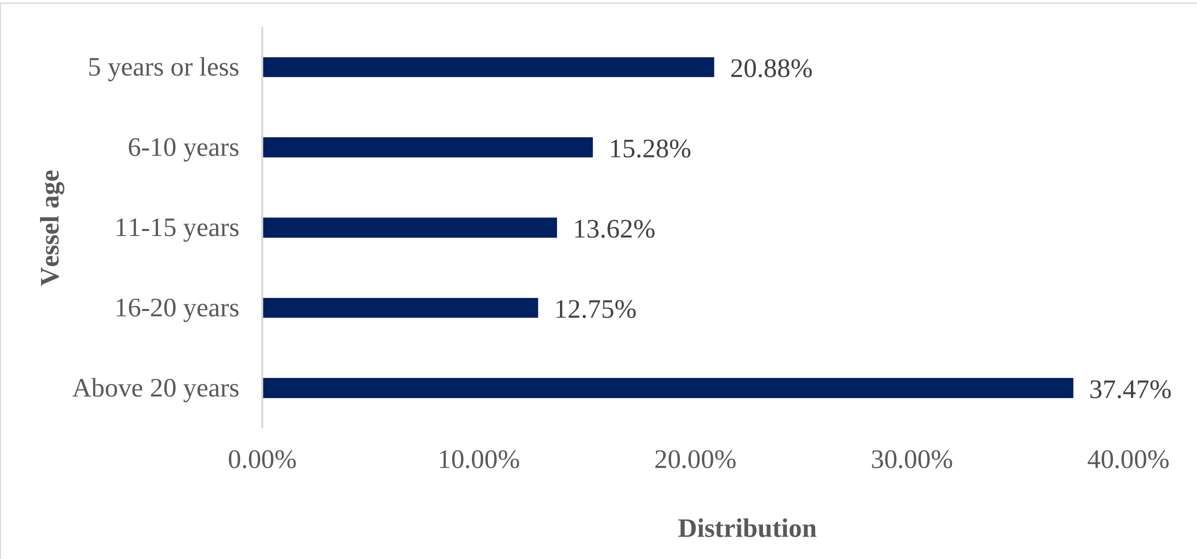


Figure 5.4. Number of accidents per vessel age for the period 1992-2016 (N=2533)

5.3.3 **Descriptive Analysis Related to Accident Consequences**

The following is a statistical description of the number of injuries and fatalities per ship type and accident outcome. Thus, Table 5.3 displays the total number of injuries and fatalities per ship type, which are distributed amongst crew members (C), passengers (P) and others (O). Regarding the number of injuries, it is observable that the majority of injured crew members were allocated to passenger ships (26.50%) and service ships (21.68%). This is a consequence of the exposure of crew members on this particular vessels. In addition, it was noticeable that passengers were mostly injured in passenger ships (59.70% of total injured passengers). Passenger ships are in general safer when compared to other ship types (e.g. fishing vessels). However, due to the high number of passengers that are carried on passenger ships on a daily basis (who are generally not familiar with the vessel), it is plausible to assume that there will be more injuries in this vessel category. In addition, with respect to the number of fatalities, cargo ships and recreational crafts presented the higher distribution in terms of crew members (40.00% and 28.00% respectively). Furthermore, the totality of passenger fatalities corresponded to recreational crafts, for all the period analysed.

To provide further insight into the dissemination of the total number of fatalities, Table 5.4 provides a more detailed explanation of the fatalities distribution per accident outcome for each vessel category. It is noticeable that the majority of fatalities occurred first, in capsizing/listing of recreational crafts, and second, in hull failure in cargo ships (25.00% and 18.75% of total losses respectively).

Table 5.3. Number of injuries and fatalities per vessel for the period 1992-2016 (N=2533)

Ship Type	**Injuries**					**Fatalities**				
	C	**P**	**O**	**Total**	**%**	**C**	**P**	**O**	**Total**	**%**
Inland waterway vessels	4	14	0	18	11.84%	0	0	0	0	0.00%
Recreational crafts	14	13	0	27	17.76%	7	4	1	12	37.50%
Service ships	18	0	0	18	11.84%	1	0	0	1	3.13%
Passenger ships	22	40	2	64	42.11%	1	0	0	1	3.13%
Cargo ships	13	0	0	13	8.55%	10	0	2	12	37.50%
Fishing vessels	12	0	0	12	7.89%	6	0	0	6	18.75%
Total	**83**	**67**	**2**	**152**	**100.00%**	**25**	**4**	**3**	**32**	**100.00%**

Table 5.4. Number of fatalities per ship type and accident outcome for the period 1992-2016 (N=2533)

Ship Type	Accident Outcome	Total	%
Recreational crafts	Capsizing/listing	8	25.00%
	Fire/explosion	1	3.13%
	Flooding/foundering	1	3.13%
	Grounding/stranding	2	6.25%
Service ships	Collision	1	3.13%
Passenger ships	Fire/explosion	1	3.13%
Cargo ships	Capsizing/listing	2	6.25%
	Fire/explosion	3	9.38%
	Hull failure	6	18.75%
	Loss of control	1	3.13%
Fishing vessels	Flooding/foundering	3	9.38%
	Fire/explosion	3	9.38%
Total		**32**	**100.00%**

5.3.4 **Analysis Related to the Accident Location**

The following is a statistical description of the total number of accidents per accident location. Figure 5.5 indicates that over 80% of the accidents occurred in internal waters (81.01%) and inland waters (13.38%).

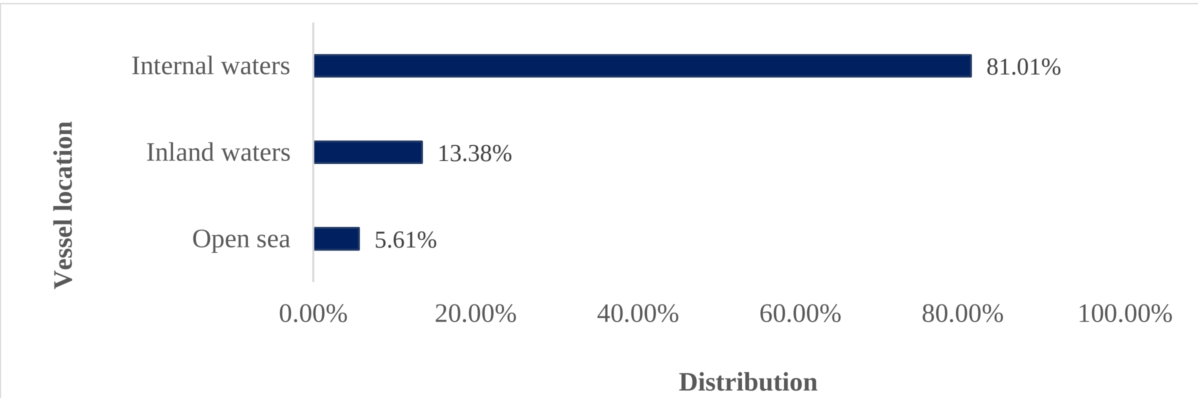


Figure 5.5. Number of accidents per vessel location for the period 1992-2016 (N=2533)

In addition, Figure 5.6 provides the total number of accidents per more descriptive accident location. Thus, all accidents allocated to internal waters took place in the port area, while the majority of accidents in inland waters occurred on rivers (11.76%).

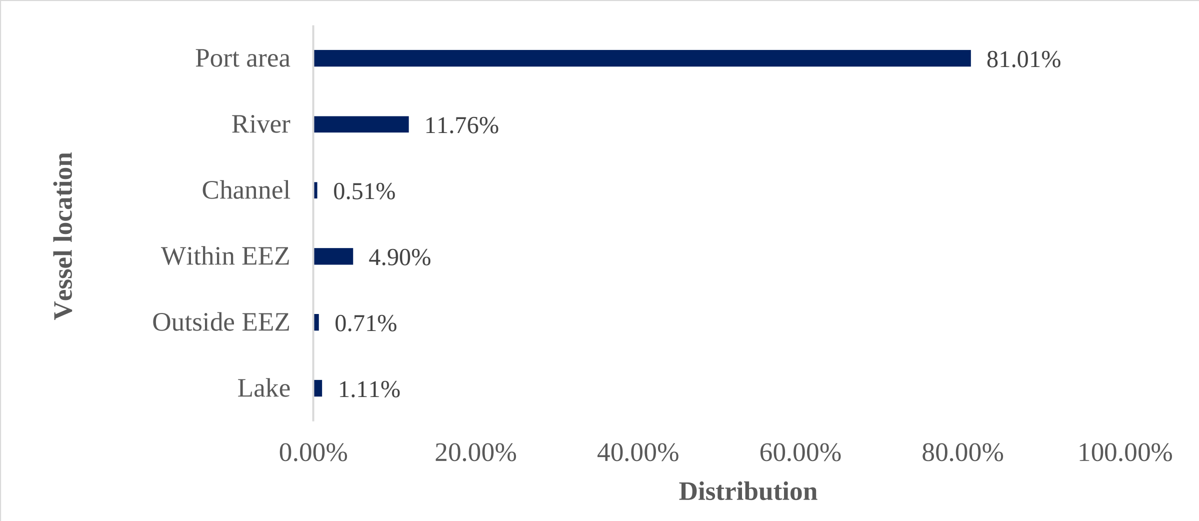


Figure 5.6. Number of accidents per more detailed vessel location for the period 1992-2016 (N=2533)

5.3.5 Analysis Related to the Environmental Conditions

The following is a statistical description of the distribution of the total number of accidents per sea state, visibility and wind force. First, Figure 5.7 displays the accident distribution per sea state. It is possible to observe that the majority of accidents occurred between a smooth and moderate sea state (81.92%).

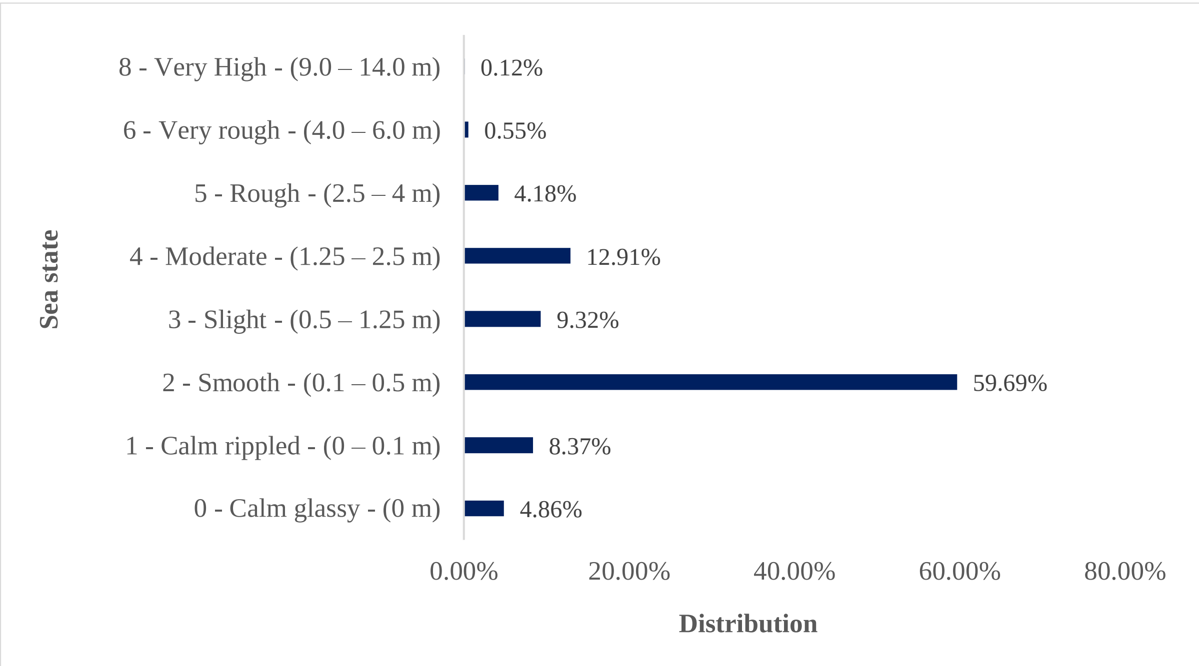


Figure 5.7. Number of accidents per sea state for the period 1992-2016 (N=2533)

Second, Figure 5.8 provides the accident distribution per visibility, from where it is noticeable that a high distribution of the accident occurred with good visibility conditions (81.33%).

Finally, Figure 5.9 indicates the accident distribution per wind force, showing that the majority of the accidents (85.83%) took place during moderate conditions (below Force 6 in Beaufort scale), while almost half of the accidents (48.21%) occurred with relatively calm conditions (below Force 3 in Beaufort scale).

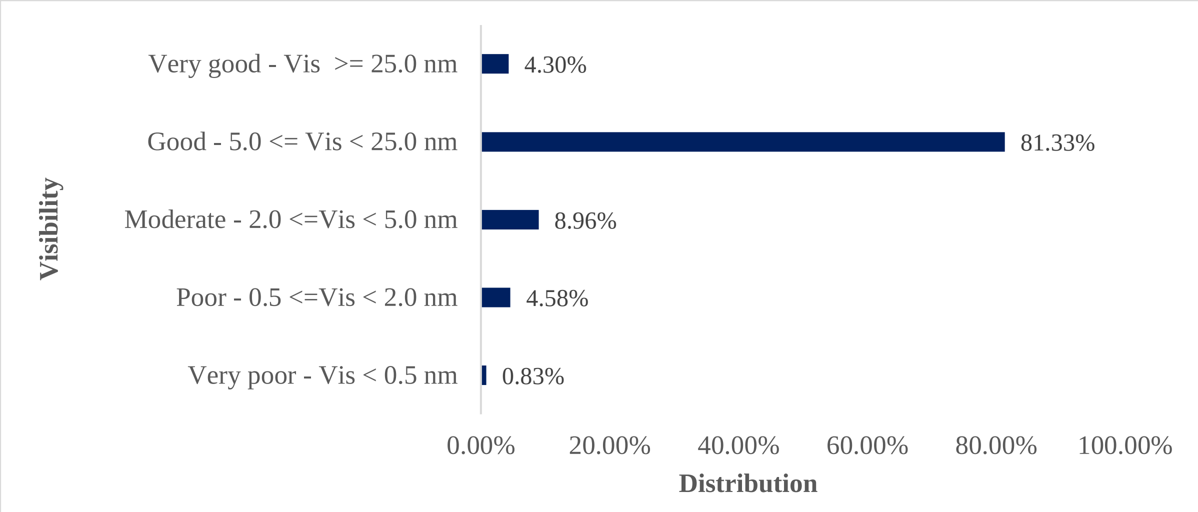


Figure 5.8. Number of accidents per visibility for the period 1992-2016 (N=2533)

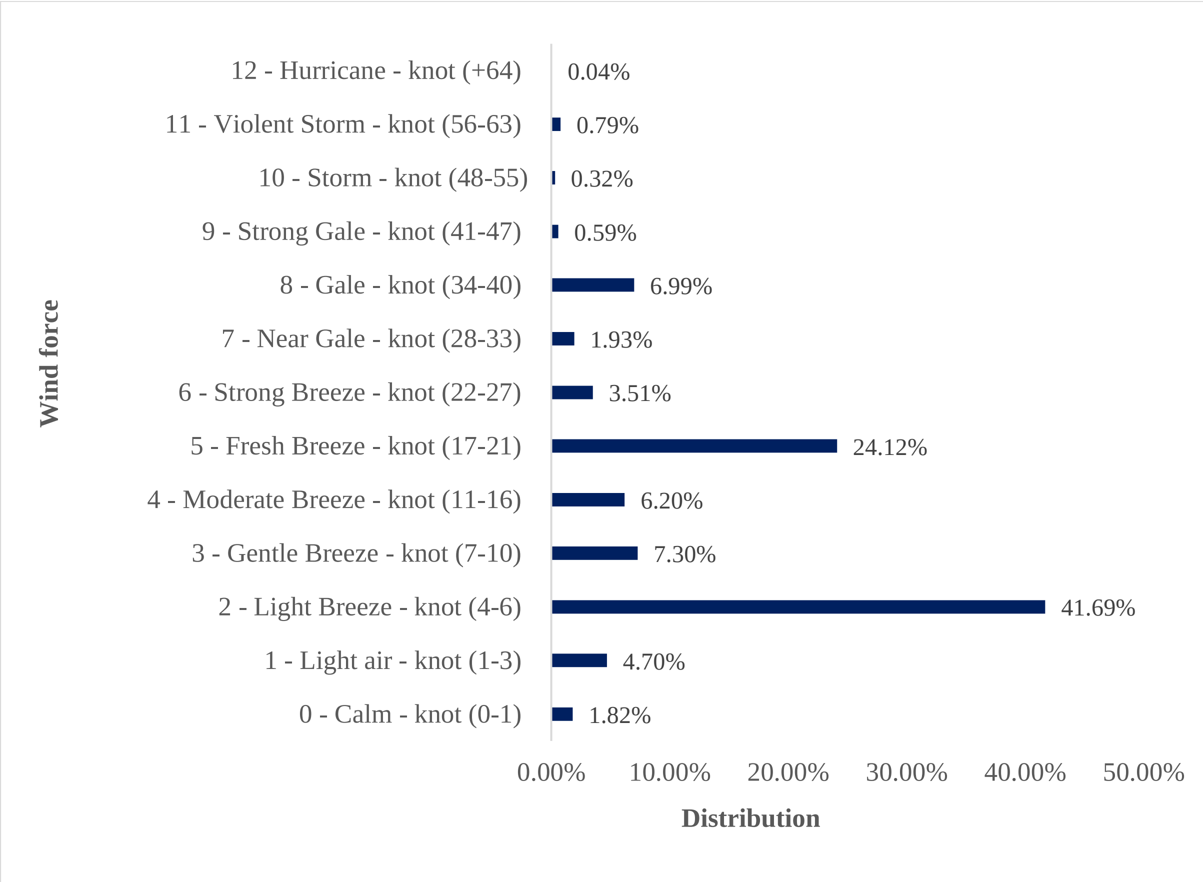


Figure 5.9. Number of accidents per wind force for the period 1992-2016 (N=2533)

Surprisingly, from the above information, it is derived that the majority of the accidents took place during good weather conditions (i.e. good visibility, wind and sea state). However, this fact might be explained due to two main reasons. First, ships will not generally operate within extreme environmental conditions, and second, during good weather conditions, crew members' surveillance might be reduced.

5.4 Hypothesis Tests Analysis on MAIB database for the period 1992-2016

This section performs a set of hypothesis tests (i.e. chi-square test) to identify if a significant association exists amongst various pairs of variables. In addition, this section applies the symmetric correspondence analysis test to investigate additional associations between categorical variables.

Therefore, this section starts by explaining how to interpret the results of the symmetric correspondence analysis test. Second, a set of hypothesis tests are performed. The various null hypothesis that are analysed in this section may be classified as follows: 1) the ship type and the accident outcome are related; 2) the number of fatalities and injuries are related to the ship type and accident outcome; 3) the accident location is related to the ship type and accident outcome; 4) the environmental conditions are related to the accident outcome.

5.4.1 **Interpretation of the Symmetric Correspondence Analysis Test**

The chi-square test only shows if two datasets are significantly different from each other, but it does not provide additional information concerning the direction of the effects (Field, 2009). Therefore, the symmetric correspondence analysis test can be utilized to investigate additional associations between categorical variables.

It is important to understand that a correspondence analysis test provides information about the relativity correspondence that exists amongst two variables (e.g. ship type and accident outcome). Thus, meaningful results can be extracted from the symmetric correspondence analysis graph by taking into account a set of principles. First, graph proximity indicates that there is a similarity between two categorical variables. Second, if the value of the angle resulted from drawing a line from the origin to a value pertaining to each categorical variable is small; those two specific values are likely to be associated. In addition, if the aforementioned angle is wide, there is no relation amongst those variables (or the existing relation is weak). Third, a relation exists between the variables distance from the origin and their association. Thus, points that are close to the origin show a weak association and vice versa. Finally, a relation exists between the variables distance from the origin and how these variables are discriminated. Hence, relatively close points to the origin present lower discrimination and vice versa.

In addition, there is a need to assess how much variance the symmetric correspondence test explains within the scope of each analysis. Thus, more variance means that fewer insights into the analysis will be missed.

5.4.2 The Association amongst the Ship Type and the Accident Outcome

To examine whether the ship type has been associated with specific accident outcomes, a chi-square test (X^2) was conducted. The term "chi-squared test," often refers to the Pearson's chi-squared test, which is used to determine whether there is a statistically significant difference (i.e. a magnitude of difference that is unlikely to chance alone) between the expected frequencies and the observed frequencies in one or more categories. In addition, the degrees of freedom (df) provides information about the numbers in the grid that are actually independent. For example, for a chi-square grid, the degrees of freedom are the number of cells required to be filled in before, given the totals in the margins, the rest of the grid can be filled using a formula. Thus, the number of cells that can be filled in independently provide information about the actual amount of variation permitted by the data set. Finally, the chi-square value and the degrees of freedom are utilised to decide the probability (p-value) of independence.

The result of the test was significant (X^2 = 3083.927, df = 56, p = 0,000), which indicates that there is a significant association between ship type and accident outcome. Nevertheless, it is not possible to determine individual relationships amongst these two categorical variables by simply applying a chi-square test. Thus, to conduct a more detailed investigation, a correspondence analysis test was also performed. Figure 5.10 displays the results from the symmetric correspondence test, in which 77.60% of the variance is explained (52.10% for the x-axis and 25.50% for the y-axis). As it was stated before, the interpretation of the results in a correspondence analysis test is not straight forward, as specific considerations must be taken into account.

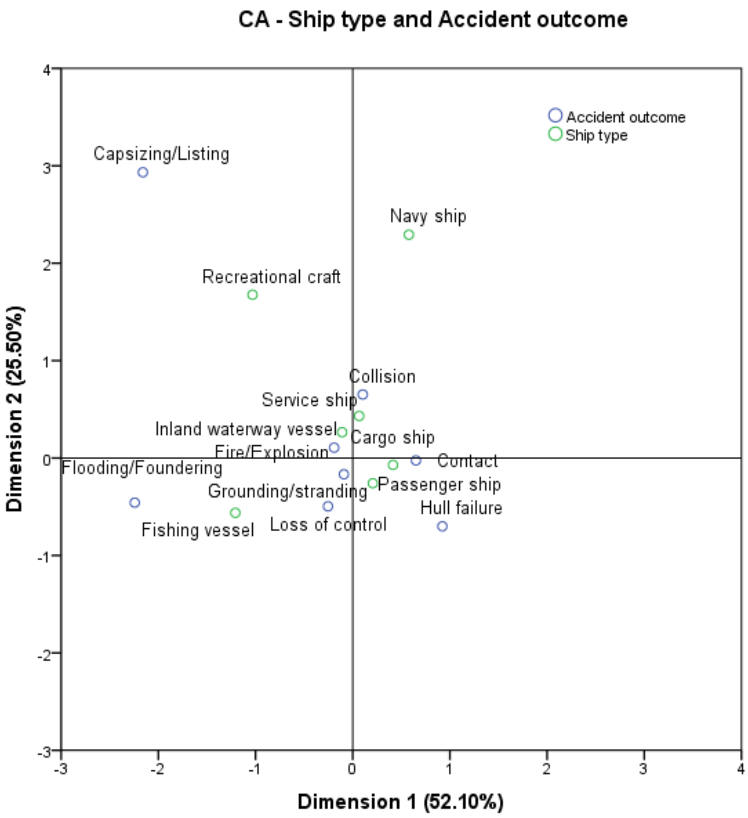


Figure 5.10. Symmetric correspondence analysis between ship type and accident outcome for the period 1992-2016 (N=2533)

Therefore, by taking into account above-explained considerations, possible interpretations extracted from Figure 5.10 are as follows: First, the accident outcomes “Fire/explosion”, “Grounding/stranding”, and “Loss of control”seems to present similarities due to their proximity on the graph, while “Capsizing/listing is separated from other accident outcomes. Similarly, the pair of ship types “Cargo ship” and “Passenger ship “, and “Service ship” and “Inland waterway” are comparable, while “Navy ship” is far from other vessel categories. Second, this analysis reveals that there is a relation between “Contact” and “Cargo ships”, “Collision” and “Service ships”, and “Capsizing/Listing” and “Recreational crafts”, as the existing angles between the origin and these values are small.

Previous findings reveal that there are differences between specific accident outcomes and ship types. This is in line with findings from Bye and Aalberg (2018), and similar studies that revealed that specific accident outcomes are dependent on the type of vessel (N. P. Ventikos et al., 2017; Yip, 2008).

5.4.3 **The Association amongst Fatalities and Injuries, Ship type, and Accident Outcome**

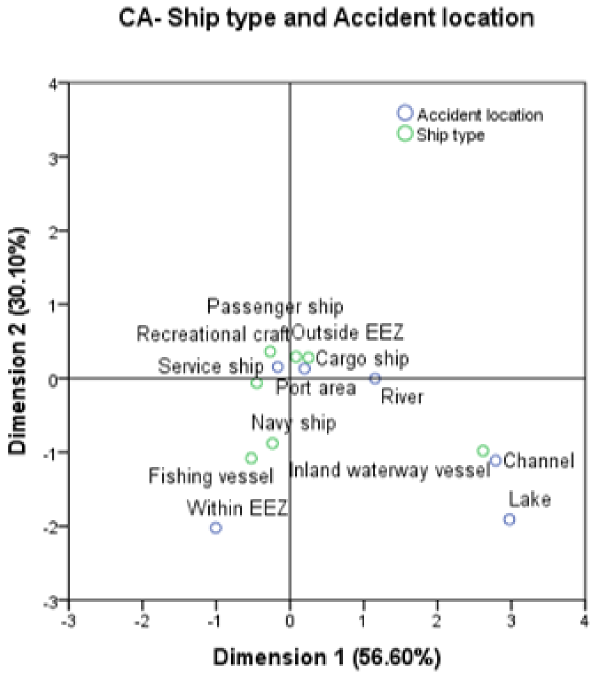
To determine if the number of fatalities and/or injuries is associated with specific ship types, chi-square tests were performed. The result of the test was significant for loss of lives (X^2 = 129.583, df = 24, p = 0,000), and for injuries (X^2 = 151.569, df = 66, p = 0,000), which reveals that there is a significant association between fatalities and/or injuries and the ship type.

In addition, to establish if the number of fatalities and/or injuries is associated with specific accident outcomes, chi-square tests were conducted. The result of the test was significant for loss of lives (X^2 = 1566.328, df = 28, p = 0,000), and for injuries (X^2 = 104.251, df = 77, p = 0,021), which also indicates that there is a significant association between fatalities and/or injuries and the accident outcome. Nevertheless, it is not possible to conduct a more detailed investigation for the previous scenarios by means of a correspondence analysis test, as the number of fatalities and the number of injuries are not categorical variables. However Table 5.4 in previous section shows the distribution of fatalities between different types of vessels.

5.4.4 **The Association amongst Accident Location, Ship type, and Accident Outcome**

In order to establish if an association exists for the variables accident location, ship type, and accident outcome, chi-square tests were also conducted. The result of the test was significant for ship type (X^2 = 599.795, df = 30, p = 0,000), and for accident outcome (X^2 = 2823.767, df = 24, p = 0,000), which indicates that there is a significant association between aforementioned variables. Thus, Figure 5.11 provides in the left the results from the symmetric correspondence test between ship type and accident location, in which 86.70% of the variance is explained. In addition, it provides in the right the results from the symmetric correspondence test between accident outcome and accident location, in which 94.60% of the variance is explained.

Regarding the variables ship type and accident location, it is possible to observe that a strong relationship exists amongst “Cargo ships” and “Port area”, and between “Inland waterway vessels” and “Channels”. Similarly, with respect to the variables accident outcome and accident location, Figure 5.11 indicates that “Grounding/stranding” and “River”, “Contact” and “Port area” or “Capsizing/listing” and “Lakes” are strongly connected.



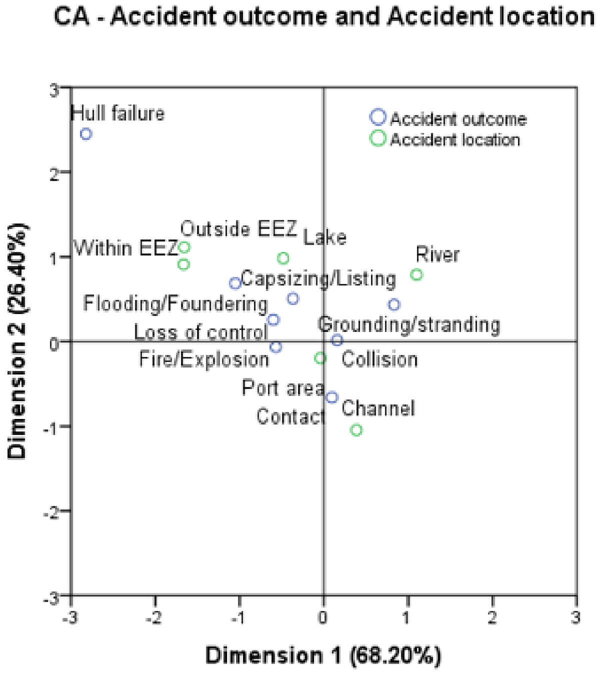


Figure 5.11. Symmetric correspondence analysis between ship type and the accident location (left), and symmetric correspondence analysis between accident outcome and the accident location (right). Period 1992-2016 (N=2533)

5.4.5 **The Association amongst Environmental Conditions and Accident Outcome**

Finally, chi-square tests were performed to determine if there is a relationship between environmental conditions (i.e. sea state, visibility and wind force) and accident outcome. The result of the test was significant for sea state (X^2 = 2729.109, df = 64, p = 0,000), visibility (X^2 = 2592,466, df = 40, p = 0,000), and wind force (X^2 = 2820.580, df = 104, p = 0,000), which indicates that there is a significant association between aforementioned variables. Figure 5.12 provides the results from the symmetric correspondence test between accident outcome and above-mentioned environmental conditions. Thus, a relation is observable amongst the majority of accident outcomes and low sea states, good visibility and low wind forces (below Force 5 in Beaufort scale) which is in line with the findings from B Navas de Maya et al. (2019) that revealed that the majority of accidents occur during good and/or moderate weather conditions.

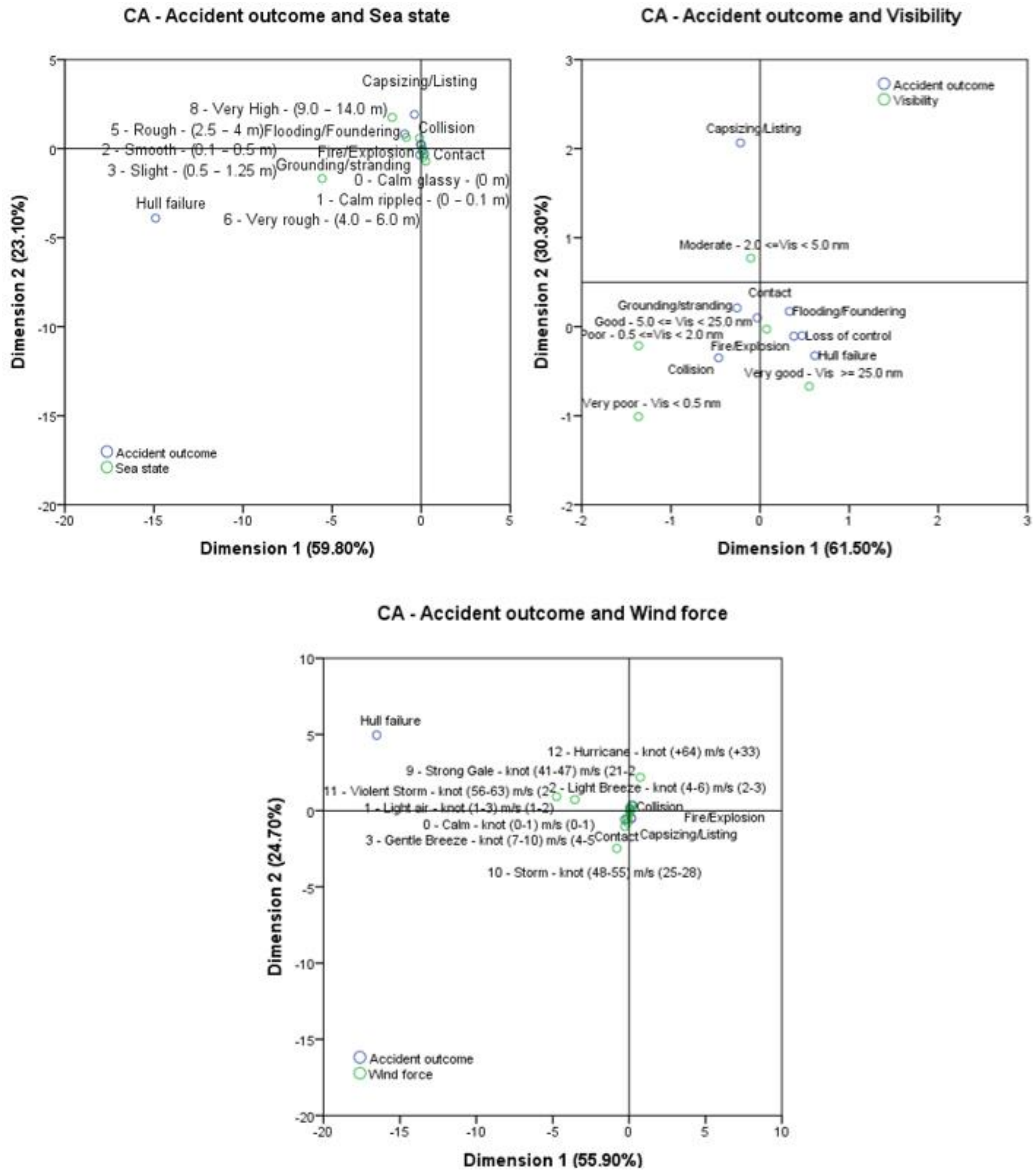


Figure 5.12. Symmetric correspondence analysis accident outcome and sea state (above left), symmetric correspondence analysis between accident outcome and visibility (above right), and symmetric correspondence analysis between accident outcome and wind force (below). Period 1992-2016 (N=2533)

5.5 Discussion on the Statistical Analysis Results

The aim of this chapter was to show the current distribution of maritime accidents, in order to provide a better understanding of accidents as complex processes. To complete this aim, first, a set of descriptive analysis was performed. Second, a set of statistical analyses were conducted to investigate the relationship between various variables from the database.

Regarding the descriptive analysis, the findings from this study showed that cargo ships (40.66%), passenger ships (20.61%), service ships (15.99%) and fishing vessels (14.17%) are the vessel types with the highest number of accident recorded. Furthermore, additional analyses revealed that navigational accidents (i.e. collision, contact and grounding/stranding) and loss of control account for more than 85% of the total accidents.

Moreover, a comparison between vessel age and the number of accidents was performed. As expected, older vessels are more likely to contribute to an accident. With respect to the number of injuries, it was observable that the majority of injured crew members were allocated to passenger ships (26.50%) and service ships (21.68%), while passengers were mostly injured in passenger ships. In addition, regarding the number of fatalities, cargo ships and recreational crafts presented the higher distribution in terms of crew members (40.00% and 28.00% respectively). Furthermore, the totality of passenger fatalities corresponded to recreational crafts. Regarding the accident location, this study revealed that 80% of the accidents occurred in internal waters (81.01%) and inland waters (13.38%).

Concluding with the descriptive analysis, a last set of analyses was performed to study the relationship between environmental conditions (i.e. sea state, visibility and wind force) and accident distribution. Surprisingly, it was found that the majority of the accidents took place during good weather conditions (i.e. good visibility, wind and sea state). Nevertheless, this condition may be explained due to two main reasons. First, vessels will not often operate within extreme environmental conditions. Second, during good weather conditions, crew members stay less alert to their surroundings and they are more likely to rely on equipment. Therefore, if there is a technical failure or an obstacle on the vessel’s course, it may be not identified on time, with the consequent accident development.

Finally, regarding the hypothesis tests, it was observed that there is a relation amongst specific variables. First, between the ship type and accident outcome. Second, amongst the total number of injuries and fatalities, and the ship type and the accident outcome. Third, between the location, the ship type, and the accident outcome. Finally, there is a relation amongst environmental conditions (i.e. sea state, visibility and wind force) and the accident outcome.

5.6 A Data-Driven Approach to Determine the Most Influential Human Factors in Past Maritime Accidents

Symmetric correspondence analysis provided very promising results in previous sections. However, it was not possible to follow a similar approach to analyse the HFs from the MAIB database due to the high number of HFs and not enough data available in each category. Therefore for the HFs analysis, a different approach was adopted. This section aims to identify the most influential HFs from MAIB database by applying a data driven approach. Hence, this section starts by explaining the problem description and the available data from MAIB database. Secondly, this section applies a data driven approach to identify and rank the most influential Human Factors.

5.6.1 Problem Description and Available Data

As it was mentioned above, the data that is considered for this section was obtained from the MAIB accident database. The aforementioned accident records were extracted according to the definitions comprising the generic accident categories as defined by the European Marine Casualty Information Platform (EMCIP) (EMSA, 2014). Hence, the following accident categories, as specified in above-mentioned EMCIP taxonomy, were included in the analysis carried out in this section:

- Grounding/Stranding (C1): event during which a moving navigating ship, either under command or not (i.e. power or drift conditions), strikes the sea bottom, shore or underwater wrecks.
- Capsizing/Listing (C2): event during which the ship no longer floats in the right-side-up mode due to external factors (i.e. negative initial stability, transversal shift of the centre of gravity, or the impact of external forces.
- Contact (C3): casualty caused by a ship striking or being struck by an external object. Thus, the sea bottom is excluded (i.e. a contact with the sea bottom is considered as a grounding event).
- Collision (C4): casualty caused by ships striking or being struck by another ship. This event might involve more than two vessels.
- Fire/Explosion (C5): an uncontrolled ignition on board of a ship.
- Flooding/Foundering (C6): event during which the ship is taking water on board; It can be progressive or massive.
- Hull Failure (C7): failure event affecting the general structural strength of the ship.

- Loss of Control (C8): event during which a total or temporary loss of the ability to operate or manoeuvre the ship, failure of electric power occurs.
- Damage to Ship or Equipment (C9): damage to equipment, system or the ship not covered by any of the previous casualty types.

In addition, the data-driven approach was applied to different relabelling of above described accident outcomes, aiming to demonstrate the hypothesis that the identified HFs remain significantly constant, independently of the accident outcome analysed. Hence, four different aggregations of the accident outcomes were created as follows (Coraddu, Oneto, Navas de Maya, & Kurt, 2020):

- Aggregation 1 (A1): All the nine accident categories outcomes have been considered as independent categories. However, within this aggregation, the number of data points in each category is low, which results in an unbalanced category distribution.
- Aggregation 2 (A2): In order to mitigate the unbalancing effect among categories and to increase the number of data points for each category, the previous accident outcomes were aggregated into two main categories: navigational accidents (i.e. Grounding/ Stranding, Contact, and Collision), and non-navigational accidents, which includes all the remaining categories considered as a unique group.
- Aggregation 3 (A3): The accident outcomes have been aggregated into seven groups, the first group incorporate all navigational accidents, while the Non-Navigational Accidents are all considered as individual categories.
- Aggregation 4 (A4): The nine accident outcomes have been aggregated into four similar accident categories. Navigational Accidents have been still considered as an independent group. The Hull Failure (C7), Loss of Control (C8) and Damage to Ship or Equipment (C9) conformed a second group, which was created as these accident outcomes might be considered as prior conditions that can derive into additional accidents. Fire/Explosion (C5) was independently considered as a third group due to its own accident nature. Finally, Capsizing/Listing (C2) and Flooding/Foundering (C6) were considered as the fourth group as they are more related with safety and stability than the other accident outcomes.

5.6.2 **Identification and Ranking of Human Factors**

In order to address the problem of determining the most influential human factors in maritime accidents based on their ability to be influential in predicting the type of accident in the set of accidents available, a two-steps approach was adopted (Coraddu et al., 2020). First, a predictive model was built, which aimed to predict the presence or not of a specific HF. The aforementioned model was built by utilising two different approaches: Random Forests (RF) and Multiclass Support Vector Machines with Boolean Kernels (MSVM-BK) since the presence or not of the different human factors can be represented with a Boolean vector. Second, a ranking of the different human factors based on their ability to influence the model outputs was performed. While the RF approach provided the ranking by default, for the MSVM-BK approached the authors exploited the backward elimination method. Table 5.5 and Table 5.6 includes the top HFs ranked by both approaches for each of the aggregations previously defined.

Table 5.5. Top HFs ranked by RF approach on the different aggregations proposed

Random Forests (RF)				
No	**A1**	**A2**	**A3**	**A4**
1	Lack of knowledge	Inadequate work preparation	Lack of knowledge	Training ignored
2	Training ignored	Training ignored	Training ignored	Emergency training program
3	Emergency training program	Inadequate work method	Emergency training program	Inadequate work preparation
4	Contingency plans not updated	Inadequate manning	Inadequate work preparation	Contingency plans not updated
5	Social and cultural barriers and conflicts	Emergency training program	Contingency plans not updated	Improper performance of maintenance/repair
6	Anthropometric factors	Lack of skill	Improper performance of maintenance/repair	Inadequate work method
7	Improper performance of maintenance/repair	Anthropometric factors	Safety awareness, cutting corners	Lack of knowledge
8	Inadequate briefing, instruction	Expectation of supervisor is unclear	Inadequate work method	Safety awareness, cutting corners
9	Improper supervisory example	LTA medical services provided	Lack of skill	LTA communication
10	Lacks initiative to deal with emergencies	Lack of knowledge	LTA medical services provided	Lack of skill

Table 5.6. Top HFs ranked by MSVM-BK approach on the different aggregations proposed

Multiclass Support Vector Machines with Boolean Kernels (MSVM-BK)				
No	**A1**	**A2**	**A3**	**A4**
1	Emergency training program	Training ignored	Emergency training program	Emergency training program
2	Anthropometric factors	Emergency training program	Contingency plans not updated	Improper performance of maintenance/repair
3	Training ignored	Improper performance of maintenance/repair	Anthropometric factors	Anthropometric factors
4	Contingency plans not updated	Contingency plans not updated	Training ignored	Contingency plans not updated
5	Inadequate work preparation	Anthropometric factors	Improper performance of maintenance/repair	Training ignored
6	Inadequate briefing, instruction	Inadequate briefing, instruction	Inadequate manning	Inadequate work preparation
7	Inadequate manning	Inadequate work method	Inadequate briefing, instruction	Inadequate manning
8	Inadequate work method	Inadequate manning	Inadequate work method	Inadequate work method
9	Improper performance of maintenance/repair	Inadequate work preparation	Lack of knowledge	Inadequate briefing, instruction
10	Lack of knowledge	Lack of knowledge	Inadequate work preparation	Lack of skill

5.6.3 Discussion on the Results

From the top HFs that were ranked from both, the RF and M-SVM-BK methods, it is possible to note that the majority of these factors are related with inadequate procedures or deviation from Standard Operating Procedures (SOP) (e.g. Contingency plans not updated, Inadequate work methods, etc.), or with inadequate training e.g. Emergency training program, Lack of knowledge, Lack of skill, etc.). Inadequate procedures have been often identified in the literature as a potential cause for maritime accidents. For example, research conducted in EU funded SEAHORSE project concluded that up to a third of SOP are ineffective hence not being adequately followed during ship operations (R. Kurt et al., 2015; R. E. Kurt, Arslan, Comrie, Khalid, & Turan, 2016). Moreover, regarding inadequate training, a study of various maritime accidents conducted by Puisa, Lin, Bolbot, and Vassalos (2018), revealed that inadequate training was often an observable feature across all accident reports analysed. Thus, Graziano et al. (2016) applied the Technique for Retrospective and Predictive Analysis of Cognitive Errors (TRACEr) to reveal that fatigue or inadequate training and instruction led to most of the failures identified in their study.

Furthermore, the data-driven approach presented in this section also revealed additional accident contributing factors, which are neither related to inadequate procedures nor insufficient training (i.e. Anthropometric factors, Improper performance of maintenance/repair, Inadequate briefing, instruction and Inadequate manning). Above-mentioned factors are not often referred to in the literature as a common accidental cause. Nevertheless, one of the main limitations in EMCIP taxonomy is the lack of a proper description for each contributing factor, which often lead to misinterpretation when accident investigators are identifying which accidental factors are involved in a specific accident scenario. Thus, this misinterpretation may often lead to the inadequate selection of certain contributing factors when analysing an accident, which causes that certain factors are accounted more times that they appear.

In conclusion, from the analysis carried out in this section, it is possible to observe that most HFs remain significantly constant, independently of the accident outcome that is being considered. However we still do not know how this observation could affect maritime safety. Hence these results were the main reason that motivated the researcher to conduct a more detailed analysis in the next chapter to better understand HFs structure and nomenclature within the MAIB accident database and to develop a set of more generic and better-defined HF groups, aiming to better identify the contribution of HF into maritime accidents.

5.7 Chapter Summary

This chapter examined various historical accident databases (i.e. IMO, CASMET and MAIB) to identify the most suitable data set for this research study. Thus, this chapter also performed a set of descriptive analyses to provide a general statistical description of the accident sample. Moreover, a set of hypothesis tests were conducted by applying the SPSS software, aiming to investigate the relationship between various variables from the database. Finally, a data-driving approach was adopted to identify within the MAIB database the most influential HFs from past maritime accidents. Overall, from the analysis conducted, it was observed that only a low number of HF data is included in MAIB database, as the majority of entries in the database are blank when it comes to indicate those HFs responsible for a maritime accident. Thus, it was noticed that numerous HFs are similar to each other (e.g. emergency plans and emergency procedures), which reduces the visibility of important factors.

Therefore, Chapter 6 will address the need for a reduction and redefinition in the list of HFs provided in the selected accident database. Thus, a study will be also conducted in the next chapter, which aims to understand HFs structure and nomenclature within the aforementioned MAIB database, and to develop a set of more generic and better-defined HFs groups by applying a card-sorting technique.

6 PROPOSAL FOR A HUMAN-FACTOR CLASSIFICATION

6.1 Overview

To understand and analyse accidents successfully, it is mandatory to ensure that the information regarding the sequence of events and the HFs involved in the accident process is available. Unfortunately, accident databases for the maritime domain have not reached their full potential when considering HFs. The HFs provided as responsible for the outcome of certain accidents, do not match the reality, as they are recorded inconsistently, and lack a clear description. Hence, there is a lack of a clearly defined HFs structure, which would allow accident investigators to match each maritime accident with the most suitable HFs. Thus, efforts and resources may be channelled into developing strategies to overcome those HFs, and hence, improve overall maritime safety. The purposes of this chapter are first, to understand HFs structure and nomenclature within the Maritime Accident Investigation Branch (MAIB) accident database. And second, to develop a set of more generic and better-defined HF groups by applying a card-sorting technique.

This chapter[2] first, provides in Section 6.2 the current HF classification that is available within the MAIB accident database. Then, highlighting in Section 6.3 the needs for a reduction and redefinition of the HFs contained in the MAIB database. The potential alternatives and their limitation to reduce the aforementioned number of HFs are described in Section 6.4. Second, introduces in Section 6.5 the technique that is finally applied for the proposed HF reduction, the so-called card-sorting method, including its definition, application and the available techniques for the analysis of results. Third, includes in Section 6.6 the results of an open card-sorting case study. The analysis of the results from the aforementioned open card-sorting case study is included in Section 6.7. In addition, it provides in Section 6.8 the results of a hybrid card-sorting case study, which was launched to complete the results obtained from the open card-sorting session. The results of the aforementioned hybrid card-sorting session are further analysed in Section 6.9. Moreover, Section 6.10 includes an initial proposal for an HF classification, which is amended and validated by performing a co-occurrence analysis in Section 6.11. Furthermore, experts in the area of HFs are asked in Section 6.12 to provide their insight into the initial HF classification proposed and the final amendments are made by

[2] The card-sorting approach described on this chapter to classify human factors of past maritime accidents has been already converted to a journal paper and published in Maritime Policy & Management (Beatriz Navas de Maya, Hassan Khalid, & Rafet Emek Kurt, 2020).

incorporating their feedback. Lastly, a final HF classification is proposed in Section 6.13. A flowchart with the process that was finally adopted to classify the initial list of HFs from the MAIB database is presented in Figure 6.1.

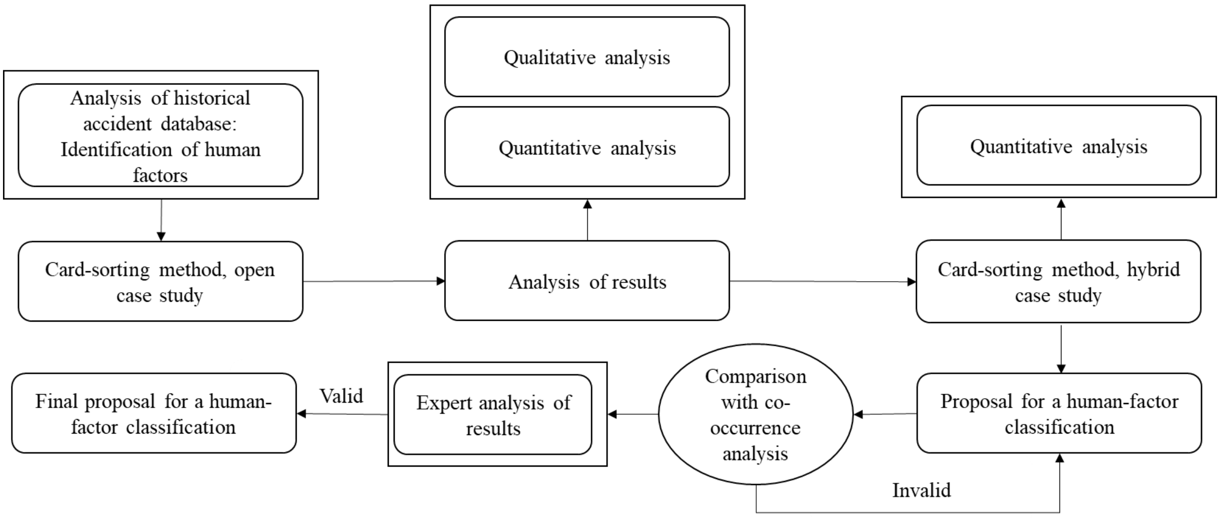


Figure 6.1. Classification of HFs flowchart

6.2 Current Human Factors Identified within the MAIB Accident Database

MAIB accident database contains information regarding ninety-four different HFs, which are responsible for maritime accidents involving UK vessels worldwide and all vessels operating in UK territorial waters for the period from 2011 to 2016. Although the previous chapter included a detailed analysis of maritime accidents for the period 1992 to 2016, the MAIB database only started recording HFs with the European Marine Casualty Information Platform (EMCIP) nomenclature in 2011. A complete list of HFs from the MAIB database is displayed in Table 6.1.

Table 6.1. List of human factors identified from MAIB accident database

No	Human factor	No	Human factor	No	Human factor
1	Anthropometric factors, dimensions	33	Inadequate promotion of Safety	65	LTA* physical/ physiological capability
2	Audit	34	Inadequate standards or specifications	66	LTA* planning
3	Checks	35	Inadequate testing	67	LTA* Safety plan and program
4	Conflicting orders, cross-pressure (ex. master's standing orders)	36	Inadequate training program	68	LTA* System review and evaluation
5	Contingency plans not updated	37	Inadequate work methods	69	Management training
6	Cowboy attitudes, horseplay	38	Inadequate work preparation (ex. passage plan)	70	No review or critical tasks/operations
7	Crisis handling	39	Inappropriate peer pressure	71	Person-to-person conflict / animosity
8	Cross-pressure from schedule & economy	40	Inappropriate regulations	72	Pressure to keep schedule and costs
9	Design (DESIGN)	41	Inspection	73	Regulation
10	Design error	42	Lack of communication & coordination	74	Regulatory procedures
11	Deviation from standards/specifications	43	Lack of co-ordination of tasks	75	Regulatory standards
12	Display design, controls	44	Lack of information, inadequately presented information	76	Resistance to change
13	Emergency plans	45	Lack of knowledge	77	Restricted fairway
14	Emergency procedures	46	Lack of leadership	78	Right tools and equipment unavailable
15	Emergency training program	47	Lack of maintenance	79	Safety awareness, cutting corners
16	Expectations of supervisor is unclear	48	Lack of motivation/morale	80	Sea motion
17	Failure not detected during IMR*	49	Lack of priority to IMR*	81	Selection/training of officers
18	Follow-up of non-conformities,	50	Lack of resources	82	Social & cultural barriers & conflicts
19	Frequent change of watch schedule	51	Lack of responsibility for own job	83	Supervision (SUPER)
20	Hazardous/ messy workplace	52	Lack of skill	84	Supervisors not in touch
21	Health control of personnel	53	Lack of warning systems	85	Surveillance
22	Hiring and selection policy	54	Lacks initiative to deal with emergencies	86	Too high workload / low workload
23	Idleness, waiting	55	Language problem	87	Too low visibility for observation
24	Improper performance of maintenance/ repair	56	Lifesaving equipment	88	Traffic density hinders vessel control
25	Improper supervisory example	57	Long working periods, much overtime	89	Training ignored
26	Inadequate briefing, instruction (ex. passage briefing plan)	58	Low job satisfaction, monotony	90	Unclear roles and responsibility
27	Inadequate control of life-saving equipment	59	LTA* assessment of needs and risks	91	Use of wrong equipment
28	Inadequate fighting equipment	60	LTA* communication (oral, written/read and visual)	92	Work instruction
29	Inadequate illumination	61	LTA* design verification	93	Work place inspections
30	Inadequate maintenance	62	LTA* Formal safety assessment, risk analysis	94	Wrong person assigned
31	Inadequate manning	63	LTA* medical services provided	*	IMR (Inspection, Maintenance, and Repairs)
32	Inadequate procedures and checklists (ship/port, maintenance, company, emergency, other)	64	LTA* mental and psychological state	*	LTA (Less than Adequate)

6.3 Needs for a Reduction of Human Factors from the MAIB Database

The total number of entries in the MAIB database with specific information about human accident contributors only includes 129 accidents. This is a result of the well-known problem of lack of awareness and lack of an effective approach to identify underlying accident causes related to human factors, which currently exists in maritime accident investigations. Amongst these accidents, 94 human contributing factors were identified as directly responsible for the accidents' outcome, as shown in Table 6.1. Due to the high number of HFs identified, there was an initial dilemma between focusing on the statistically most frequent HFs from the list, or taking into account all initial 94 HFs.

Statistical analysis may reveal which HFs have the highest frequency of occurrence in past accidents. However, they cannot provide further insight into which of these HFs are more crucial in accident development. For instance, alcohol or drug consumption on board is statistically a rare issue; nevertheless when officials are under the influence of drugs; their actions and behaviour will have a higher chance to cause an accident. Therefore, in order to consider all the possible interrelations between HFs that will contribute to an accident, it was decided to take into account all the initial 94 HFs identified from the MAIB accident database. Nevertheless, further steps in this research study (e.g. collecting expert opinion) would be extremely challenging with such high numbers of HF categories. Hence, it was proposed to reduce and re-define the 94 HFs by grouping those factors with similar characteristics into the same group. The decision to group similar HFs was considered as a feasible alternative due to the following reasons:

- Within the initial 94 HFs, which are listed in Table 6.1, it was observed that some of the HFs had a similar name (e.g. HF No 13-"Emergency plans" and HF No 14-"Emergency procedures"; or HF No 36-"Inadequate training program" and HF No 89-"Training ignored").
- For some of the aforementioned HFs, their description was not clear from the database, for example, HF No 1-"Anthropometric factors, dimensions" and HF No 6-"Cowboy attitudes, horseplay", and it was required to look further into the accident events in order to have a better understanding of their meaning. A more detailed analysis of the MAIB database revealed that HF No 1 is related to physical dimension problems, for example, a lack of deck space that makes the operations on board more difficult. In addition, for

HF No 6, the accident description indicated that the officers were holding a party on the bridge.

- Finally, the next step in this research study will include expert-based data collection regarding the interrelationship between each pair of HFs. As it will be almost an impossible task to distribute and collect data from a questionnaire with size 94 by 94, grouping together those HFs with similar characteristics seems like a reasonable alternative.

Therefore, due to the above-mentioned reasons, it was decided to still take into account all the initial 94 HFs, but also to come up with a new HF terminology that will allow the next steps of this research study to run smoothly.

6.4 Alternatives vs their Limitations to Group the Initial Human Factors into New Categories

In order to reduce and re-define the initial list of HFs provided by MAIB, some potential techniques and methods were reviewed, and their limitations were highlighted. The approaches, which were tried within this research study are as follows: 1) Factor analysis, 2) K means method, and 3) Expert opinion.

6.4.1 **First Approach: Factor Analysis**

Conducting a factor analysis was identified as the first logical approach. Factor analysis is a statistical method that is applied to uncover the underlying structure of a set of variables. As defined by Bolt et al. (2016) "factor analysis identifies sets of observed variables that have more in common with each other than with other observed variables in the analysis". In order to perform a factor analysis, the database was restructured as a matrix table, where the rows were the accidents being analysed (129 rows), and the columns were the initial list of HFs (94 columns). As HFs might be or might not be presented in a specific accident (i.e. there is no intermediate option), it was decided to assign each HF a value of one if that specific factor was involved in an accident or a value of zero if the factor was not recorded as an accident contributing factor.

The factor analysis that was identified first was the Common Factor Analysis (CFA), however, due to the aforementioned dichotomous nature of the variables (i.e. zero or one value for each HF), it was not possible to run a CFA by using the SPSS software. Therefore, an extended literature review was conducted to identify a potential solution to this problem. In statistics, a polychoric correlation is a technique that allows estimation of the correlation between two normal distributed continuous variables. The main problem is that the HFs analysed within this study do not have a normal distribution. However, there is a special case of the aforementioned polychoric correlation (i.e. the tetrachoric correlation), which is designed for dichotomous variables. Thus, a tetrachoric correlation was performed, and the correlations and p-values were obtained. After obtaining the correlations' values, the following issues were noticed:

- There were relatively large correlation coefficients, which are widespread.
- However, the majority of these correlations were insignificant due to the size of the available data (i.e. not many entries in the database contain information about HFs involved in past accidents).
- From the 94 factors, thirty-four accounted for less than 1.00% of the accidents. Hence, due to their low rate, there is a possibility that the accident investigators recorded wrongly aforementioned factors.
- It was observed that fifty factors (i.e. all the factors that accounted for less than 1.00% of the accidents, and sixteen factors with at least 1.00% occurrence) were not displaying any significant relationship with other factors (p-value > 0.05). Henceforth, these factors could not be grouped into further categories and they would remain as independent factors within this approach.
- Moreover, forty-four factors were displaying a significant relationship with at least one other factor (p-value ≤ 0.05). These factors could be subjected to factor analysis to identify new factor groups.

After analysing the results obtained from the tetrachoric correlation, it was decided that a factor analysis approach was not the optimal solution to group our data for two reasons. First, the dataset (i.e. the number of accidents) was insufficient to perform a qualitative correlation, and the results would be subjected to critics. Second, the results from the tetrachoric correlation indicated that there are fifty factors that cannot be grouped together, which means that in the best scenario the HFs would be grouped into no less than sixty groups. As highlighted in the previous section, the next step in this research study will require to collect expert opinion by means of a questionnaire. Thus, a 60 by 60 questionnaire is still not an optimal solution to collect information successfully.

6.4.2 **Second Approach: K-Means Method**

As an alternative method to factor analysis, a clustering approach known as k-means was selected. K-means is a partitioning method, which aims to classify data into "k" mutually exclusive clusters. K-means first treats each observation (i.e. each HF) as an object with a specific location in space. Then, it finds a suitable partition, in which objects within each cluster are as close to each other as possible (while also remaining as far as possible from objects in other clusters). Moreover, each cluster is defined by its member objects (i.e. its HFs) and by its centroid. This is the point to which the sum of distances from all objects in that cluster is minimized.

In order to effectively apply k-means to cluster the initial 94 HFs into smaller groups, the accident database was converted into a matrix table, where the rows were the accidents being analysed (129 rows) and the columns the initial list of HFs (94 columns). Then, if a specific HF was presented in a particular accident, it would have a value of one. Moreover, if that HF was not involved in the accident, it would have a value of zero. As explained in the previous section, as an HF might be or might not be presented in a specific accident (there is no intermediate option), there are no more possible values than ones or zeros within this approach.

The main limitation of this clustering technique is that k-means does not provide a priori the optimal number of clusters for a dataset. In order to overcome this drawback, there are various techniques available, as the Calinski-Harabasz clustering evaluation criterion, the distortion in percent or the sum of the square area. The aforementioned techniques were applied and the three techniques agreed that the optimal number of clusters would be around ninety. Thus, it was demonstrated that although this method might be an optimal tool to cluster information, it was not suitable for this study; mainly due to the problem definition (i.e. only ones or zeros values are allowed to indicate the presence or absence of a particular HF in an accident).

6.4.3 **Third Approach: Expert Judgement**

As demonstrated in previous sections, neither a factor analysis nor a clustering approach was successful clustering available HF categories into broader high level groups. Therefore, a more suitable approach was needed. Hence, due to the nature of the data being analysed, it was decided to use experts to come up with potential new groups containing the initial list of HFs. In addition, it was established that the target audience for this study should be a group of experts with experience in the fields of HFs, on-board operations and accident investigations (e.g. seafarers, surveyors, etc.). The classification of HFs can be a tedious task, hence, it was decided that applying a technique that is easy to understand and utilize, as the card-sorting method, would be highly beneficial.

6.5 Card-Sorting Method as a Research Technique

The card-sorting method is a qualitative technique that was developed in the 1980s (Tullis, 1985). Nevertheless, it was not until the early 2000s that it became popular as a user experience design method (Hudson, 2012; Sinha & Boutelle, 2004). The so-called card sorting technique has been accessible for some time (Rugg & Petre, 2007), therefore, there are numerous definitions available. For instance, according to Paul (2014), card-sorting is a method to elicit people's underlying mental models about a conceptual domain. In addition, Faiks and Hyland (2000) define it as a qualitative technique, where participants are asked to sort cards into piles according to their own perceptions. As the card-sorting method is easy to replicate (Faiks & Hyland, 2000), and its application allows saving resources (i.e. time, funds and a large number of participants) (Nicholson, 2016), it has become a popular information architecture method in the last decade (Paul, 2014).

Traditional card-sorting techniques involve sorting a set of pictures, objects or labelled cards into distinct categories (Faiks & Hyland, 2000; Fincher & Tenenberg, 2005; Rugg & Petre, 2007). A card-sorting study may be conducted in various ways; nevertheless, the general methodology is similar for all cases (Paul, 2014). First, a set of concepts (i.e. cards), which represent a certain research domain are created. Second, participants are asked to sort the aforementioned cards into different groups based on their own interpretation. These groups may be predefined by the researchers (i.e. a closed card-sorting study), or they may be created by the participants (i.e. open card-sorting study). Alternatively, a combination of both is also possible; where some groups are predefined but participants are allowed to create additional groups (i.e. a hybrid card-sorting study). Third, participants are asked to name the created groups based on the topic that they represent (only applicable to open or hybrid card-sorting studies) (Nicholson, 2016; Paul, 2014).

As a card-sorting study is easy to conduct, it has been successfully applied in various domains and with diverse objectives. For instance, it has been used in visualization research, to explore people’s mental models of classifying visualization methods (Eppler & Platts, 2007). It has also been applied as a way to conduct a task analysis of geo-visualization tools and interactions (Lloyd, Dykes, & Radburn, 2008). Additionally, it has been used as a potential tool in marketing, computer science, and psychological investigations (Duncan, 2012). Furthermore, card-sorting concepts are developed into standard procedures, which are accepted and utilised by a wide range of users. For instance, the Dimensional Change Card Sort (DCCS) and the Wisconsin card sort are widely used in neuroscience, neuropsychiatry, and psychology, and the Pediatric Activity Card Sort (PACS) is commonly used as an occupation-based assessment tool (Bialystok & Martin, 2004; Haaland, Vranes, Goodwin, & Garry, 1987; Laws, 1999; Zelazo, 2006).

Card-sorting data can be analysed using both, qualitative and quantitative methods (Paul, 2014). However, the most common methods to analyse card-sorting data are qualitative methods (Fincher & Tenenberg, 2005; Righi et al., 2013). Thus, qualitative methods strongly rely on designer intuition and interpretation. Qualitative analysis is mainly focused on understanding the topics created by each participant, and the cards grouped under each topic. Traditional techniques include manually analysing and understanding the agreement of group and topic naming, the meaning of the topics, the relationships between groups, the context of participant use, or the domain of use (Deibel, Anderson, & Anderson, 2005; Paul, 2014; Sanders et al., 2005). Thus, one of the most common qualitative techniques is the so-called topic normalisation, which consists of merging similar participant-created groups (i.e. groups with a similar terminology) into a single topic for further analysis (Paul, 2014). Nevertheless, qualitative analysis is a manual, time-consuming process that trades off analysis effort with a rich understanding of the data (Paul, 2014).

On the other hand, quantitative analysis methods include descriptive and statistical techniques. Descriptive methods examine the shape of the data, such as the number of groups and number of cards within each group (Deibel et al., 2005), while statistical methods assess the significance of features within the data (Deibel et al., 2005; Sanders et al., 2005).

6.6 Open Card-Sorting Case Study

After selecting the technique that would be applied to reduce and redefine the initial list of HFs provided by MAIB, the next logical step was to create an open card-sorting case study. Thus, an open case study was conducted by gathering participants with experience in relevant fields for this study (i.e. HFs, accident investigation and ship operations) with the purpose to obtain reliable results. The aforementioned participants were selected from diverse geographical areas, in an attempt to capture social and cultural differences on maritime operations and procedures. The card-sorting case study was performed in two different phases. In the first phase, a workshop was organized, which allowed obtaining two sets of answers (i.e. Group1 and Group2). In order to reach additional experts with knowledge on the historical accident database selected and how accident investigations are conducted, an online open card-sorting case study was launched in the second phase. In the second phase, two additional sets of answers were collected (i.e. Group3 and Group4). The aforementioned sets of collected answers are included in Appendix A.

6.6.1 **First Phase of Open Card-Sorting Case Study, Workshop Organization**

6.6.1.1 **Participants**

Prior to holding the workshop, special attention was given to the participant selection. Participants with diverse backgrounds and working experience in the maritime sector were invited to obtain better qualitative results. In addition, the experts that were chosen to participate in this workshop came from diverse geographical areas, in an attempt to capture social and cultural differences in interpreting the human factor taxonomy in use. Figure 6.2 shows the geographical distribution of the participants that attended the workshop.

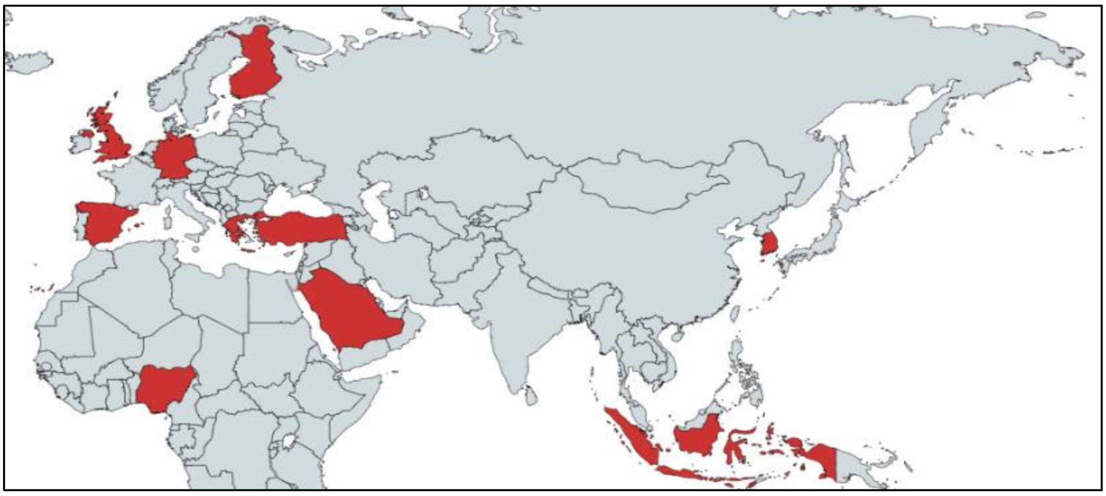


Figure 6.2. Geographical distribution of participants

On the day, ten experts attended and contributed with their expertise to the workshop. Figure 6.3 provides a better insight into the participants' background. Since some of the experts had experience in more than one field, Figure 6.3 shows both, the main area of expertise and the accumulated experience of each participant (i.e. a participant with experience as a seafarer and academic experience would be represented in both groups).

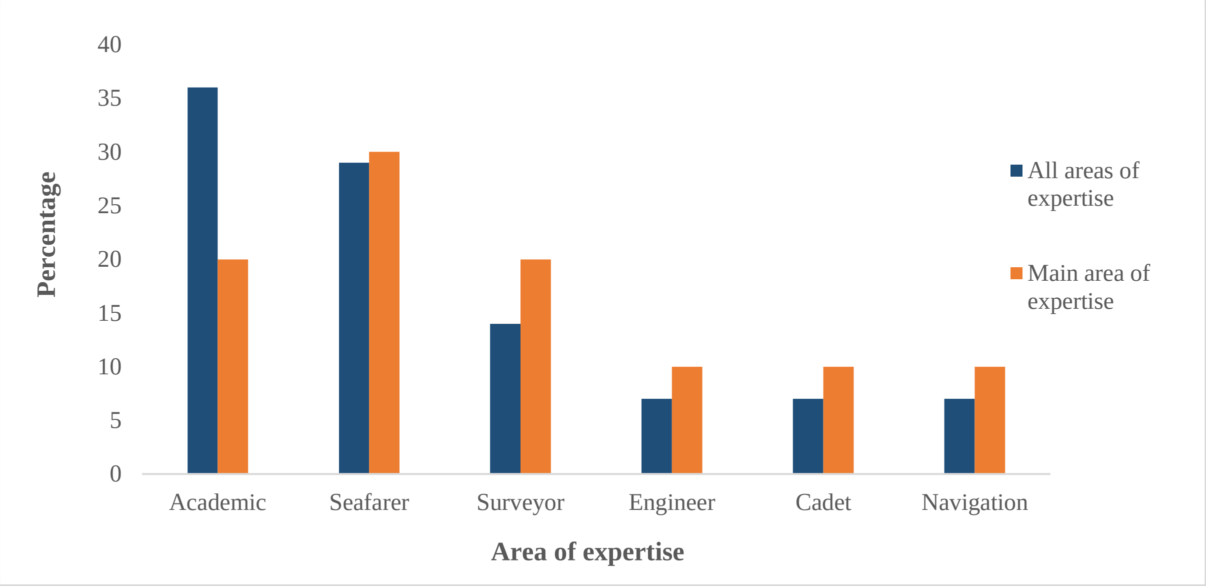


Figure 6.3. Background of participants.

6.6.1.2 Workshop Structure

A workshop was held at the University of Strathclyde on the 21st of March, 2019. The workshop was allocated at John Houlder MSc room at the Department of Naval Architecture, Ocean & Marine Engineering (NAOME) as shown in Figure 6.4. A workshop information form, which explains the objectives and the planned activities of the workshop, was provided to the participants at the beginning of the workshop. This information form is provided in Appendix B.

Figure 6.4. Workshop location

The workshop consisted of three parts or steps. Figure 6.5 shows the overall structure of the workshop.

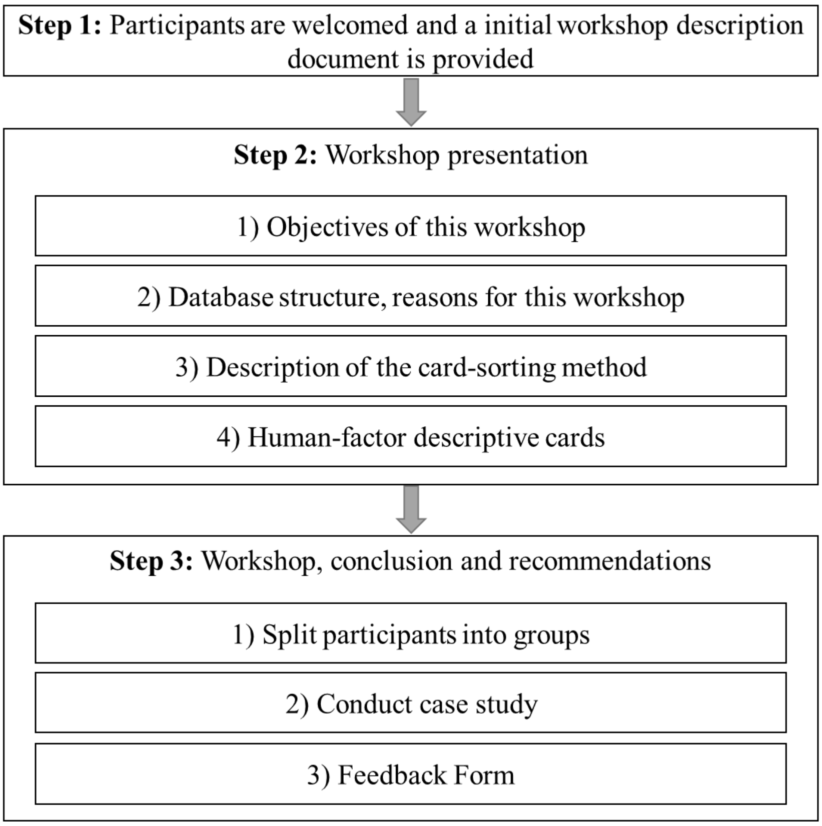


Figure 6.5. Structure of the workshop

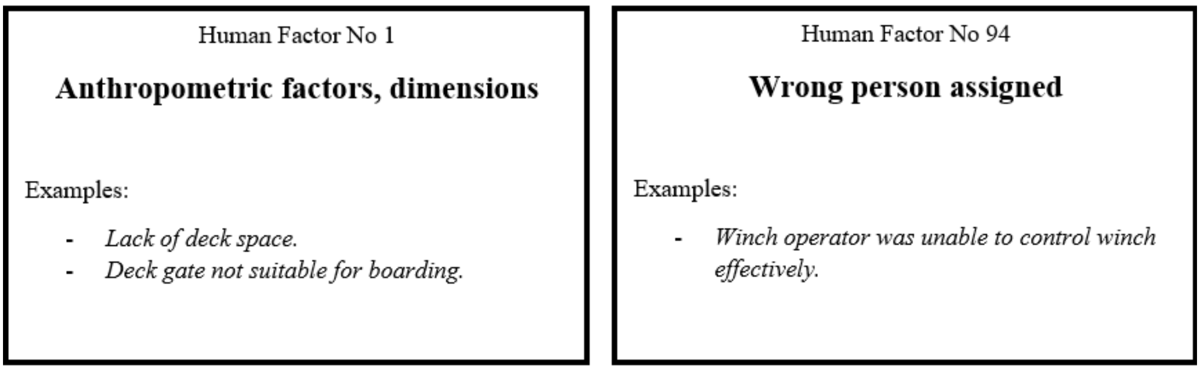
In order to explain the purpose of the workshop and tasks for each group a short presentation was made by the workshop moderator. Furthermore, participants were encouraged to raise questions at any time during the workshop to make sure that each group was generating reliable outputs. However, the presentation was designed to explain the objectives of the workshop clearly and briefly in order to maximize the time allocated for the main activity of the workshop (i.e. to sort HFs into more generic categories). Therefore, no additional questions were raised regarding the presentation.

The presentation was followed by a brief introduction of all experts to identify their main area of expertise. Then, based on the number of experts attending the workshop and the background of each expert, two different groups were set to sort the aforementioned HFs separately. Thus, each group had a similar distribution in terms of background and work experience. The purpose of creating two different groups was mainly to analyse if groups of experts with similar expertise levels would classify HFs in a similar way. Finally, a feedback form was delivered to each participant to obtain further comments and recommendations. This feedback form is provided in Appendix C.

6.6.1.3 Workshop Process

During the workshop, the participants reviewed and sorted 94 HFs (see Table 6.1) into more generic categories. The method that was applied to fulfil this task is known as the card-sorting method. This method is used to organize, structure, and label content in an effective way. Hence, the card-sorting method aims to help users find information and complete a predefined task, understanding how all the pieces fit together to create a larger picture. In a card sorting session, participants organize topics into categories that make sense to them, and they also might be asked to label these groups. Although this activity could be carried out individually by using a card-sorting software (e.g. OptimalSort software), it was decided to use actual cards. By using real cards, this session would be more beneficial as it would allow each member to interact with each other in the group, sharing his or her ideas to classify each HF.

In order to apply this method successfully, an initial explanation was given during the presentation, to explain the card-sorting procedure and how to apply it in an effective way. Then, a set of 94 HF descriptive cards was given to each group. Figure 6.6 shows as an example the first and the last cards of the card-set. These cards show the number of each HF at the top, following the same order as the initial list of HFs provided in Table 6.1. Then, each HF appears in bold text. Finally, some examples are provided at the bottom of each card with the aim to provide additional information about each HF, especially for those cases where the HF is not self-explanatory. These examples were extracted directly from accident investigators' comments. The complete set of 94 HF descriptive cards is provided in Appendix D.


Human Factor No 1

Anthropometric factors, dimensions

Examples:

- *Lack of deck space.*
- *Deck gate not suitable for boarding.*

Human Factor No 94

Wrong person assigned

Examples:

- *Winch operator was unable to control winch effectively.*

Figure 6.6. Example of HF descriptive cards

In addition, a different colour-coded set of cards was distributed amongst the groups to label each new HF category resulting from the discussions in each group. As there was no limit regarding how many new categories could be created, each group obtained initially thirty-two label cards. Moreover, the participants were informed that there were more label cards available if needed. Figure 6.7 provides an example of the label-cards format used during the workshop.

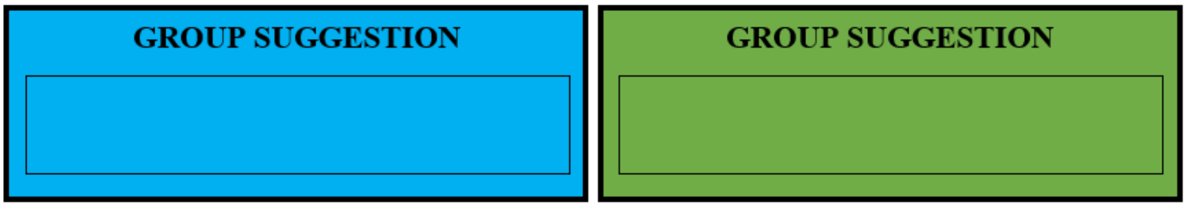


Figure 6.7. Example of HFs label cards

6.6.2 First Phase of Open Card-Sorting Case Study, Groups Created by Group1 and Group2

The main aim of the activity was to reduce the number of HFs listed in the database by grouping similar factors together and forming high-level HF categories from them. The participants examined the set of HF descriptive cards provided. Each group went through 94 cards and sorted them under the most suitable category according to their experience and background.

The first group of experts (i.e. Group1) sorted the 94 HF descriptive cards into eight new HF groups. The number of factors in each group was distributed unevenly but logical categorisation of factors was prioritised. The least populated group had five HF descriptive cards assigned (i.e. "Communication" group), while the highest number of cards sorted into a group was seventeen (i.e. "Safety culture" group).

Aforementioned new groups were named by the participants as follows: 1) "Communication", 2) "Supervision on-board ship", 3) "Technical and installation", 4) "Company issue and economic pressure", 5) "Regulations (mainly ISM)", 6) "Lack of training and competence", 7) "Behaviour", and 8) "Safety culture". Figure 6.8 shows which HFs were distributed under each of the aforementioned HF groups.

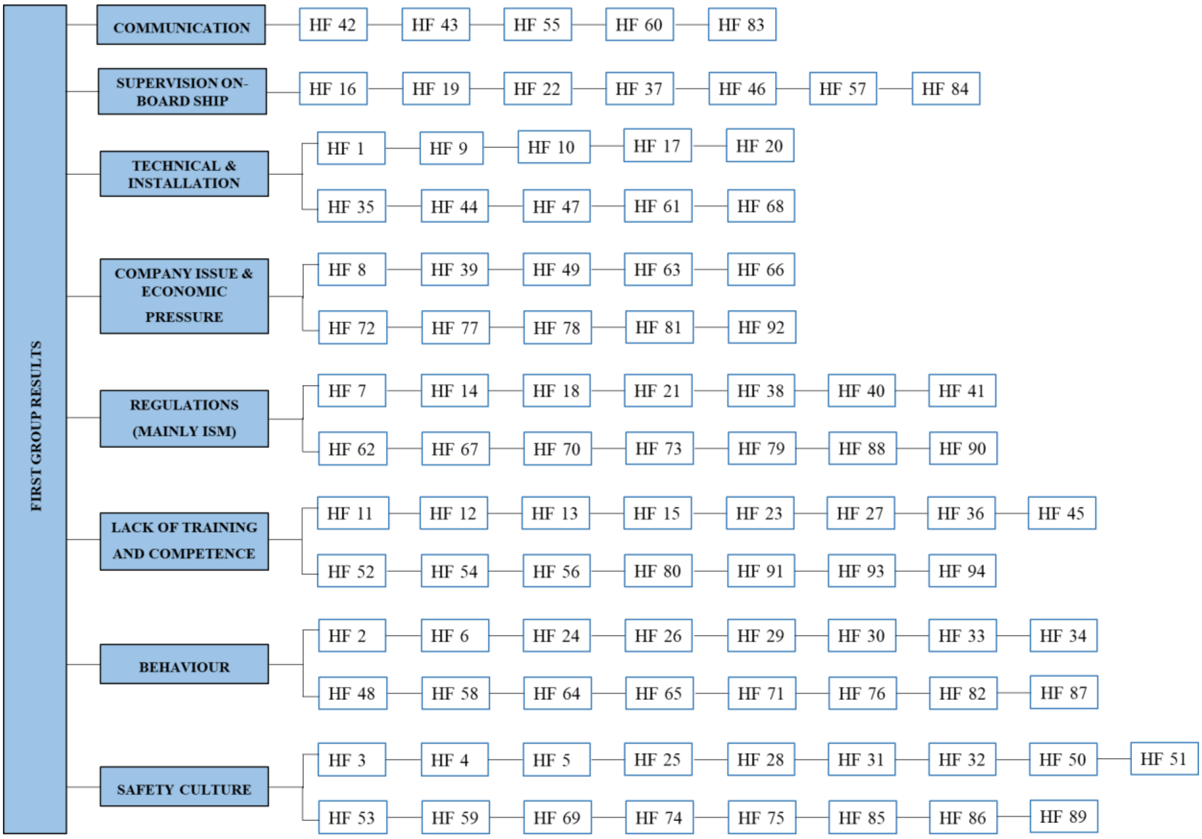


Figure 6.8. The HF classification provided by the first group (i.e. Group1)

The second group of experts (i.e. Group2) sorted their set of HF descriptive cards into fifteen new HF groups. It is worth to mention that for the second group of experts, a more unbalanced distribution was observed regarding the number of HFs assigned to each new group. Therefore, it is possible to clearly distinguish two different types of groups created, based on the number of HFs that each group contained. The first-type group have five or fewer HFs sorted in each of them. For some of these groups, participants indicated that the reasons given in the example were either not clear enough or conflicting with the category based on their expertise. Therefore, the group members could not come to an agreement to assign these HFs into more generic groups. Within this first-type group, participants defined nine groups as follows: 1) “External factors (weather condition, visibility, etc.)”, 2) “Restricted fairway, port congestion or heavy traffic”, 3) “Non-compliance”, 4) “Fatigue and workload”, 5) “Improper or lack of maintenance”, 6) “Commercial pressure”, 7) “Lack of equipment & PPE”, 8) “Lack of physical & mental fitness”, and 9) “Lack of or improper supervision”. For the second type, the HFs were better explained; hence, it was easier to sort them into more generic groups. Thus, six new groups were created and, in each group, at least six HFs are included. The participants named these groups as follows: 10) “Improper design”, 11) “Substandard monitoring (negligence on monitoring)", 12) "Lack of communication & coordination", 13) "Lack of training", 14) "Unprofessional behaviour", and 15) "Improper or deviation from procedures".

In addition, it can be noted that the least populated groups had only two HF descriptive cards assigned (i.e. 1) "External factors (weather condition, visibility, etc.)", 2) "Restricted fairway, port congestion or heavy traffic" and 3) "Non-compliance" groups), while the highest number of cards sorted into a group was nineteen (i.e. 15) "Improper or deviation from procedures"). Figure 6.9 shows which HFs were sorted into each HF group by the second group of experts.

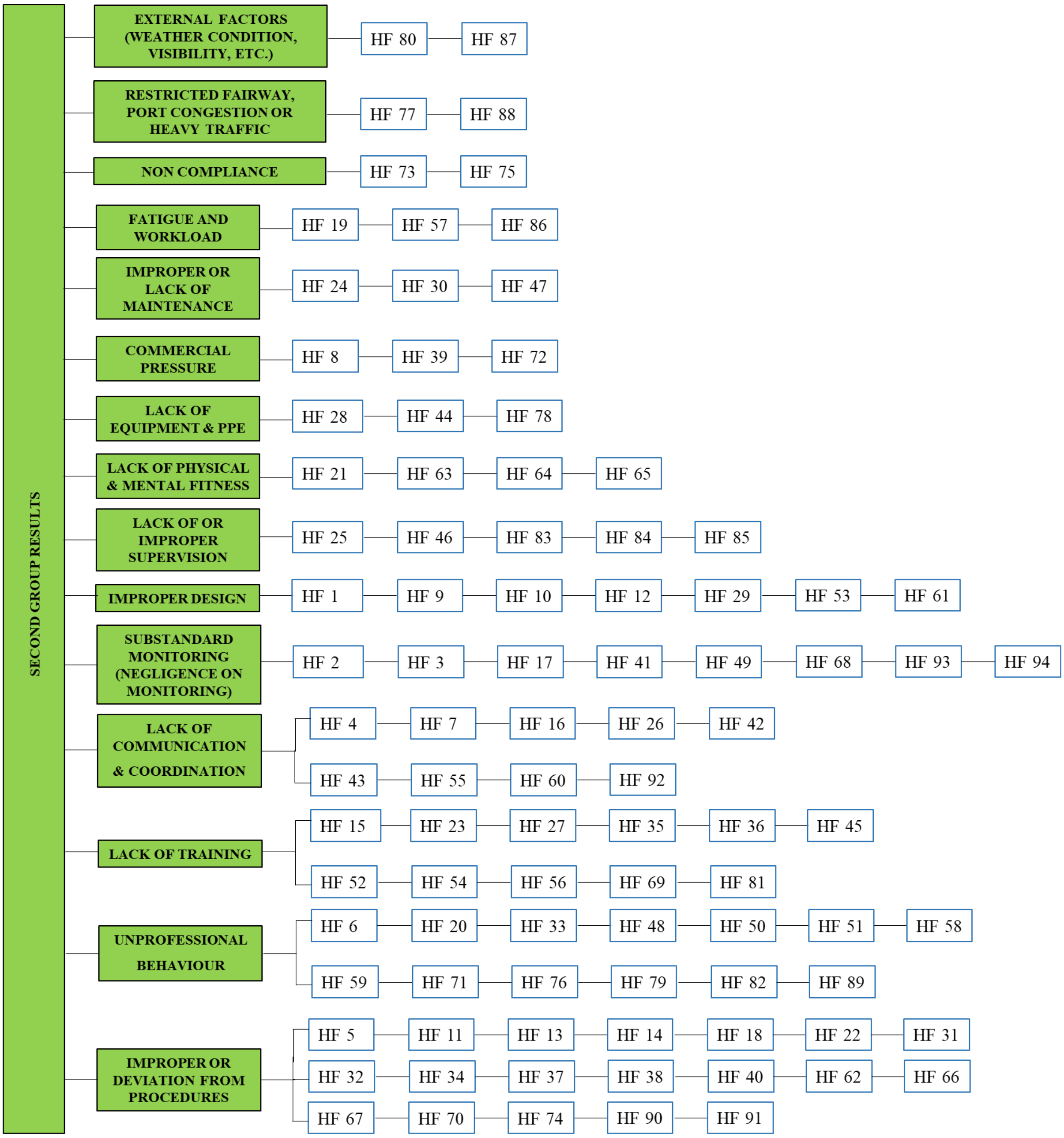


Figure 6.9. The HF classification provided by the second group (i.e. Group2)

6.6.3 First Phase of Open Card-Sorting Case Study, Workshop Evaluation

Finally, a workshop evaluation was carried out to examine whether the intended objectives of the workshop were completed. Thus, it allowed identifying areas of improvement and the way ahead by collecting and analysing a feedback form, which is displayed in Appendix C.

6.6.3.1 Immediate Feedback from Participants

After the workshop, discussions were conducted with participants to give their immediate feedback and comments. Participants felt happy with the outcome of categories they have generated as a result of the following card sorting method. They felt that their expertise was appropriate to conduct card sorting tasks related to HF in maritime accidents. Moreover, the majority of the participants found that the time allocated to the workshop was adequate.

A feedback form was delivered to the participants to evaluate the workshop. It consisted of two sections. For each section, a set of statements were presented to the participants. They were asked to indicate to what extent they agree or disagree with a particular statement. The scale ranged from 1 (i.e. strongly disagree) to 5 (i.e. strongly agree). The first section was related to the participants' background regarding accident investigations, HFs, and ship operations. It also included a few questions related to their main area of expertise and experience. The second section was focused on the workshop structure and content. Thus, this section was divided into three themes. The first theme was related to the presentation of the workshop. The second theme aimed to reflect the workshop structure and its impact. Besides, the third theme was focused on the tool used during the workshop (i.e. the card sorting method). Moreover, additional space was provided on the feedback form to capture further comments and feedback from the participants.

6.6.3.2 Participants' Answers to the First Section

This section was related to each participant's background. Table 6.2 shows the mean value, the standard deviation, and the minimum and maximum scores ranging from 1 (i.e. strongly disagree) to 5 (i.e. strongly agree), which have been attributed by participants regarding their own background.

Table 6.2. Participants' answers regarding their background

No	Statement	Mean	SD	Min	Max
1	Level of knowledge regarding accident investigations	3.90	0.74	3	5
2	Level of knowledge regarding human factors	3.50	1.27	2	5
3	Level of knowledge regarding ship operations	4.30	0.48	4	5

It can be noted that almost 80% of participants (mean value of 3.90) had a high level of knowledge regarding accident-investigation processes. Thus, 70% of participants (mean value of 3.50), had a high level of knowledge regarding HFs. Finally, more than 85% of participants (mean value of 4.30) were highly familiar with ship operations.

Furthermore, the years of experience of each participant are shown in Figure 6.10. It can be observed that participants have an average of twelve years of experience. In addition, only three participants had three or fewer years of experience when the workshop took place. Finally, information regarding the origin of participants and their areas of expertise (e.g. academic, surveyor, etc.) was provided at the beginning of this section, in Figure 6.2 and Figure 6.3 respectively.

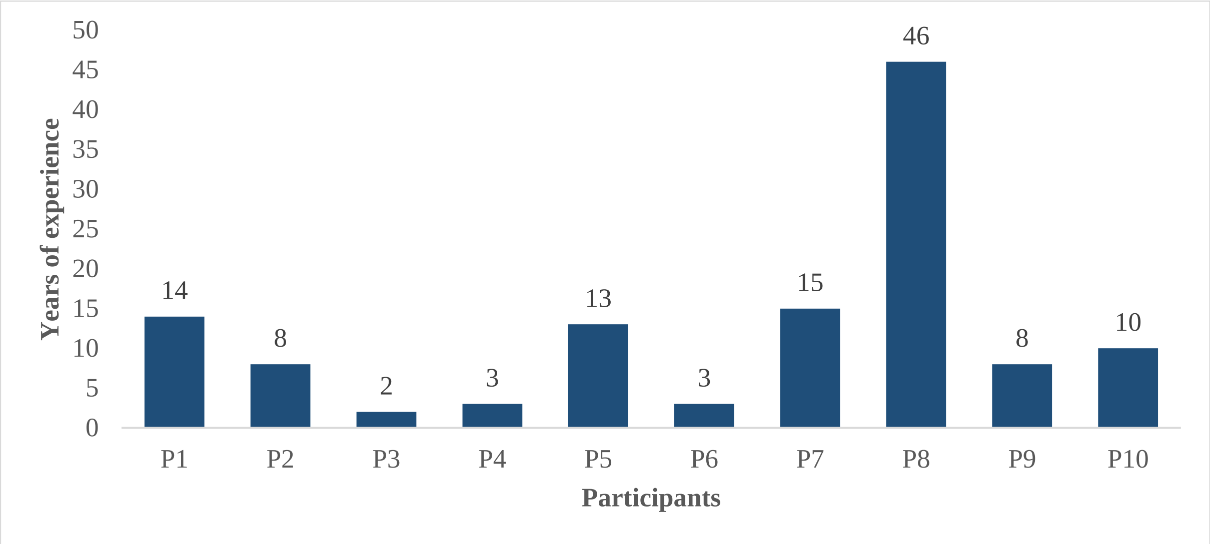


Figure 6.10. Participants' years of experience

6.6.3.3 Participants' Answers to the Second Section

As discussed above, this section was divided into three themes. The first theme was related to the presentation given by the author to explain the workshop objectives and the selected technique to classify the initial list of HFs. Table 6.3 shows the mean value, the standard deviation, and the minimum and maximum scores ranging from 1 (i.e. strongly disagree) to 5 (i.e. strongly agree), which have been attributed by participants regarding the introduction.

Table 6.3. Participants' answers regarding the introduction

No	Statement	Mean	SD	Min	Max
1	The information was clearly given by the presenter	4.30	0.67	3	5
2	The presenter attracted audience attention	4.20	0.79	3	5
3	The presentation was well-structured	3.00	1.28	1	5
4	The presenter answered appropriately to the questions	4.50	0.71	3	5
5	The presenter helped to achieve the workshop objectives in time and content	4.70	0.48	4	5

The majority of the answers regarding the introduction were positive. As can be seen from the table given above, the participants' answers can be summed up as follows. More than 85% of the participants found the information clearly given by the presenter (mean value of 4.30). The presenter attracted the audience's attention for almost 85% (mean value of 4.20). The presentation was well structured according to 60% (mean value of 3.00). The presenter answered the questions appropriately for more than 90% (mean value of 4.50). In addition, the presenter helped to achieve the workshop objectives in time and content according to almost 95% (mean value of 4.70).

The second theme of this section aimed to reflect the workshop structure and its impact on each participant. Table 6.4 shows the mean value, the standard deviation, and the minimum and maximum scores ranging from 1 to 5, which have been attributed by participants regarding the aforementioned workshop structure and impact.

Table 6.4. Participants' answers regarding the workshop structure and its impact

No	Statement	Mean	SD	Min	Max
1	The workshop was relevant for me	4.40	0.84	3	5
2	The workshop was interesting	4.90	0.32	4	5
3	The workshop content was significant for me	4.00	1.05	2	5
4	The workshop pushed me to reflect on my own thoughts	4.30	0.82	3	5
5	The time allocated to this workshop was adequate	4.70	0.48	4	5

With respect to the structure and impact of the workshop, the majority of the participants found the workshop

- Relevant for them (almost 90%, a mean value of 4.40),
- Interesting (more than 95%, a mean value of 4.90),
- The content was significant for them (80%, a mean value of 4.00),

- The workshop pushed them to reflect on their own actions (more than 85%, a mean value of 4.30),
- The time allocated was adequate (almost 95%, a mean value of 4.70).

Finally, the last theme addressed the technique used during the workshop (i.e. card sorting method). Table 6.5 shows the mean value, the standard deviation, and the minimum and maximum scores ranging from 1 to 5, attributed by participants regarding the last theme.

Table 6.5. Participants' answers regarding the workshop technique (i.e. card sorting method)

No	Statement	Mean	SD	Min	Max
1	Card sorting method was easy to understand and use	4.70	0.67	3	5
2	Card sorting method is suitable to classify human factors	4.40	0.70	3	5
3	Card sorting method generated a debate among participants	4.80	0.42	4	5

It can be noted that almost 95% of participants (mean value of 4.70) found that the card-sorting method was easy to understand and apply. For almost 90% (mean value of 4.40), the card-sorting method was a suitable method to classify HFs. Finally, more than 95% of participants (mean value of 4.80) found that the card-sorting method generated a debate among them.

6.6.3.4 Participants' Additional Feedback and Recommendations

Some participants also provided additional feedback and recommendations. Thus, some issues and conflict of ideas during the HF classification process were addressed on these comments. The comments received from these participants are given below, where "P" stands for participants.

- **P1, additional comments:** "The presentation I would say was generally good. However, due to the complexity of scenarios, it was a bit difficult to comprehend or allocate some of the cards. So I believe the difficulties are actually part of the research".
- **P2, additional comments:** "It would be convenient to cite proper/representative examples of the HFs since the ones utilized for the workshop were atrocious of best".
- **P2, additional comments:** "Advise participants/teams to create generic HF groups to avoid exhaustive amounts of HF groups and save time".
- **P4, additional comments:** "Some examples are not relevant with the title".
- **P5, additional comments:** "In HF No 54, the reasons given might not lead to an accident. Even if they led to an aggravation of risk may not be always obvious. There

may be reasons beyond such as potential economic pressure as it may have been the case under example 54".

- **P6, additional comments:** "It was a very interesting workshop".
- **P8, additional comments:** "Excellent exercise to communicate with students of different angles and opinions of questions".
- **P8, additional comments:** "Easy to use and understand".

6.6.4 Second Phase of Open Card-Sorting Case Study

Additionally, an online open card-sorting case study was created by using the OptimalSort software, aiming to reach additional experts (i.e. Group3 and Group4). Thus, following the same structure that the workshop, the online case study included a description of the 94 HFs from the historical accident database. Figure 6.11 provides an insight into the software that was used for the online open card-sorting case study.

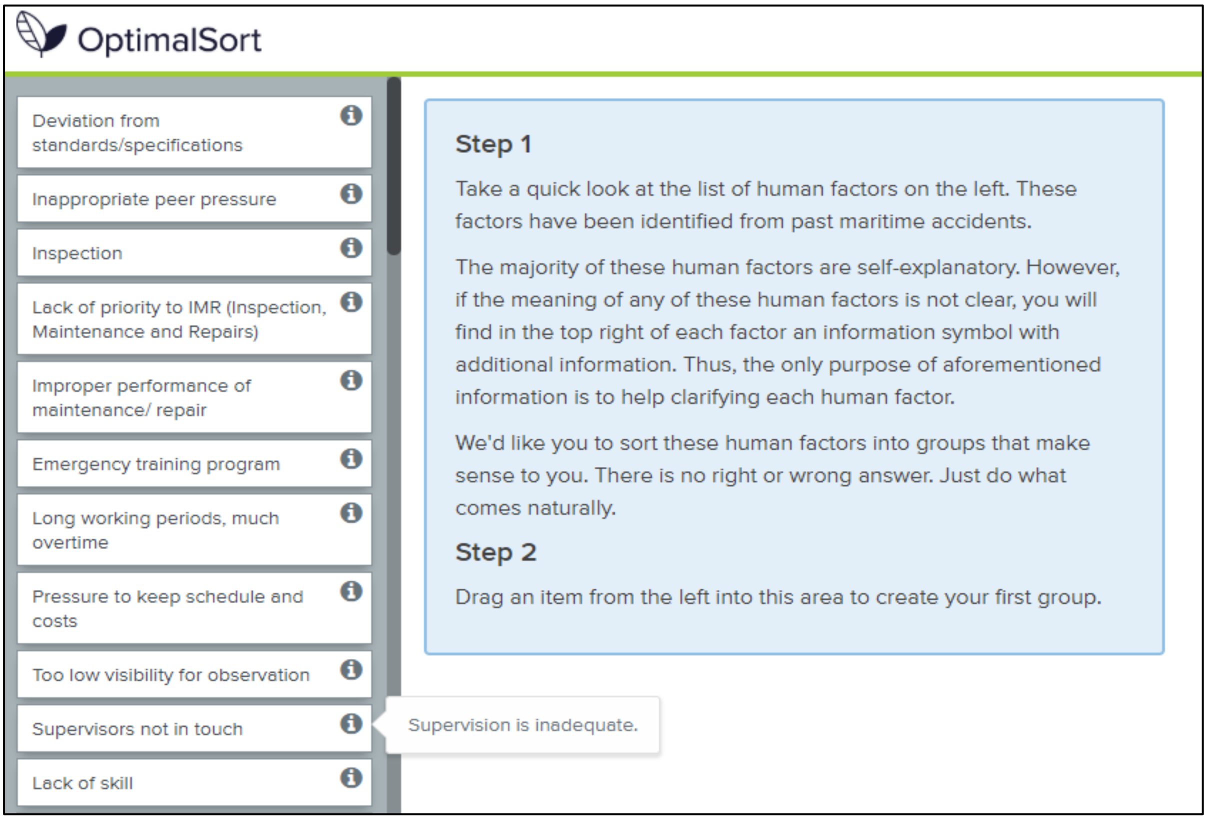


Figure 6.11. The platform that was used for the online case study

6.7 Analysis of the Open Card-Sorting Results

With the aim of analysing the four sets of results obtained from the open card-sorting session, first a set of qualitative and quantitative analysis was conducted. The first of the aforementioned qualitative analysis was the so-called topic normalisation, in which experts analysed the results from the participants to merge those HF groups with a similar terminology into a single HF category. Second, statistical analysis was conducted to assess the significance of features within the data. In addition, an expert analysis was carried out, aiming to group additional HFs that were not categorized successfully by means of statistical analysis.

6.7.1 Groups' Normalisation

As it was stated in previous sections, a topic normalisation is one of the most common qualitative techniques, which is widely applied to analyse the outcome of card-sorting sessions. Thus, the groups created by the four participants of this open case study were analysed by means of the aforementioned technique. To perform this analysis, two experts on HFs were asked to compare the numerous groups created within this case study and merge similar groups into common HF categories. Table 6.6 provides the most common groups created amongst participants. To create each normalised group, it was established to consider those categories from the open case study in which at least two participants created a similar group. The only exemption to the previous requirement was the category "Substandard monitoring", however, it was agreed by the experts that a substandard monitoring category was highly important and it should be included within this study, even if only one participant created it. Hence, a list of the normalised groups proposed is shown in Table 6.7.

Table 6.6. Major groups created within the open card-sorting case study and normalised results

Participant1	**Participant2**	**Participant3**	**Participant4**
Company issue & economic pressure	Commercial pressure	Commercial environment	X
X	External factors (weather condition, visibility, etc.)	Environment-external	Environs
Technical & installation	Improper design	Working environment	Design and equipment
Supervision on-board ship	Lack of or improper supervision	Leadership and supervision	X
Communication	Lack of communication & coordination	X	Process-communication
X	Improper or lack of maintenance	Maintenance	X
Lack of training and competence	Lack of training	Training	Process-training
Safety culture	X	Safety culture-shore management and safety culture-ship's staff	X
Regulations (mainly ism)	Improper or deviation from procedures	Regulatory	Regs
X	Substandard monitoring (negligence on monitoring)	X	X
Behaviour	Unprofessional behaviour	X	X

Table 6.7. Results from the open-case study. Normalised groups

No	Group Name	No	Group Name
1	Commercial pressure	7	Lack of training
2	Effect of environmental and external factors	8	Safety culture
3	Improper design, installation, and working environment	9	Safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)
4	Inadequate leadership and supervision	10	Safety management system: Substandard monitoring
5	Lack of communication and coordination	11	Unprofessional behaviour
6	Lack of, improper or late maintenance		

6.7.2 Statistical Analysis

The next logical step was to analyse the results from a quantitative perspective. Hence, statistical analysis was performed to identify how often and which HFs were sorted into the same group. Thus, Table 6.8 provides those cards that were sorted by at least half of the participants in the same group together with the statistical frequency and the normalised groups in which the cards were sorted. Thus, a list with the above-mentioned normalised groups was provided in Table 6.7.

Table 6.8. Statistical analysis. Open card-sorting case study

Card	Freq.	Group No	Card	Freq.	Group No	Card	Freq.	Group No
1	1.00	Group 3	81	0.75	Group 7	48	0.5	Group 11
9	1.00	Group 3	84	0.75	Group 4	50	0.5	Group 8
10	1.00	Group 3	87	0.75	Group 2	51	0.5	Group 8
15	1.00	Group 7	88	0.75	Group 2	53	0.5	Group 3
36	1.00	Group 7	6	0.5	Group 11	54	0.5	Group 7
8	0.75	Group 1	14	0.5	Group 9	55	0.5	Group 5
12	0.75	Group 3	16	0.5	Group 4	56	0.5	Group 7
29	0.75	Group 3	18	0.5	Group 9	58	0.5	Group 11
40	0.75	Group 9	19	0.5	Group 4	62	0.5	Group 9
42	0.75	Group 5	23	0.5	Group 7	67	0.5	Group 9
43	0.75	Group 5	25	0.5	Group 4	68	0.5	Group 3
45	0.75	Group 7	27	0.5	Group 7	70	0.5	Group 9
46	0.75	Group 4	30	0.5	Group 6	71	0.5	Group 11
52	0.75	Group 7	33	0.5	Group 11	73	0.5	Group 9
60	0.75	Group 5	34	0.5	Group 9	75	0.5	Group 9
61	0.75	Group 3	37	0.5	Group 4	76	0.5	Group 11
69	0.75	Group 7	38	0.5	Group 9	82	0.5	Group 11
72	0.75	Group 1	39	0.5	Group 1	83	0.5	Group 4
74	0.75	Group 9	41	0.5	Group 9	85	0.5	Group 8
77	0.75	Group 2	44	0.5	Group 3	89	0.5	Group 8
80	0.75	Group 2	47	0.5	Group 6	90	0.5	Group 9

6.7.3 Expert Analysis

After the first quantitative analysis (i.e. the aforementioned statistical analysis) was conducted, the results of the open card-sorting case study were assessed by two experts in HFs in order to understand the data collected and to analyse participants' answers. Thus, the aim of this analysis was to group additional HFs that were not classified successfully by means of statistical analysis. Table 6.9 provides a list of the additional HFs that were classified into the above-mentioned normalised groups by applying expert knowledge.

Table 6.9. Additional human factors that were classified by applying expert analysis

Card	Group No	Card	Group No	Card	Group No	Card	Group No
2	Group 10	13	Group 9	24	Group 6	49	Group 6
3	Group 10	17	Group 6	26	Group 4	79	Group 11
4	Group 4	21	Group 9	32	Group 9	93	Group 10
5	Group 10	22	Group 9	35	Group 3		

6.8 Hybrid Card-Sorting Case Study

As it was described in the previous section, eleven HFs groups were created within the open-card sorting case study. In addition, after conducting statistical analysis and expert judgment of the answer provided by the participants, it was observed that 78 out of the initial 94 HFs from the accident database (Table 6.1) had been sorted successfully. Then, in order to complete aforementioned classification and obtain results that are more reliable, a new hybrid card-sorting case study was created with the remaining unsorted HFs, aiming to collect responses from additional participants (i.e. HF7, HF11, HF20, HF28, HF31, HF57, HF59, HF63, HF64, HF65, HF66, HF78, HF86, HF91, HF92, HF94).

Therefore an online hybrid card-sorting case study was created by using the OptimalSort software, in which the normalised groups obtained within the open card-sorting case study were provided, but participants were also allowed creating additional groups. Thus, following the same structure that the open card-sorting case study, the above-mentioned hybrid case study included a description of the remaining sixteen HFs. Table 6.10 includes the results collected from the hybrid case study.

Table 6.10. Results from the hybrid case study

Card No	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
7	G 7	G 4	G 7	G 8	G 10	G 7	G 7	G 7	G 4	G 9
11	G 9	G 1	G 9	G 9	G 3	G 9	G 9	G 3	G 3	G 9
20	G 8	G 6	G 8	G 11	G 8	G 11	G 8	G 10	G 11	G 8
28	G 3	G 6	G 8	G 1	G 10	G 8	G 8	G 7	G 6	G 3
31	G 9	G 8	G 1	G 1	G 10	G 10	G 10	G 4	G 9	G 9
57	G 9	G 11	G 1	G 1	G 10	G 10	G 10	G 3	G 1	G 10
59	G 7	G 5	G 8	G 8	G 8	G 11	G 8	G 9	G 11	G 10
63	G 4	G 9	G 8	G 5	G 10	G 9	G 9	G 8	G 8	G 9
64	G 11	G 8	G 10	G 9	G 10	G 11	G 9	G 8	G 11	Personal factors
65	G 11	G 8	G 10	G 9	G 11	G 11	G 11	G 8	G 8	Personal factors
66	G 7	G 7	G 6	G 8	G 10	G 6	G 7	G 6	G 6	G 9
78	G 3	G 3	G 8	G 1	G 6	G 8	G 3	G 3	G 4	G 3
86	G 9	G 4	G 1	G 1	G 10	G 10	G 10	G 3	G 9	G 10
91	G 3	G 3	G 9	G 11	G 6	G 7	G 3	G 3	G 11	G 7
92	G 9	G 10	G 9	G 3	G 10	G 9	G 9	G 9	G 8	G 4
94	G 5	G 4	G 4	G 10	G 10	G 10	G 10	G 4	G 4	G 4

6.9 Analysis of the Hybrid Card-Sorting Results

6.9.1 **Statistical analysis**

With the aim of analysing the results obtained from the hybrid card-sorting session, qualitative analysis (i.e. statistical analysis) were conducted to assess how often and which HFs were sorted in the same group. Therefore, Table 6.11 provides the results after performing the aforementioned statistical analysis. For example, 60% of the participants agreed to allocated card No 11 into Group 9.

Table 6.11. Statistical analysis. Hybrid card-sorting case study

Card	Freq.	Group No	Card	Freq.	Group No	Card	Freq.	Group No
11	0.6	Group 9	57	0.4	Group 10	91	0.4	Group 3
7	0.5	Group 7	59	0.4	Group 8	28	0.3	Group 8
20	0.5	Group 8	63	0.4	Group 9	31	0.3	Group 9
78	0.5	Group 3	65	0.4	Group 11	64	0.3	Group 11
92	0.5	Group 9	66	0.4	Group 6			
94	0.5	Group 4	86	0.4	Group 10			

6.10 Initial Proposal for a Human Factor Classification

After performing first an open card-sorting case study, and second, a hybrid card-sorting case study, an initial HF classification was proposed. Hence, Table 6.12 provides the aforementioned initial HF classification, which was created by incorporating the findings from the aforementioned studies.

Table 6.12. Initial proposed human-factor classification

Card	Group No	Card	Group No	Card	Group No	Card	Group No
1	Group 3	25	Group 4	49	Group 6	73	Group 9
2	Group 10	26	Group 4	50	Group 8	74	Group 9
3	Group 10	27	Group 7	51	Group 8	75	Group 9
4	Group 4	28	Group 8	52	Group 7	76	Group 11
5	Group 10	29	Group 3	53	Group 3	77	Group 2
6	Group 11	30	Group 6	54	Group 7	78	Group 3
7	Group 7	31	Group 9	55	Group 5	79	Group 11
8	Group 1	32	Group 9	56	Group 7	80	Group 2
9	Group 3	33	Group 11	57	Group 3	81	Group 7
10	Group 3	34	Group 9	58	Group 11	82	Group 11
11	Group 9	35	Group 3	59	Group 8	83	Group 4
12	Group 3	36	Group 7	60	Group 5	84	Group 4
13	Group 9	37	Group 4	61	Group 3	85	Group 10
14	Group 9	38	Group 9	62	Group 9	86	Group 10
15	Group 7	39	Group 1	63	Group 9	87	Group 2
16	Group 4	40	Group 9	64	Group 11	88	Group 2
17	Group 6	41	Group 9	65	Group 11	89	Group 8
18	Group 9	42	Group 5	66	Group 6	90	Group 9
19	Group 4	43	Group 5	67	Group 9	91	Group 3
20	Group 8	44	Group 3	68	Group 3	92	Group 9
21	Group 9	45	Group 7	69	Group 7	93	Group 10
22	Group 9	46	Group 4	70	Group 9	94	Group 4
23	Group 7	47	Group 6	71	Group 11		
24	Group 6	48	Group 11	72	Group 1		

6.11 Validation and Amendments of Initial Proposal for a Human Factor Classification

The next step was to validate the initial proposal for an HF classification by first conducting a co-occurrence analysis, and second, by comparing the initial proposal for an HF classification with the results from the co-occurrence analysis. Adjustments to the initial proposed classification were made based on the results of the co-occurrence analysis.

6.11.1 **Co-occurrence Analysis**

The so-called co-occurrence analysis aims to calculate the number of times that cards are paired together, independently of the group in which they are sorted. Thus, a co-occurrence analysis aims to identify strong common relationships between cards, which would emerge regardless of the different sorting mental models amongst participants. Furthermore, a co-occurrence analysis can be used as a confidence measure to help judge the validity of a card group (Paul, 2014). Thus, Table 6.13 provides the results that were obtained from the co-occurrence analysis. Only card relationships that have 75% agreement or greater may be considered high confidence (Paul, 2014). Therefore, only those cases in which at least three participants paired the same cards (i.e. 75% agreement) are included in Table 6.13, where C. A stands for Card A and C. B stands for Card B.

Table 6.13. Results from co-occurrence analysis by participants

C. A	C. B	P1	P2	P3	P4	Total	C. A	C. B	P1	P2	P3	P4	Total
1	9	X	X	X	X	4	19	46	X		X	X	3
1	10	X	X	X	X	4	19	57	X	X		X	3
6	48	X	X	X	X	4	23	45	X	X		X	3
6	58	X	X	X	X	4	23	52	X	X		X	3
6	76	X	X	X	X	4	23	56	X	X	X		3
8	72	X	X	X	X	4	30	47		X	X	X	3
9	10	X	X	X	X	4	31	32	X	X		X	3
14	62	X	X	X	X	4	31	86	X		X	X	3
15	36	X	X	X	X	4	32	59	X		X	X	3
23	54	X	X	X	X	4	32	62		X	X	X	3
42	60	X	X	X	X	4	35	61	X		X	X	3
45	52	X	X	X	X	4	36	45	X	X	X		3
48	58	X	X	X	X	4	36	52	X	X	X		3
48	76	X	X	X	X	4	36	69		X	X	X	3
51	89	X	X	X	X	4	36	81		X	X	X	3
58	76	X	X	X	X	4	37	38		X	X	X	3
67	70	X	X	X	X	4	41	73	X		X	X	3
67	90	X	X	X	X	4	42	43	X	X		X	3
70	90	X	X	X	X	4	42	55	X	X	X		3
1	61	X	X	X		3	43	60	X	X		X	3
2	93		X	X	X	3	44	68	X		X	X	3
3	32	X		X	X	3	45	54	X	X		X	3
3	59	X		X	X	3	46	83		X	X	X	3
5	13		X	X	X	3	46	84	X	X	X		3
5	32	X	X	X		3	48	51		X	X	X	3
5	67		X	X	X	3	48	64	X		X	X	3
5	70		X	X	X	3	48	71	X	X		X	3
5	90		X	X	X	3	48	89		X	X	X	3
6	51		X	X	X	3	49	66	X		X	X	3
6	64	X		X	X	3	50	59	X	X		X	3
6	71	X	X		X	3	51	58		X	X	X	3
6	89		X	X	X	3	51	76		X	X	X	3

C. A	C. B	P1	P2	P3	P4	Total	C. A	C. B	P1	P2	P3	P4	Total
9	61	X	X	X		3	52	54	X	X		X	3
10	61	X	X	X		3	53	61		X	X	X	3
12	29		X	X	X	3	54	56	X	X	X		3
13	67		X	X	X	3	55	60	X	X	X		3
13	70		X	X	X	3	57	86		X	X	X	3
13	90		X	X	X	3	58	64	X		X	X	3
14	18	X	X		X	3	58	71	X	X		X	3
14	32		X	X	X	3	58	89		X	X	X	3
14	67	X	X	X		3	62	67	X	X	X		3
14	70	X	X	X		3	62	70	X	X	X		3
14	90	X	X	X		3	62	90	X	X	X		3
15	45	X	X	X		3	64	65	X	X		X	3
15	52	X	X	X		3	64	76	X		X	X	3
15	69		X	X	X	3	69	81		X	X	X	3
15	81		X	X	X	3	71	76	X	X		X	3
16	26		X	X	X	3	71	82	X	X	X		3
16	84	X		X	X	3	74	75	X		X	X	3
17	47	X		X	X	3	76	89		X	X	X	3
17	49		X	X	X	3	77	88		X	X	X	3
18	40	X	X	X		3	80	87		X	X	X	3
18	62	X	X		X	3	93	94	X	X		X	3

6.11.2 **Comparison between the Co-occurrence Analysis Results and the Initial Proposal for a Human Factor Classification**

Table 6.14 provides the agreement between the initial proposed classification and the co-occurrence results. In addition, it is possible to observe an initial 80.19% agreement between the co-occurrence results and the proposed classification before applying any re-definitions in the created groups.

Table 6.14. Agreement between the co-occurrence analysis and the proposed classification

C. A	C. B	Proposed taxonomy	C. A	C. B	Proposed taxonomy	C. A	C. B	Proposed taxonomy	C. A	C. B	Proposed taxonomy
1	9	✓	14	32	✓	35	61	✓	52	54	✓
1	10	✓	14	62	✓	36	45	✓	53	61	✓
1	61	✓	14	67	✓	36	52	✓	54	56	✓
2	93	✓	14	70	✓	36	69	✓	55	60	✓
3	32	×	14	90	✓	36	81	✓	57	86	×
3	59	×	15	36	✓	37	38	×	58	64	✓
5	13	×	15	45	✓	41	73	✓	58	71	✓
5	32	×	15	52	✓	42	43	✓	58	76	✓
5	67	×	15	69	✓	42	55	✓	58	89	×
5	70	×	15	81	✓	42	60	✓	62	67	✓
5	90	×	16	26	✓	43	60	✓	62	70	✓
6	48	✓	16	84	✓	44	68	✓	62	90	✓
6	51	×	17	47	✓	45	52	✓	64	65	✓
6	58	✓	17	49	✓	45	54	✓	64	76	✓
6	64	✓	18	40	✓	46	83	✓	67	70	✓
6	71	✓	18	62	✓	46	84	✓	67	90	✓
6	76	✓	19	46	✓	48	51	×	69	81	✓
6	89	×	19	57	×	48	58	✓	70	90	✓
8	72	✓	23	45	✓	48	64	✓	71	76	✓
9	10	✓	23	52	✓	48	71	✓	71	82	✓
9	61	✓	23	54	✓	48	76	✓	74	75	✓
10	61	✓	23	56	✓	48	89	×	76	89	×
12	29	✓	30	47	✓	49	66	✓	77	88	✓
13	67	✓	31	32	✓	50	59	✓	80	87	✓
13	70	✓	31	86	×	51	58	×	93	94	×
13	90	✓	32	59	×	51	76	×			
14	18	✓	32	62	✓	51	89	✓			

6.11.3 Adjustments in the Initial Proposal for a Human Factor Classification after Incorporating the Results from the Co-occurrence Analysis

With the aim of increasing the agreement between the co-occurrence results and the proposed classification, additional adjustments were applied to the proposed HF classification. Thus, Table 6.15 provides further insight into those HFs that were reallocated within the aforementioned proposed classification. Consequently, by comparing the results between the co-occurrence analysis and the adjusted classification, it is possible to increase the agreement on the results up to 98.11%, as shown in Table 6.16.

Table 6.15. Adjustment of proposed human-factor classification

No HF	Previous group before adjustment	Final group after adjustment
3	Safety management system: Substandard monitoring	Safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)
5	Safety management system: Substandard monitoring	Safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)
37	Inadequate leadership and supervision	Safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)
50	Safety culture	Safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)
51	Safety culture	Unprofessional behaviour
59	Safety culture	Safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)
86	Safety management system: Substandard monitoring	Improper design, installation, and working environment
89	Safety culture	Unprofessional behaviour
94	Inadequate leadership and supervision	Safety management system: Substandard monitoring

Table 6.16. Agreement between cards paired and proposed classification, after re-adjustments

C. A	C. B	Proposed taxonomy	C. A	C. B	Proposed taxonomy	C. A	C. B	Proposed taxonomy	C. A	C. B	Proposed taxonomy
1	9	✓	14	32	✓	35	61	✓	52	54	✓
1	10	✓	14	62	✓	36	45	✓	53	61	✓
1	61	✓	14	67	✓	36	52	✓	54	56	✓
2	93	✓	14	70	✓	36	69	✓	55	60	✓
3	32	✓	14	90	✓	36	81	✓	57	86	✓
3	59	✓	15	36	✓	37	38	✓	58	64	✓
5	13	✓	15	45	✓	41	73	✓	58	71	✓
5	32	✓	15	52	✓	42	43	✓	58	76	✓
5	67	✓	15	69	✓	42	55	✓	58	89	✓
5	70	✓	15	81	✓	42	60	✓	62	67	✓
5	90	✓	16	26	✓	43	60	✓	62	70	✓
6	48	✓	16	84	✓	44	68	✓	62	90	✓
6	51	✓	17	47	✓	45	52	✓	64	65	✓
6	58	✓	17	49	✓	45	54	✓	64	76	✓
6	64	✓	18	40	✓	46	83	✓	67	70	✓
6	71	✓	18	62	✓	46	84	✓	67	90	✓
6	76	✓	19	46	✓	48	51	✓	69	81	✓
6	89	✓	19	57	×	48	58	✓	70	90	✓
8	72	✓	23	45	✓	48	64	✓	71	76	✓
9	10	✓	23	52	✓	48	71	✓	71	82	✓
9	61	✓	23	54	✓	48	76	✓	74	75	✓
10	61	✓	23	56	✓	48	89	✓	76	89	✓
12	29	✓	30	47	✓	49	66	✓	77	88	✓
13	67	✓	31	32	✓	50	59	✓	80	87	✓
13	70	✓	31	86	×	51	58	✓	93	94	✓
13	90	✓	32	59	✓	51	76	✓			
14	18	✓	32	62	✓	51	89	✓			

6.12 Expert Analysis on Initial Proposal for a Human Factor Classification

Finally, expert opinion was requested to analyse the initial classification proposed after incorporating the results from the co-occurrence analysis. Thus, the aim of including expert analysis was to understand if the initial HFs from the accident database (Table 6.1) were properly classified into the aforementioned initial classification proposed. Therefore, experts in the area of HFs were asked to answer a five-point Likert scale, which is shown in Table 6.17. In order to obtain more reliable results, three highly qualified experts were selected. Two of the aforementioned experts had a PhD in the HFs area since 2006 and 2008 respectively, while the third expert was a PhD researcher with four years of experience in HFs.

Table 6.17. Level of expert agreement with the proposed classification

HF	Expert 1	Expert 2	Expert 3	HF	Expert 1	Expert 2	Expert 3
1	Strongly agree	Strongly agree	Strongly agree	48	Agree	Neither agree nor disagree	Disagree
2	Neither agree nor disagree	Agree	Neither agree nor disagree	49	Strongly agree	Strongly agree	Strongly agree
3	Strongly agree	Agree	Neither agree nor disagree	50	Neither agree nor disagree	Neither agree nor disagree	Neither agree nor disagree
4	Strongly agree	Strongly agree	Strongly agree	51	Agree	Agree	Agree
5	Strongly agree	Strongly agree	Strongly agree	52	Agree	Strongly agree	Strongly agree
6	Strongly agree	Strongly agree	Strongly agree	53	Strongly agree	Strongly agree	Strongly agree
7	Strongly agree	Strongly agree	Strongly agree	54	Agree	Neither agree nor disagree	Disagree
8	Strongly agree	Strongly agree	Strongly agree	55	Agree	Strongly agree	Agree
9	Strongly agree	Strongly agree	Strongly agree	56	Neither agree nor disagree	Neither agree nor disagree	Neither agree nor disagree
10	Strongly agree	Strongly agree	Strongly agree	57	Neither agree nor disagree	Disagree	Disagree
11	Strongly agree	Strongly agree	Strongly agree	58	Agree	Disagree	Disagree
12	Strongly agree	Strongly agree	Strongly agree	59	Agree	Agree	Agree
13	Agree	Agree	Agree	60	Strongly agree	Strongly agree	Strongly agree
14	Agree	Strongly agree	Agree	61	Strongly agree	Strongly agree	Strongly agree
15	Strongly agree	Strongly agree	Strongly agree	62	Agree	Neither agree nor disagree	Agree
16	Strongly agree	Strongly agree	Strongly agree	63	Neither agree nor disagree	Neither agree nor disagree	Agree
17	Strongly agree	Strongly agree	Strongly agree	64	Agree	Disagree	Neither agree nor disagree
18	Neither agree nor disagree	Neither agree nor disagree	Agree	65	Agree	Disagree	Disagree
19	Agree	Neither agree nor disagree	Neither agree nor disagree	66	Neither agree nor disagree	Disagree	Agree
20	Neither agree nor disagree	Neither agree nor disagree	Strongly agree	67	Agree	Agree	Agree
21	Neither agree nor disagree	Agree	Agree	68	Neither agree nor disagree	Disagree	Agree
22	Neither agree nor disagree	Agree	Neither agree nor disagree	69	Strongly agree	Strongly agree	Strongly agree
23	Neither agree nor disagree	Neither agree nor disagree	Disagree	70	Neither agree nor disagree	Agree	Neither agree nor disagree
24	Strongly agree	Strongly agree	Strongly agree	71	Strongly agree	Agree	Disagree

HF	Expert 1	Expert 2	Expert 3	HF	Expert 1	Expert 2	Expert 3
25	Strongly agree	Strongly agree	Strongly agree	72	Strongly agree	Strongly agree	Strongly agree
26	Neither agree nor disagree	Agree	Agree	73	Strongly agree	Strongly agree	Strongly agree
27	Agree	Neither agree nor disagree	Strongly agree	74	Strongly agree	Strongly agree	Strongly agree
28	Neither agree nor disagree	Disagree	Agree	75	Strongly agree	Strongly agree	Strongly agree
29	Strongly agree	Strongly agree	Strongly agree	76	Agree	Agree	Agree
30	Strongly agree	Strongly agree	Strongly agree	77	Strongly agree	Strongly agree	Strongly agree
31	Neither agree nor disagree	Agree	Neither agree nor disagree	78	Agree	Agree	Agree
32	Strongly agree	Strongly agree	Strongly agree	79	Strongly agree	Strongly agree	Strongly agree
33	Agree	Strongly disagree	Agree	80	Strongly agree	Strongly agree	Strongly agree
34	Strongly agree	Strongly agree	Strongly agree	81	Strongly agree	Strongly agree	Strongly agree
35	Neither agree nor disagree	Neither agree nor disagree	Disagree	82	Strongly agree	Strongly agree	Disagree
36	Strongly agree	Strongly agree	Strongly agree	83	Strongly agree	Strongly agree	Strongly agree
37	Neither agree nor disagree	Agree	Agree	84	Strongly agree	Strongly agree	Strongly agree
38	Neither agree nor disagree	Agree	Agree	85	Agree	Agree	Agree
39	Strongly agree	Neither agree nor disagree	Strongly agree	86	Neither agree nor disagree	Disagree	Disagree
40	Strongly agree	Strongly agree	Strongly agree	87	Strongly agree	Strongly agree	Strongly agree
41	Neither agree nor disagree	Disagree	Neither agree nor disagree	88	Strongly agree	Strongly agree	Strongly agree
42	Strongly agree	Strongly agree	Strongly agree	89	Strongly agree	Strongly agree	Strongly agree
43	Strongly agree	Strongly agree	Strongly agree	90	Neither agree nor disagree	Agree	Neither agree nor disagree
44	Neither agree nor disagree	Agree	Agree	91	Agree	Disagree	Neither agree nor disagree
45	Agree	Agree	Agree	92	Neither agree nor disagree	Neither agree nor disagree	Neither agree nor disagree
46	Strongly agree	Strongly agree	Strongly agree	93	Agree	Agree	Agree
47	Strongly agree	Strongly agree	Strongly agree	94	Neither agree nor disagree	Disagree	Disagree

In addition, an online workshop was conducted with the three aforementioned experts in HFs to discuss the results of expert agreement levels as shown in Table 6.17. Hence, as a final adjustment, it was decided to re-adjust a set of fourteen HFs (i.e. HF23, HF28, HF33, HF35, HF41, HF48, HF50, HF54, HF58, HF64, HF65, HF68, HF91, HF94) as requested by the expert analysis. Thus, Table 6.18 includes the final modifications that were made in the initial proposed classification, after incorporating the expert judgment results.

Table 6.18. Adjustment of proposed human-factor classification

No HF	Previous group after expert adjustment	Final group after expert adjustment
23	Lack of training	Inadequate leadership and supervision
28	Safety culture	Improper design, installation, and working environment
33	Unprofessional behaviour	Safety culture
35	Improper design, installation, and working environment	Lack of, improper or late maintenance
41	Safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)	Safety management system: Substandard monitoring
48	Unprofessional behaviour	Inadequate leadership and supervision
50	Safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)	Improper design, installation, and working environment
54	Lack of training	Unprofessional behaviour
58	Unprofessional behaviour	Inadequate leadership and supervision
64	Unprofessional behaviour	Inadequate leadership and supervision
65	Unprofessional behaviour	Inadequate leadership and supervision
68	Improper design, installation, and working environment	Safety management system: Substandard monitoring
91	Improper design, installation, and working environment	Lack of training
94	Safety management system: Substandard monitoring	Inadequate leadership and supervision

6.13 Final Proposal for a Human Factor Classification

Finally, Table 6.19 includes the final proposal for a human factor classification, after incorporating the results from expert judgment.

Table 6.19. The final proposal for a human factor classification after incorporating the findings from expert judgment

No	Group Name	Human Factors
1	Commercial pressure	8, 39, and 72
2	Effect of environmental and external factors	77, 80, 87, and 88
3	Improper design, installation and working environment	1, 9, 10, 12, 28, 29, 44, 50, 53, 57, 61, 79, and 86
4	Inadequate leadership and supervision	4, 16, 19, 23, 25, 26, 46, 48, 58, 64, 65, 83, 84, and 94
5	Lack of communication and coordination	42, 43, 55, and 60
6	Lack of, improper or late maintenance	17, 24, 30, 35, 47, 49, and 66
7	Lack of training	7, 15, 27, 36, 45, 52, 56, 69, 81, and 91
8	Safety culture	20 and 33
9	Safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)	3, 5, 11, 13, 14, 18, 21, 22, 31, 32, 34, 37, 38, 40, 59, 60, 63, 67, 70, 73, 74, 75, 90, and 92
10	Safety management system: Substandard monitoring	2, 41, 68, 85, and 93
11	Unprofessional behaviour	6, 51, 54, 71, 76, 79, 82, and 89

6.14 Chapter Summary

This chapter first provided the current MAIB HF classification. Second, it highlighted the need for a reduction and redefinition of MAIB HFs. In addition, various alternatives to reduce the aforementioned HFs were described, and their limitations were explained. Third, this chapter introduced the so-called card-sorting method, which was finally selected as the most suitable technique for the proposed HF reduction. Moreover, this chapter included the results of an open card-sorting case study and the analysis of the aforementioned results. Thus, the results and the analysis of a hybrid card-sorting case were also included. The next section included an initial proposal for an HF classification, which was validated through a co-occurrence analysis. Furthermore, experts in the area of HFs provided their feedback into the initial classification proposed and the last amendments were made, completing the final proposal for an HF classification.

Chapter 7 will introduce the Marine Accident Learning with Fuzzy Cognitive Maps (MALFCMs) method framework. Thus, the aim of the MALFCMs method is to calculate the weighting for each human-contributing factor that is involved in maritime accidents.

7 THE MARINE ACCIDENT LEARNING WITH FUZZY COGNITIVE MAPS (MALFCMS) METHOD

7.1 Overview

Although it has been demonstrated in Chapter 2 that a Fuzzy Cognitive Map (FCM) is an alternative and powerful method to model and analyse dynamic interactions between concepts or systems, it has an important limitation. As FCMs are designed to transcribe experts' opinions, its weaknesses lay on the uncertainty related to each expert's response. As a result, an FCM can equally encode the experts' lack of knowledge. Therefore, the reliability of a traditional FCM is linked to the experts' knowledge, background, and familiarity with the topic that is being addressed. In order to overcome this limitation, a method for Marine Accident Learning with Fuzzy Cognitive Maps (MALFCMs), which differs from the traditional FCM approach, is proposed. Within this new method, each FCM is developed through establishing relationships between factors from past accident experiences and, combining the results with expert opinion. Therefore, the results from the MALFCMs technique might be considered more objective, as this new approach overcomes the main disadvantage of fuzzy cognitive maps (i.e. the subjective results and knowledge deficiencies between experts).

This chapter[3] describes the overall framework of the MALFCMs method, which is proposed with the aim to establish weightings for contributing factors involved in past maritime accidents. Thus, the MALFCMs method is described in four major stages. First, Section 7.2 describes the first stage of the MALFCMs development, which involves the construction of an individual interaction matrix and a state vector, which are the required components to create an FCM as discussed in Chapter 2. The above-mentioned interaction matrix and state vector are based on the data gathered from a historical accident database. Second, Section 7.3 discusses the second stage of the MALFCMs approach, which is concerned with the construction of an individual interaction matrix and a state vector for each expert, and their posterior aggregation. Thus, this section also includes the data collection and analysis procedures, the description of the experts that participated in this research study, and the criteria that were adopted to determine the credibility weighting of each expert. Third, Section 7.4 explains the third stage of the MALFCMs method, which involves the construction of two

[3] The MALFCMs framework described on this chapter has been already converted to a journal paper and published in MethodsX (Beatriz Navas de Maya & Rafet Emek Kurt, 2020)

dynamic FCMs. The first dynamic FCM is created from the interaction matrix and state vector from the historical accident database. Thus, the second dynamic FCM is obtained from the aggregated individual interaction matrix and state vector. Finally, Section 7.5 includes the consolidation of the results by combining the findings from both FCMs, which is achieved through a sensitivity analysis of the weightings that are obtained from both FCMs. In addition, an overview of the overall MALFCMs method is provided in Figure 7.1.

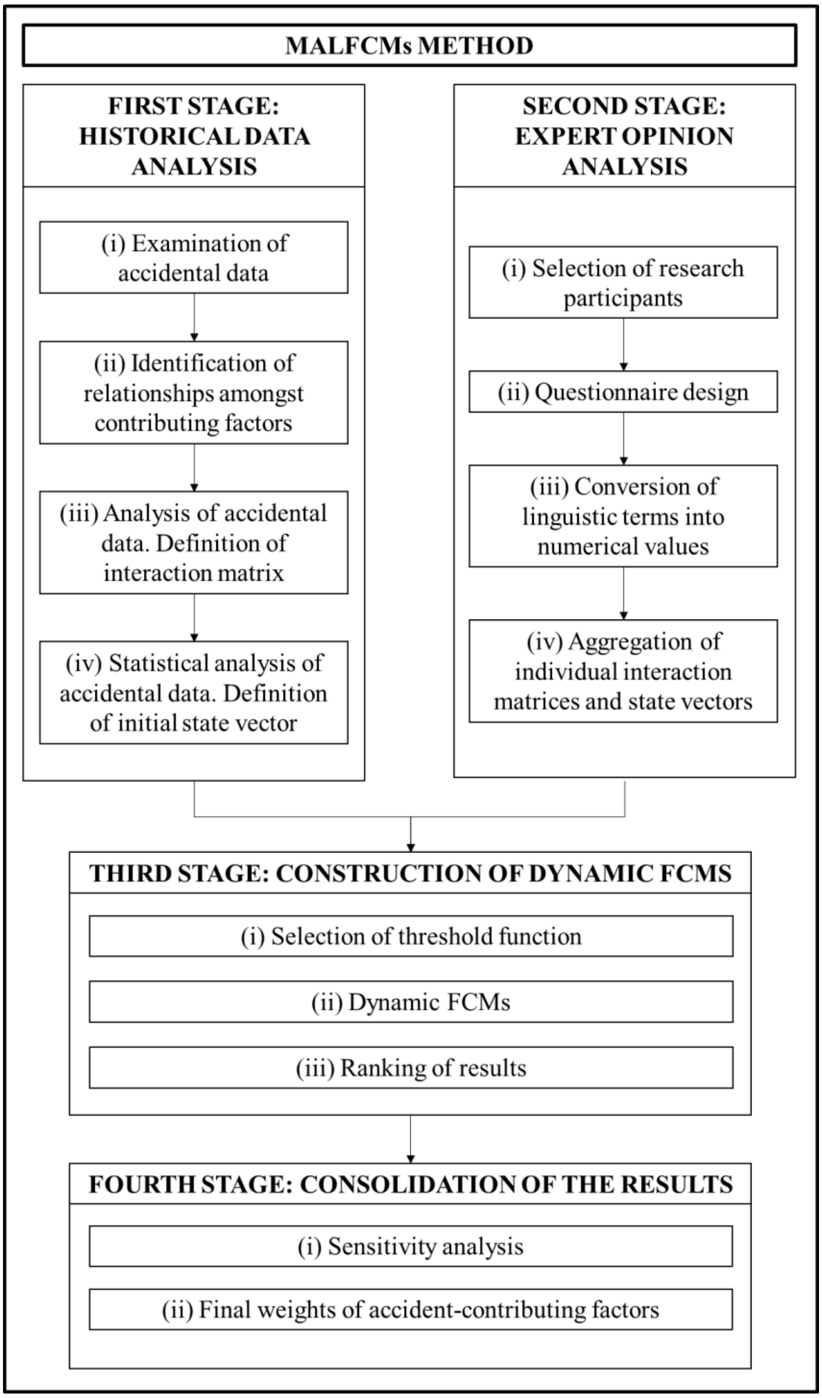


Figure 7.1. MALFCMs method overview

7.2 First Stage of MALFCMs Method: Construction of Individual Interaction Matrix and State Vector from Historical Data

As explained in the previous section, the initial stage of the MALFCMs development consists of defining an interaction matrix and a state vector based on the data gathered from a historical accident database. By analysing and considering historical accident data, it is possible to obtain results that are more reliable than only considering expert opinion, as the quality of expert's feedback depends on the experience of each expert and the relevance of his/her expertise on a specific topic (Shankar, 2012). Thus, often it is not possible to obtain reliable results due to the unavailability of relevant experts.

Within this first stage of the MALFCMs approach, the accidental data, which was analysed in Chapter 5 and utilised in Chapter 6 toward the proposal for an HF classification, is examined and relevant information is extracted towards creating an interaction matrix and a state vector, in four consecutive steps. The first step includes the examination of the accident database to identify which contributing factors are involved in the specific accident scenario being analysed. Once all the factors have been identified, the second step examines the data to elicit whether relationships arising between contributing factors are either positive or negative. A positive relationship, and therefore a positive sign, is assigned to two specific factors when an increase in the causal factor leads to an increase in the effected factor and vice versa. On the other hand, if an increase in the causal factor leads to a decrease in the effected factor, then it is considered a negative relationship, in which a negative sign is assigned to the relationship. It is assumed that in most cases, a positive relationship will arise as a consequence of the nature of maritime accidents. Nevertheless, the contributing factors which will be included in the FCM are rephrased in a manner that was designed to subsequently lead to a positive relationship, as encouraged by Bart Kosko (1986). For example, if a relationship exists between an adequate "safety culture" and "unprofessional behaviour" it will be a negative relationship, as if there is an increase in the safety culture on board, this will improve the crew attitude, and therefore, reduce their unprofessionalism. Hence, in the previous example, the factor "safety culture" may be rephrased as an "inadequate safety culture" to facilitate a positive relation amongst both contributing factors. Figure 7.2 provides an example of a positive and a negative relationship between contributing factors.

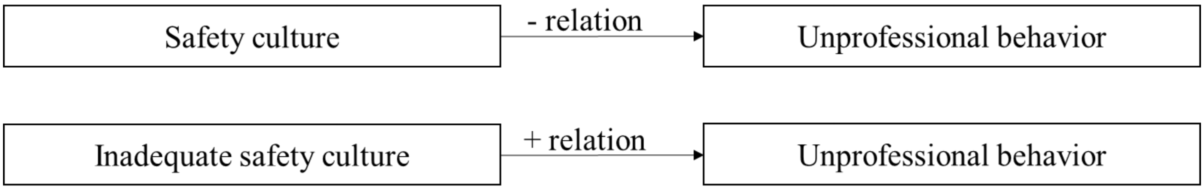


Figure 7.2. Example of a negative (above) and a positive (below) relationship between accident contributing factors

In addition, within the third step, database analysis is carried out to calculate the interrelation level that exists between each pair of contributing factors. For example, in order to determine the interrelation between the contributing factors C_i and C_j, a frequency based investigation is carried out. In other word, the historical accident database is analysed to obtain how frequently C_i and C_j have been recorded into past accidents individually (W_{Ci} and W_{Cj} respectively). In addition, the historical accident database is further analysed to calculate how frequently C_i and C_j have been recorded into the same accident together, as common accident contributing factors (i.e. $W_{Ci \cap Cj}$). Thus, the above-described process is repeated to calculate all the interrelations amongst contributing factors. Following the previous example, the weighting of C_i over C_j (i.e. $W_{i,j}$) is established as the relation between the number of accidents that share both contributing factors in common, and the accidents that have recorded C_i as a contributing factor. While the weighting of C_j over C_i (i.e. $W_{j,i}$) is established as the relation between the number of accidents that share both contributing factors in common, and the accidents that have recorded C_j.

Equation 7.1 provides a better picture of the process being described. This process is repeated in order to obtain the weightings for each pair of factors, which allow creating an interaction matrix n x n, in which n shows the total number of contributing factors that are involved in the research study.

$$W_{i,j} = \frac{W_{Ci \cap Cj}}{W_{Ci}}$$

Equation 7.1. Formula to calculate the value of each component for the interaction matrix created for the historical data analysis stage.

Finally, in the last step, statistical analysis is carried out to define the initial state vector. Hence, the state vector is obtained by considering the number of occurrences of each accident-contributing factor in the accident database. For example, for the contributing factor C_i, its state vector value is defined as the relation of the total number of accidents with C_i recorded as a contributing factor, and the total number of accidents recorded on the historical accident database.

7.3 Second Stage of MALFCMs Method: Construction of Individual Interaction Matrix and State Vector from Expert Analysis, and Posterior Aggregation of the Results

The second stage of the MALFCMs development consists of defining an interaction matrix and a state vector for each expert, their conversion into numerical values, and their posterior aggregation. Each of these steps will be further explained below in this section.

7.3.1 Selection of Research Participants

An adequate selection of participants is considered one of the first and critical steps to construct a reliable FCM. Hence, for applying the second stage of the MALFCMs approach, participants with experience in the fields of accident investigation, HFs or ship operations are targeted. Participants with the above-mentioned experience possess a level of knowledge and expertise which will result in obtaining high quality and reliable results. These results can be compared to the results obtained from the analysis of the historical accident database, which is conducted in the first stage of the MALFCMs method.

7.3.2 Mode of Data Collection

There are six major sources of data collection including documentation, archival records, interviews, direct observation, participant observation, and physical artefacts (Yin, 2009). Nevertheless, FCM literature indicates that questionnaires are used as one of the main modes of data collections, which usually condenses the following steps: (1) Identification of key concepts; (2) Identification of relationships among the variables; and (3) Estimation of strength values (Hossain, 2006).

7.3.3 Design of a Questionnaire for Data Collection

In order to design an effective questionnaire, a number of principles, which need to be taken into consideration, are listed below (Lietz, 2010):

- The wording of the questions and/or statements must be as clear and concise as possible. The general advice is to keep sentences as short as possible so that the comprehension of each participant is increased.

- Limit the number of words in a sentence. For Lietz (2010), the maximum number of words in a sentence should not exceed sixteen. Nevertheless, other authors have extended the word limit up to twenty words for each sentence (Brislin, 1986).
- In addition, active rather than passive voice, specific rather than general words, and the use of adverbs of frequency are recommended. Besides, it is not recommended to use negatively worded questions.

Therefore, the aforementioned principles are taken into account for the design of a questionnaire, which collects the required information to construct an individual interaction matrix and an individual state vector for each participant. Thus, the questionnaire presents a list of contributing factors, which were obtained in the first stage of the MALFCMs method as discussed in the previous section. Regarding each contributing factor, there are two types of closed questions modelled in the questionnaire, "type A" and "type B". These questions are formulated as clear and concise as possible, by following the principles described above, so that they are comprehensive for the participants.

There are various alternatives for experts to express their beliefs, as discussed in the FCM literature. Nevertheless, given that some experts find it extremely challenging to assign numeric values in specific scenarios, the choices in the questionnaire are presented as linguistic terms.

"Type A" questions inquiry how influential a particular contributing factor would need to be in order to have a minimum contribution to a maritime accident. The choices given are "None or very very low", "Very low", "Low", "Medium", "High", "Very high", and "Very very high" as suggested by Markinos et al. (2007). From the response to "Type A" questions, it will be possible to determine not only whether a contributing factor is considered influential in the scenario being analysed but also the degree of influence. Thus, answers to "Type A" questions for each participant will define each individual state vector. In addition, "Type B" questions ask, given a change in a particular contributing factor C_i, what would be the level of the effect on the contributing factor C_j. The choices given are "None", "Very small", "Small", "Moderate", "Big", "Very big", and "Very very big" as suggested by Markinos et al. (2007). In addition, answers to "Type B" questions for each participant will define each individual interaction matrix.

Furthermore, the questionnaire is made available in two formats, namely web-based online survey and paper format. For the web-based version, the Qualtrics Survey Software was utilized. Thus, the above-mentioned paper format questionnaire is included in Appendix E.

7.3.4 Conversion of Linguistic Terms into Numerical Values

The next step involves the conversion of each individual interaction matrix and state vector derived at the previous step, expressed in linguistic terms, into numerical terms. This is an essential transition, as each individual interaction matrix and state vector needs to be further aggregated in the next step. As described in the literature, a linguistic weight may be transformed into a numerical value by means of a linguistic-numerical conversion. Therefore, the five linguistic conversions proposed by Tsadiras et al. (2001) were adapted to include the seven linguistic terms used by participants in this research study, which were equated to values ranging from a minimum of 0 to a maximum value of 1, following a similar approach that Tsadiras et al. (2001). Table 7.1 provides the conversion measures that are applied to obtain each individual state vector. Thus, the conversion measures applied to obtain a numerical interaction matrix for each participant are shown in Table 7.2.

Table 7.1. Fuzzy conversion measures for the state vector

Fuzzy linguistic terms	**None**	**Very low**	**Low**	**Medium**	**High**	**Very high**	**Very very high**
Fuzzy numerical weights	0.000	0.165	0.330	0.495	0.660	0.825	1.000

Table 7.2. Fuzzy conversion measures for the interaction matrix

Fuzzy linguistic terms	**None**	**Very small**	**Small**	**Moderate**	**Big**	**Very big**	**Very very big**
Fuzzy numerical weights	0.000	0.165	0.330	0.495	0.660	0.825	1.000

The aforementioned conversion measures are applied to transform each linguistic interaction matrix and state vector into a numerical interaction matrix and state vector.

7.3.5 Aggregation of Individual Interaction Matrices and State Vectors

After all the individual interaction matrices and state vectors have been transformed from linguistic into numerical values, the next step involves the process of aggregating the individual interaction matrixes and state vectors to form one main, which reflects the knowledge of all participants. Thus, some participants may be more credible due to their level of expertise. Hence, it is possible to weigh each expert with a different credibility weight, as shown in Equation 7.2 (Kandasamy & Smarandache, 2003; Bart Kosko, 1992).

$$F = \sum w_i F_i$$

Equation 7.2. Credibility weight for FCMs components

Where F_i represents the FCM components for $expert_i$ and w_i is equal to the credibility weight of $expert_i$.

Many authors in the literature have defended the use of $w_i=1$ (Taber, 1987). Nevertheless, as different experts may have various credentials and expertise areas, it is not reasonable to assume the same credibility weight for each participant. Therefore, the credibility weighting for each expert is established by adapting the method developed by Hossain (2006).

The aforementioned method is based on a listed criterion concerned with expert knowledge in relation to diverse areas of expertise. Although this method was originally developed for the domain of educational software adoption in schools, its methodology has been adapted to this study to address the areas of HFs, accident investigations, and ship operations. Within this method, numeric values are associated with a participant´s level of expertise, in order to provide a relative numeric measure. Each participant's background is drawn to establish if they met each criterion. For each criterion that is successfully met, the associated numeric value to that criterion is assigned to the participant.

Thus, all numeric values are totalled, providing a credibility weight, which is unique for each participant. Hence, resulting credibility weights are substituted into Equation 7.2. Finally, this process is followed by a normalisation step (Tsadiras et al., 2001), where the previous matrix is divided by the total credibility weight, as shown in Equation 7.3.

$$F = \frac{\sum_{i=1}^{n} w_i F_i}{\sum_{i=1}^{n} w_i}$$

Equation 7.3. Formula to calculate the interaction matrix and state vector resulting from combining all participants' results.

Where F_i represents the FCM components for $expert_i$, n is equal to the number of experts, and w_i is equal to the credibility weight of $expert_i$.

Table 7.3 shows the criteria that were considered to assign credibility weights for each expert. In addition, Table 7.4 provides the key to the criteria table, which was adapted from Hossain (2006).

Table 7.3. Criteria to assign credibility weights. Adapted from Hossain (2006)

No	Criteria to be used for participants	Why is this criterion important to determine the credibility of each participant for this specific research?	Numerical value associated with these criteria
1	The participant possesses a solid background on accident investigation	The participant has a low/standard/high level of understanding of how maritime accidents are investigated. The participant is able to offer insight and information to this research based on its own expertise/academic level.	2 to 4
2	The participant possesses a solid background on human factors	The participant has a low/standard/high level of human factors understanding. The participant is able to offer insight and information to this research based on its own expertise/academic level.	3 to 5
3	The participant possesses a solid background on ship operations	The participant has a low/standard/high level of understanding of how ships are operated. The participant is able to offer insight and information to this research based on its own expertise/academic level.	2 to 4

Table 7.4. Key to criteria table. Adapted from Hossain (2006)

Factor assessed	Expert answer	Score for credibility weight
Q1: Knowledge level regarding accident investigation	1 to 2	2
	3	3
	4 to 5	4
Q2: Knowledge level regarding human factors	1 to 2	3
	3	4
	4 to 5	5
Q3: Knowledge level regarding ship operation	1 to 2	2
	3	3
	4 to 5	4

On the above key to criteria table, it was decided to merge the answers with the lowest score provided by the experts under the same credibility weight, following a similar approach that the study conducted by Hossain (2006). Thus, same approach was followed to merge the answers with the highest score. Once the credibility value for each participant has been calculated in the previous step, Equation 7.3 is applied to obtain one main interaction matrix and state vector, which results from combining the answers from all the participants by also taking into account their level of expertise.

7.4 Third Stage of MALFCMs Method: Construction of Dynamic FCMs

In order to proceed with the third stage of the MALFCMs method, a threshold function is selected. Numerous threshold functions are available for performing a dynamic FCM. However, the logistic signal or Sigmoid function (Equation 2.2) is the most suitable threshold function as discussed in the FCM literature. Hence, it is selected for this research study. Then, the aforementioned threshold function is applied to two sets of data, creating two different dynamic FCMs. The first FCM is created by incorporating the results from historical accident data (i.e. the interaction matrix and the state vector obtained from the first stage in the MALFCMs method), while the second FCM utilises the findings from the expert analysis. For both FCMs, the results are analysed separately, and the weights obtained for each accident-contributing factor are ranked.

7.5 Fourth Stage of MALFCMs Method: Consolidation of the Results by Means of a Sensitivity Analysis

To combine the results obtained from two different data sets, a sensitivity analysis is conducted in the fourth stage of the MALFCMS method. The purpose of a sensitivity analysis is to understand how the uncertainty in the output of a mathematical model or system can be divided and allocated to different sources of uncertainty in its inputs. Hence, as the aim of this stage is to combine the outputs from the historical data and expert opinion analyses, a sensitivity analysis seems adequate to perform this task. Thus, it has been already applied in the literature to merge the outputs from expert analysis and questionnaires (A. Azadeh, Salehi, Arvan, et al., 2014).Therefore, in the last stage of the MALFCMs method, the final weight for each accident-contributing factor is obtained by performing a sensitivity analysis, which combines the results from both FCMs created in the previous stage.

Thus, although MALFCMs is conceptually designed to incorporate the findings from historical data and expert opinion together, it can be perfectly applied exclusively to both, historical data and expert opinion. Furthermore, depending on the case study that is being investigated relative influence of each part (expert opinion and historical data) can be manipulated by changing the weighting for consolidating the results.

7.6 Aspects to Consider when Applying the MALFCMs Method

The aim of this section is to provide generic guidelines for the application of the above-explained MALFCMs method.

For the successful completion of the historical data analysis stage, it is suggested to have accidental data for a minimum period of five years, as this period is considered to be significant enough to represent the state of current maritime accidents. Thus, there are no special requirements regarding the taxonomy or the nomenclature needed in the accidental database, as the MALFCMs is not a taxonomy-based method.

In addition, the MALFCMs method can be applied exclusively to accidental data or expert opinion. However, it has been designed to achieve more reliable results by incorporating both data sources through a sensitivity analysis. For instance, Chapter 8 provides an example of the application of the MALFCMs method only to historical accidental data. Thus, a MATLAB code has been developed and included in Appendix G, which allow for the automation of the calculations involved in the FCM simulation process for the historical data analysis stage. In addition, a complete application of the four stages of the MALFCMs method is included in Chapter 9.

Regarding the expert opinion analysis stage, there are no requirements in terms of how many experts are required to perform this analysis. For example, the case study presented in Chapter 9 has considered five experts. However, additional studies in the literature that also apply some source of expert judgement often consider a minimum of three experts in order to get results that are more reliable (Beatriz Navas de Maya, Hassan Khalid, & Rafet Emek Kurt, 2020). In addition, expert data collection can be achieved through a workshop or by developing and filling a questionnaire. Nevertheless, when the number of experts is low (i.e. three experts) it is suggested to collect their answers by means of a questionnaire, as this reduces the chances of their answers being affected by other experts´ judgement.

7.7 Chapter Summary

This chapter explained and described the MALFCMs method, which was developed with the aim of successfully establishing weightings for contributing factors involved in accidents.

Chapter 8 will demonstrate the possibility to utilize the MALFCMs method by only relying on historical accident data. Thus, the MALFCMs method will be partially applied to a specific vessel category and to specific accident outcomes to obtain weightings for all contributing factors.

8 MARINE ACCIDENT LEARNING WITH FUZZY COGNITIVE MAPS (MALFCMS) METHOD. A CASE STUDY ON THE SOLE USE OF HISTORICAL ACCIDENT DATA

8.1 Overview

This chapter[4] partially applies the Marine Accident Learning with Fuzzy Cognitive Maps (MALFCMs) method, which was introduced and described in Chapter 7, to a real case study.

This chapter first includes the case study specifications in Section 8.2. Second, Section 8.3 calculates and ranks the contributing factors from collision accidents in bulk carriers. Similarly, Section 8.4 obtains and ranks the contributing factors from grounding accidents, and Section 8.5 establishes and ranks the contributing factors from contact accidents in the same vessel category. Third, Section 8.6 calculates and ranks the contributing factors from fire and explosion accidents in bulk carriers, aiming to demonstrate the differences that exist amongst navigational accidents (i.e. collision, grounding, and contact) and fire and explosion accidents. Finally, Section 8.7 discusses the validity of the results obtained in the previous sections by comparing the results from this case study with the findings from similar studies in the literature.

8.2 Case Study Specifications

This case study aims to illustrate how the MALFCMs method can be applied by only relying on historical accident data. Therefore, to fulfil the aforementioned aim, this case study considers both human and technical factors involved in maritime accidents, which were obtained from the Maritime Accident Investigation Branch (MAIB) historical accident database for the period 2000-2011. The aforementioned database was selected because the researcher did not have access to a more updated version of the database at the time of performing this case study. In addition, the purpose of this study is only to demonstrate that the MALFCMs approach can be utilised only by relying on historical accident data; hence, the dataset under consideration is not an influential factor for this purpose. Furthermore, as this case study does not take into account expert judgement, there was no need to limit the number

[4] The MALFCMs case study described on this chapter has been already converted to a journal paper and published in Ocean Engineering (Beatriz Navas de Maya & Rafet Emek Kurt, 2020)

of contributing factors by following the card-sorting approach demonstrated in Chapter 6. Therefore, this case study considers all contributing factors as they are included in the MAIB database between 2000 and 2011, before the EMCIP taxonomy was adopted.

For the aforementioned period, the MAIB database contains 2690 entries related to accident contributing factors (both human and technical) that led to past maritime accidents according to accident investigators' reports. One of the most populated vessel categories amongst the MAIB database for the analysed period is bulk carriers, which is selected for investigation in this case study.

There are twelve accident categories linked to bulk carriers, from where four are considered for this case study due to data availability. The accident categories analysed include navigational accidents (i.e. collision, grounding, and contact), and fire and explosion accidents. The last accident category is included in order to examine the differences between the results obtained from navigational accidents. Thus, from the 110 human and technical factors identified from the old MAIB database for the period 2000-2011 (i.e. before EMCIP nomenclature was introduced), Table 8.1 only includes those human and technical factors identified in at least one accident in bulk carriers for the period 2000-2011.

Table 8.1. List of human and technical factors identified in at least one accident in bulk carriers. Period 2000-2011

No	Factor Description	No	Factor Description
3	Alcohol use	59	Misapplication of regulations, policies, procedures or practices
9	Characteristic defect	61	No compliance
10	Communication	62	Operation Instructions inadequate
12	Company standing orders inadequate, insufficient, conflicting	63	Other vessels
13	Competence	64	Outside operational design limits
14	Complacency	65	Perception abilities
15	Construction defect	66	Perception of risk
16	Corrosion	68	Personality
17	Culture	69	Personnel unfamiliar with equipment/not trained in use
18	Current	71	Poor decision making/information use
19	Design inadequate	75	Poor regulations, policies or practices
21	Diminished motivation	76	Pressures - organisational
23	Equipment badly maintained	77	Procedures inadequate
25	Equipment not available	80	Safety culture
26	Equipment poorly designed for operational use	81	Seal/gasket
27	Erosion/cavitation damage	83	Ship movement weather conditions
29	Failure to maintain discipline	84	Situational awareness or communication inadequate
30	Fatigue	87	System defect
35	Hazardous natural environment	90	Technical knowledge inadequate
36	Factor 36 - Health: drugs/alcohol	93	Training
37	Health, medical condition	94	Training which itself is inadequate
38	Heavy weather	95	Training, inexperience, knowledge
41	Inadequate management of physical resources	96	Training, skills, knowledge
44	Inadequate resources	98	Ultimate tensile stress exceeded
45	Inattention	100	Uncharted underwater obstruction
48	Knowledge of regulations/standards inadequate	101	Under stimulation
49	Knowledge of ship operations inadequate	102	Unsafe working practices
50	Lack of communication or co-ordination	104	Vigilance
52	Language problem	107	Visual environment
55	Management and supervision inadequate	110	Worn out

8.3 Weightings of Accident Contributing Factors Involved in Collision Accidents in Bulk Carriers

The first logical step included defining the interaction matrix and the state vector that would allow creating a Fuzzy Cognitive Map (FCM) from the historical accident data. Therefore, the MAIB historical database was analysed by comparing each pair of factors identified in past maritime accidents. For example, in order to determine the relation between Factor 10-

"Communication" and Factor 13-"Competence" described in Table 8.1, the accident database was filtered by the accidents caused by at least one of the aforementioned contributing factors. Moreover, the database was also filtered by the accidents that shared both contributing factors as a common accident cause. Thus, the weight of Factor 10-"Communication" over Factor 13-"Competence" was considered as the relation between the number of accidents with both contributing factors involved, and the accidents with Factor 13-"Competence", as shown in Equation 8.1.

This process was repeated in order to obtain the weightings for each pair of factors. Due to the size of the interaction matrix, Table 8.2 only shows a partial representation of the interaction matrix for collisions in bulk carriers for the period 2000-2011. The complete interaction matrix is shown in Appendix F. Thus, it is important to mention that just the factors from Table 8.1 linked to collision accidents appear in Table 8.2.

$$W_{F10,F13} = \frac{W_{F10,F13}}{W_{F10}}$$

Equation 8.1. The process to determine interrelations amongst accident-contributing factors

Table 8.2. Partial representation of the interaction matrix for collision accidents in bulk carriers. Period 2000-2011

	F10	**F12**	**F13**	**F14**	**F18**	**F21**	**F41**	**F45**	**F48**	**F49**	**F50**	**F59**	**F61**	**…**
F10	0.000	0.000	1.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	…
F12	0.000	0.000	0.000	0.500	0.500	0.000	0.000	0.500	0.000	0.000	0.000	0.000	0.000	…
F13	0.333	0.000	0.000	0.000	0.333	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	…
F14	0.000	0.500	0.000	0.000	0.500	0.500	0.000	0.500	0.000	0.000	0.500	0.000	0.000	…
F18	0.500	0.500	0.500	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	…
F21	0.000	0.000	0.000	1.000	0.000	0.000	0.000	1.000	0.000	0.000	1.000	0.000	0.000	…
F41	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	…
F45	0.000	0.500	0.000	0.500	0.000	0.500	0.000	0.000	0.000	0.000	0.500	0.000	0.000	…
F48	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	1.000	0.000	…
F49	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	1.000	0.000	…
F50	0.000	0.000	0.000	0.500	0.000	0.500	0.500	0.500	0.000	0.000	0.000	0.000	0.000	…
F59	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	1.000	0.000	0.000	0.000	…
F61	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	…
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…

For this case study, the state vector was defined as the statistical occurrence of each contributing factor. For instance, for Factor 13-Competence, the state vector value was calculated as the relation of the total number of accidents with Factor 13-Competence involved, and the total number of collision accidents in bulk carriers that were recorded in the accident database. Table 8.3 shows the state vector for collisions in bulk carriers for the period 2000-2011.

Table 8.3. State vector for collision accidents in bulk carriers. Period 2000-2011

F10	F12	F13	F14	F18	F21	F41	F45	F48	F49	F50	F59
0.100	0.200	0.300	0.200	0.200	0.100	0.100	0.200	0.100	0.100	0.200	0.100

F61	F65	F66	F68	F71	F76	F77	F84	F94	F95	F104
0.100	0.100	0.200	0.100	0.100	0.100	0.100	0.400	0.100	0.100	0.100

Once the interaction matrix and the state vector were obtained, the next step included first the selection of a threshold function (as discussed in Chapter 2 the Sigmoid function provides greater benefits), and second, the creation of a dynamic FCM by following Equation 2.1 until equilibrium was reached. Thus, to illustrate the above-explained process, Figure 8.1 shows the variation in the weightings obtained for both human and technical factors involved in collision accidents in bulk carriers for the period 2000-2011, until equilibrium was reached, which occurred before step 5 for this example.

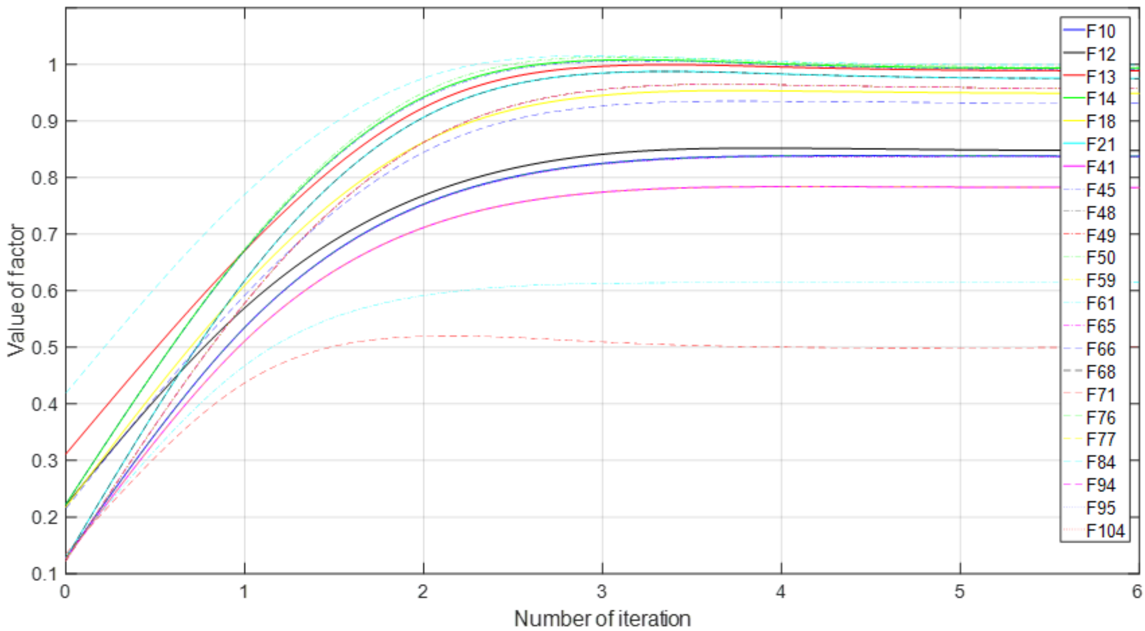


Figure 8.1. Dynamic FCM for collision accidents in bulk carriers until equilibrium is reached. Period 2000-2011

Finally, the weightings obtained for all accident-contributing factors were normalised and ranked in order to show the impact of the identified factors as a percentage. Hence, Table 8.4 shows the weighting of each accident contributor to collision accidents. It is possible to observe that Factor 84-"Situational awareness or communication inadequate" has the highest impact on collision accident while Factor 71-"Poor decision making/information use" is the least influential in this accident category.

These results are in line with the findings of Sandhåland, Oltedal, and Eid (2015), who performed a study on twenty-seven collision accidents that occurred between 2001 and 2011, in which twenty-three accidents might have been related to a loss of Situational Awareness (SA). Also, Sætrevik and Hystad (2017) identified that SA has a crucial role since it influences decision-making and performance, hence, a lack of SA might have a significant impact on safety. Moreover, Chauvin et al. (2013) analysed collision accidents using the Human Factors Analysis and Classification System (HFACS) method, which identified that a lack of SA and a deficit of attention as significant elements leading to accidents. The same study also reported that inter-ship communication problems have a significant impact on collision accidents. In this case study, a lack of SA has also been identified as the most critical factor. It can be seen that MALFCM method can produce results that are in line with the findings of previous research studies but utilises a procedure which is faster than previous methods, given that a researcher has access to a sufficient database of accidents.

Table 8.4. Weighting for each accident-contributing factor for collision accidents in bulk carriers (ranked in order of importance). Period 2000-2011

No	Factor description	Weight from FCM	Weight normalised (%)
84	Situational awareness or communication inadequate	1.000	4.881
50	Lack of communication or co-ordination	0.997	4.865
14	Complacency	0.994	4.851
45	Inattention	0.992	4.843
13	Competence	0.989	4.829
21	Diminished motivation	0.976	4.763
68	Personality	0.976	4.763
104	Vigilance	0.976	4.763
48	Knowledge of regulations/standards inadequate	0.958	4.675
49	Knowledge of ship operations inadequate	0.958	4.675
59	Misapplication of regulations, policies, procedures or practices	0.958	4.675
94	Training which itself is inadequate	0.958	4.675
18	Current	0.949	4.633
66	Perception of risk	0.932	4.548
12	Company standing orders inadequate, insufficient, conflicting	0.848	4.138
10	Communication	0.838	4.089
76	Pressures - organisational	0.838	4.089
65	Perception abilities	0.836	4.082
95	Training, inexperience, knowledge	0.836	4.082
41	Inadequate management of physical resources	0.783	3.820
77	Procedures inadequate	0.783	3.820
61	Non compliance	0.614	2.999
71	Poor decision making/information use	0.500	2.441

By further analysing the results for collision accidents, it is clearly shown in Figure 8.1 that there are twenty-three factors involved in this accident category. From all above-mentioned factors, it can be seen that apart from one factor (i.e. Factor 18-“Current”) all other accident causes are related to human factors. This observation may reinforce the perception about HF on ships as being the major contributor to maritime accidents (Graziano et al., 2016; Beatriz Navas de Maya et al., 2018; Rothblum, 2000; Turan et al., 2016), particularly in collision accidents.

8.4 Weightings of Accident Contributing Factors Involved in Grounding Accidents in Bulk Carriers

First, the interaction matrix and the state vector were obtained from the historical accident data by following the same process that was discussed in Section 8.3. Second, a dynamic FCM was created by following Equation 2.1 until equilibrium was reached, which occurred before step 5. Therefore, Figure 8.2 shows the variation in the weightings obtained for both human and technical factors involved in grounding accidents in bulk carriers for the period 2000-2011.

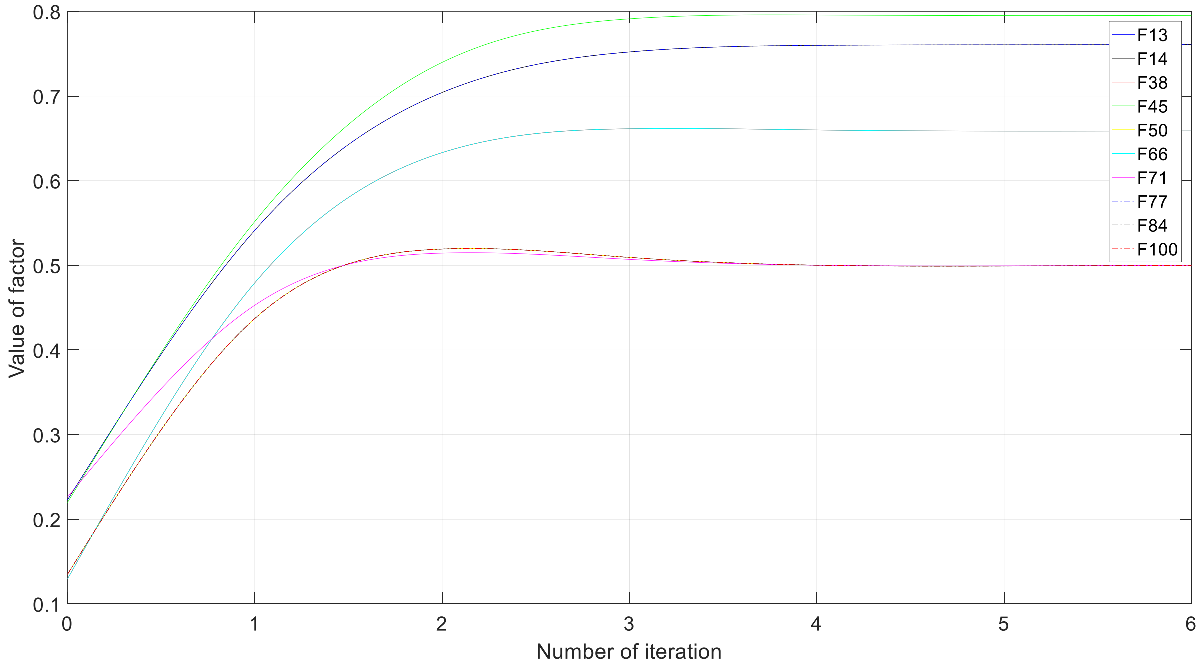


Figure 8.2. Dynamic FCM for grounding accidents in bulk carriers until equilibrium is reached. Period 2000-2011

Table 8.5 shows the weights of accident contributors in grounding accidents, where Factor 45-"Inattention" is the most relevant contributor for this accident category while Factor 100-"Uncharted underwater obstruction" has the least impact in grounding accidents. Moreover, from the eleven factors linked to grounding, just F38 and F100 are not HFs. Similar results were obtained by Yıldırım et al. (2017), who assessed grounding accidents with HFACS and statistical methods. From their study, the management of resources was identified as the most common accident category, including factors as insufficient communication or lack of procedures (e.g. incorrect passage plan). Moreover, skill-based errors and the physical environment followed the management of resources in the aforementioned study. Furthermore, Barnett (2005) also identified that a lack of SA was a dominant human error in accidents, as this case study highlighted. However, the variation in the factors ranking obtained when comparing this study with other researchers’ findings might be influenced by the difference between the accident reports, the expert groups involved, or the accident databases analysed.

Table 8.5. Weighting for each accident-contributing factor for grounding accidents in bulk carriers (ranked in order of importance). Period 2000-2011

No	Factor description	Weight from FCM	Weight normalised (%)
45	Inattention	0.795	12.965
14	Complacency	0.761	12.402
77	Procedures inadequate	0.761	12.402
38	Heavy Weather	0.659	10.741
66	Perception of risk	0.659	10.741
13	Competence	0.500	8.150
50	Lack of communication or coordination	0.500	8.150
71	Poor decision making/information use	0.500	8.150
84	Situational awareness or communication inadequate	0.500	8.150
100	Uncharted underwater obstruction	0.500	8.150

8.5 Weightings of Accident Contributing Factors Involved in Contact Accidents in Bulk Carriers

As the last navigational accident category included in this case study, Figure 8.3 shows the variation in the weightings obtained for both human and technical factors involved in contact accidents in bulk carriers for the period 2000-2011 until equilibrium was reached, which occurred before step 5.

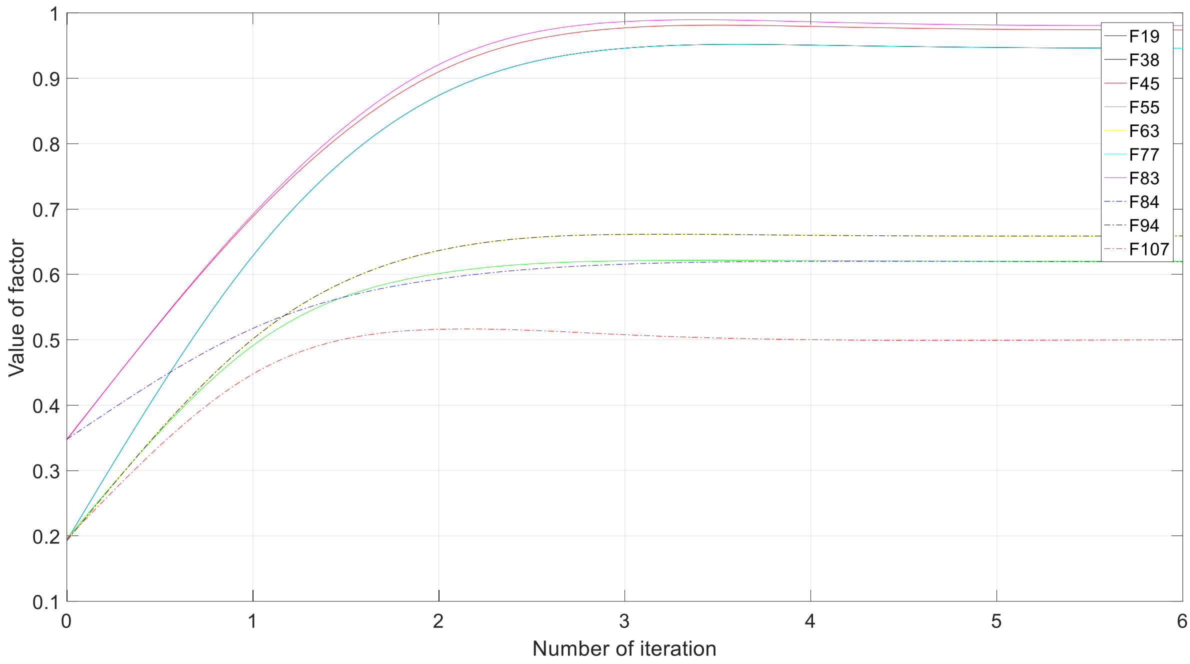


Figure 8.3. Dynamic FCM for contact accidents in bulk carriers until equilibrium is reached. Period 2000-2011

Table 8.6 shows the weightings for contributing factors in contact accidents. Factor 83-“Ship movement weather conditions” have the greatest influence while Factor 107-“Visual environment” has the minimum impact on contact accidents. From the ten factors involved in contact accidents, four are technical factors (F19, F38, F63, and F83), representing an average weighting of 44.99%. It is noticeable that this is the only navigational accident category with a closer distribution between HFs (55.01%) and technical factors (44.99%) weightings.

Table 8.6. Weighting for each accident-contributing factor for contact accidents in bulk carriers (ranked in order of importance). Period 2000-2011

No	Factor description	Weight from FCM	Weight normalised (%)
83	Ship movement weather conditions	0.981	12.494
45	Inattention	0.974	12.409
19	Design Inadequate	0.946	12.052
38	Heavy Weather	0.946	12.052
77	Procedures inadequate	0.946	12.052
63	Other Vessel	0.659	8.392
94	Training which itself is inadequate	0.659	8.392
55	Management and supervision inadequate	0.620	7.899
84	Situational awareness or communication inadequate	0.619	7.889
107	Visual environment	0.500	6.368

8.6 Weightings of Accident Contributing Factors Involved in Fire and Explosion Accidents in Bulk Carriers

Finally, this section aimed to examine the differences that exist between the accident contributing factors from navigational accidents and fire and explosion accidents. Therefore, Figure 8.4 shows the variation in the weightings obtained for both human and technical factors involved in fire and explosion accidents in bulk carriers for the period 2000-2011 until equilibrium was reached, which occurred before step 5.

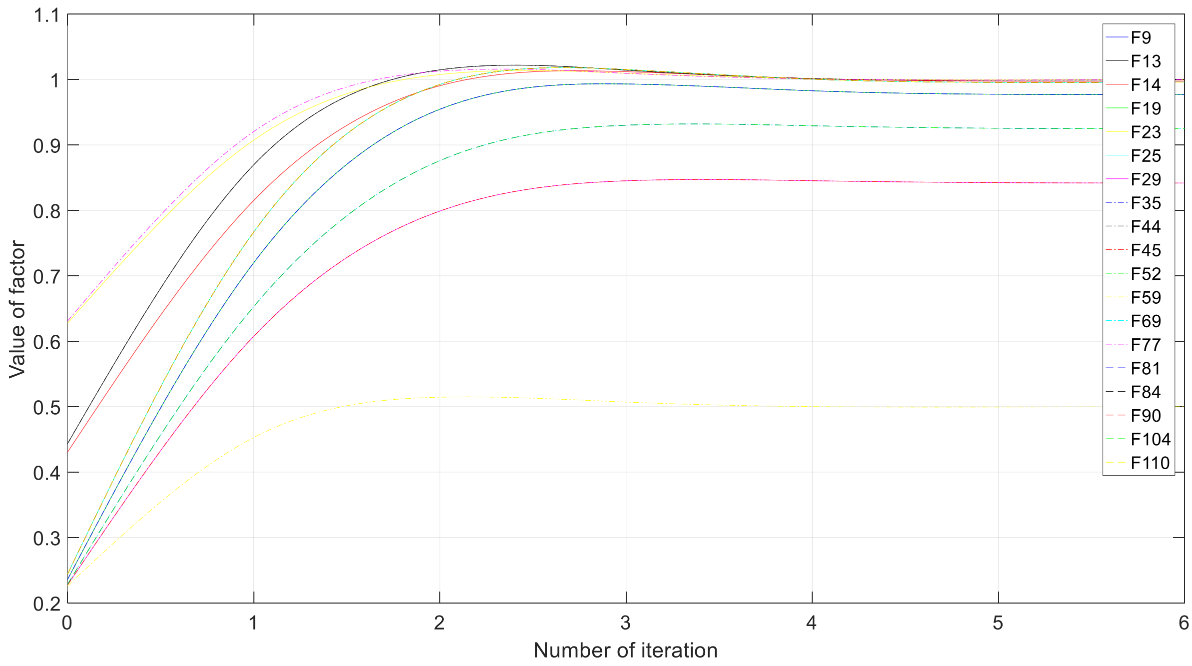


Figure 8.4. Dynamic FCM for fire and explosion accidents in bulk carriers until equilibrium is reached. Period 2000-2011

The results obtained from fire and explosion accidents are shown in Table 8.7. It can be observed from the results that, Factor 77-"Procedures inadequate" has the greatest influence while Factor 59-"Misapplication of regulations, policies, procedures or practices" has the minimum impact on fire and explosion accidents. From the nineteen factors involved in fire and explosion accidents, only five are not HFs (F9, F19, F35, F81, and F110), representing a weighting of 27.16%. Importance of inadequate procedures obtained from the above analysis can be considered to be in agreement with the research conducted in the European Union (EU) funded Safety Enhancements in transport by Achieving Human Orientated Resilient Shipping Environment (SEAHORSE) Project, which concluded that between 20 and 30% of standard operating procedures are ineffective, hence not being followed strictly during operations (R. Kurt et al., 2015; R. E. Kurt et al., 2016). This case study also presented similarities with the study conducted by Barnett (2005), who stated that deficient maintenance is one of the major causes of fire and explosion, which agrees with the first factor ranked within this case study. Moreover, Chang and Lin (2006) reviewed 242 accidents for the period 1960-2003, from where fire and explosion accounted for 85% of the aforementioned accidents, and 30% of them were caused by human error (e.g. poor operation or maintenance). Also, in their study, Chang and Lin (2006) considered inadequate procedures or inadequate resources as the top contributors in fire and explosion accidents.

In this specific case, it is noticeable that there are many accident contributing factors that affect safety, and that they are almost equally important. Within the database under consideration, only five different vessels recorded a fire and explosion on board; hence, the lack of more samples can critically affect the results, as the database does not contains a sufficient amount of data to draw relationships between factors.

Table 8.7. Weighting for each accident-contributing factor for fire and explosion accidents in bulk carriers (ranked in order of importance). Period 2000-2011

No	Factor description	Weight from FCM	Weight normalised (%)
77	Procedures inadequate	1.000	5.595
23	Equipment badly maintained	1.000	5.595
13	Competence	1.000	5.594
44	Inadequate resources	1.000	5.594
14	Complacency	0.998	5.584
25	Equipment not available	0.997	5.575
52	Language problem	0.997	5.575
84	Situational awareness or communication inadequate	0.997	5.575
90	Technical knowledge inadequate	0.997	5.575
110	Worn out	0.997	5.575
9	Characteristic defect	0.978	5.471
19	Design Inadequate	0.978	5.471
35	Hazardous natural environment	0.978	5.471
69	Personnel unfamiliar with equipment/not trained in use	0.925	5.177
81	Seal/gasket	0.925	5.177
104	Vigilance	0.925	5.177
29	Failure to maintain discipline	0.842	4.712
45	Inattention	0.842	4.712
59	Misapplication of regulations, policies, procedures or practices	0.500	2.797

8.7 Discussion on the Results Obtained from Purely Relying on Historical Data

In this case study, a new modelling and simulation approach known as MALFCMs was applied to a case study on bulk carriers. The aim of this case study was to obtain the weighting of each human and technical factor that led to past maritime accidents by purely relying on historical accident data (i.e. the second and the fourth stages of the MALFCMs method were omitted in this case study). Therefore, FCMs were developed for various accident types (i.e. navigational accidents and fire and explosion accidents), and contributing factors were analysed and presented in the previous sections.

According to the analysis carried out in Section 8.3, for collision accidents, the top five accident contributors identified were ranked as follows: Factor 84-“SA or communication inadequate”, Factor 50-“Lack of communication or co-ordination”, Factor 14-“Complacency”, Factor 45-“Inattention”, and Factor 13-“Competence”, with a normalised importance weighting of 4.88%, 4.87%, 4.85%, 4.84%, and 4.83% respectively. Findings of this case study for collision accidents appears to agree with current challenges identified by field experts in the area of collision avoidance. As collision accidents generally occur due to skills-based and competence related shortcomings, it is not a surprise to observe that factors like SA and communications problems were ranked as leading contributors to collision accidents. Hence, by purely relying on historical accident data, the results can be considered to reflect the reality of the collision accidents well. Furthermore, the maritime sector already recognizes the high contribution of skill-based factors such as “competence” to maritime accidents. Hence, training and competence issues are addressed and controlled by regulations (e.g. Standards of Training, Certification, and Watchkeeping (STCW)). However, more research is needed in order to measure the effectiveness of the current safety regime regarding the training and competence in terms of addressing the aforementioned accident contributors, for which expert opinion also needs to be considered and incorporated.

Regarding the grounding accidents, Section 8.4 concluded that the top five accident contributors were Factor 45-“Inattention”, Factor 14-“Complacency”, Factor 77-“Procedures inadequate”, Factor 38-“Heavy weather”, and Factor 66-“Perception of risk”, with a normalised importance weighting of 12.97%, 12.40%, 12.40%, 10.74%, and 10.74% respectively. These outcomes are also in line with factors identified by other researchers and experts. Since navigational accidents mainly occur due to the incorrect attitude and skill gaps that exist on-board ships, it is expected to see that "lack of attention" or the "use of inadequate procedures" are listed as critical within this case study. Moreover, findings from this study revealed that contributing factors responsible for grounding accidents are more related to individual actions or behaviour (e.g. "perception of risk" or "inattention"). On the other hand, collision accident factors related to working as a team also play an important role (e.g. "lack of communication or coordination").

In addition, for contact accidents, in Section 8.5, major contributors were ranked as Factor 83-"Ship movement weather conditions", Factor 45-"Inattention", Factor 19-"Design inadequate", Factor 38-Heavy weather", and Factor 77-"Procedures inadequate", with a normalised importance weighting of 12.49%, 12.41%, 12.05%, 12.05%, and 12.05% respectively. Moreover, this navigational accident category showed a closer distribution between HFs (55.01%) and technical factors (44.99%) weightings. It can be seen from the results that heavy weather and ship movement due to weather conditions play an important role in contact accidents, which makes ship handling more difficult, especially during tricky manoeuvres. The results look realistic, as it is common to have contact accidents in adverse weather conditions.

Finally, for fire and explosion accidents, in Section 8.6 the top five accident contributors were identified as follows: Factor 77-"Procedures inadequate", Factor 23-"Equipment badly maintained", Factor 13-"Competence", Factor 44-"Inadequate resources", and Factor 14-"Complacency", with a normalised importance weighting of 5.60%, 5.60%, 5.59%, 5.59%, and 5.58% respectively. Outcomes of this case study for fire and explosion accidents demonstrated that onboard operational procedures play a significant role in this type of accident together with badly maintained equipment, which is logical. There are studies that support the fact that poor maintenance is one of the major causes of fire and explosion accidents (Barnett, 2005). Furthermore, inadequate procedures are one of the challenging topics in shipping that is requiring urgent attention to raise the standards of safety. EU funded research project SEAHORSE concluded that a significant amount of standard operating procedures are not followed by crew members on board due to the fact that they do not represent operational realities. This situation encourages crew members to conduct workarounds, which carry additional safety shortcomings (R. E. Kurt et al., 2016).

As it can be observed from aforementioned importance weightings, navigational accidents (i.e. collision, grounding, and contact) have common accident contributing factors (e.g. "inattention" was identified in all the cases, while "procedures inadequate", "complacency", and “heavy weather” were identified in at least two of aforementioned accident categories). The identification of common accident contributing factors might be related to the characteristics of the accident categories, since they are all part of navigational accidents, and therefore, they present some similarities. However, when comparing fire and explosion accidents with navigational accidents, it was observed that there was less commonality between the factors involved in these accidents. This difference is expected since navigational accidents are mostly influenced by a lack of specific skills and situational awareness, while fire and explosion are generally due to poor maintenance or a lack of adequate procedures on board.

Based on results demonstrated in this chapter, it can be said that the proposed MALFCMs approach offers fast and consistent results with existing accident database even in the absence of expert opinions. Therefore, it is possible to apply the MALFCMs method by creating the FCMs from an accident database provided that the database contains a sufficient amount of data to draw relationships between factors. It is observed that results were sensitive to the amount of data being analysed, especially for low data case studies. On the other hand, as this approach is retrospective, it will not be able to predict new risks and emerging human factor challenges. This weakness can be addressed by the inclusion of expert opinions which will be demonstrated in Chapter 9.

8.8 Chapter Summary

In this chapter, various dynamic FCMs were created to study and rank the importance of contributing factors that led to past shipping accidents. Within this study, only historical accident data was taken into account when building the aforementioned dynamic FCMs, which can be considered as a strength to make FCMs more realistic.

Chapter 9 applies the MALFCMs method, which was introduced and fully described in Chapter 6, to a full case study, aiming to model the relationships of accident contributors by utilising information directly from an accident database, which is combined with expert opinion.

9 APPLICATION OF THE MARINE ACCIDENT LEARNING WITH FUZZY COGNITIVE MAPS (MALFCMS) METHOD: A FULL CASE STUDY

9.1 Overview

This chapter[5,6] fully applies the Marine Accident Learning with Fuzzy Cognitive Maps (MALFCMs) method, which was introduced and described in Chapter 7, to a real case study. This chapter includes the case study specifications Section 9.2, while Section 9.3 presents the first stage application of the MALFCMs method to the selected case study. Section 9.4 applies the second stage of the MALFCMs method, and Section 9.5 performs two dynamic Fuzzy Cognitive Maps (FCMs). The first FCM includes the data pertinent to the historical accident database, while the second FCM incorporates the findings obtained from a questionnaire, which was completed by a group of experts in the areas of HFs, ship operations and accident investigations. Section 9.6 combines the findings from the previous section by means of a sensitivity analysis. Finally, Section 9.7 discusses the validity of the results obtained from the FCM application, by comparing the results from this case study with the findings from similar studies in the literature.

9.2 Case Study Specifications

For the purpose of this case study, marine accidents involving UK vessels worldwide and all vessels operating in UK territorial waters between 2011 and 2016 were analysed. The database under consideration changed with respect to the previous case study due to three main reasons. First, a new version of the database, which follows the EMCIP taxonomy, was released by MAIB. Second, by utilising EMCIP taxonomy, which is applied through the European Union, it would be easier to compare the results if the MALFCMs approach is applied to other state members´ datasets. Finally, this is a more up to date database; hence, results of utilising this version will be more beneficial for maritime end users.

General cargo vessels, which are usually defined as merchant ships carrying goods and materials from one port to another, were selected for this study due to the higher number of

[5] The first stage of the MALFCMs case study described on this chapter has been already converted to a journal paper and published in Safety in Extreme Environments (de Maya et al., 2019).
[6] The comparison between the first and the second stages of the MALFCMs case study described on this chapter has been already converted to a journal paper and submitted to Ship and Offshore Structures (B Navas de Maya & R. E Kurt, 2020).

data entries when compared with other vessel categories. The distribution of accident data points regarding the vessel type is outlined in Table 9.1, in which cargo ships are the vessels with the highest number of accidents registered. Thus, Table 9.2 provides further insight into the outcome of general cargo accidents, where grounding and stranding accidents were identified as the most common accident type. Therefore, the MALFCMs method was applied to grounding and stranding accidents on a general cargo vessel in this case study, aiming to produce results that are more reliable. Thus, historical accident data for sixteen accidents were examined and analysed within this study. It is noticeable that the number of samples is low; however, as the aim of this chapter is to conduct a full MALFCMs case study by comparing historical data and expert opinion, the number of accident is not a critical aspect here.

Table 9.1. The total number of accidents per vessel type. Period 2011-2016

Vessel type	**Number of accidents**
Cargo ship	50
Fishing vessel	34
Passenger ship	19
Service ship	19
Recreational craft	9

Table 9.2. The total number of cargo ship accidents per accident outcome. Period 2011-2016

Accident outcome	**Number of accidents**	**Accident outcome**	**Number of accidents**
Grounding/stranding	16	Flooding/Foundering	2
NA	12	Damage to ship or equipment	1
Collision	10	Fire/Explosion	1
Contact	4	Hull failure	1
Capsizing/Listing	2	Loss of control	1

The next logical step was to scrutinise and analyse the sixteen maritime accidents, aiming to identify those HFs that had a contribution to grounding and stranding accidents in general cargo vessels. First, the MAIB database for the period 2011-2016 was examined, and 94 HFs were identified, as shown in Table 6.1. Then, in Chapter 6, a card-sorting approach was applied to the original list of HFs presented in the MAIB database, which allowed to propose eleven HFs (Table 6.7). Finally, nine of these eleven HFs were identified as involved in grounding/stranding accidents in general cargo vessels, as shown in Table 9.3.

Table 9.3. Human factors involved in grounding/stranding accidents in general cargo vessels. Period 2011-2016

No HF	Human factor description
HF1	Improper design, installation, and working environment
HF2	Inadequate leadership and supervision
HF3	Inadequate safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)
HF4	Inadequate safety management system: Substandard monitoring
HF5	Lack of communication and coordination
HF6	Lack of safety culture
HF7	Lack of training
HF8	Lack of, improper or late maintenance
HF9	Unprofessional behaviour

9.3 Application of the First Stage of MALFCMs Method to Grounding and Stranding Accidents on General Cargo Vessel

9.3.1 Interaction Matrix and State Vector Based on Historical Accident Data

Once all human-contributing factors were identified in the previous step, an interaction matrix was created. In order to determine the relationship between each pair of factors to fill the interaction matrix, the third step of the MALFCMs first stage, which was described in Chapter 6, was followed. For instance, to determine the relation between HF2 and HF3, the database was first filtered, resulting in five accidents sharing both HFs as common causes. In addition, eleven accidents recorded HF2, while eight accidents included HF3. Thus, the interrelation between HF2 and HF3 (i.e. $W_{2,3}$ in the interaction matrix) was calculated as the relation between the number of accidents that recorded both HFs in the same accident (five accidents) and the number of accidents that included HF2 ($W_{2,3}$=0.455). Similarly, the relation between HF3 and HF2 would be calculated as the relation between the number of accidents in common and the number of accidents that included HF3 ($W_{3,2}$=0.625).

In order to conduct the above mathematical calculations, this research study decided to use Matlab, which was selected as it would allow for the automation of the calculations involved in the FCM simulation process. Given the need to perform operations that involve creating a large interaction matrix (i.e. static FCM) and deal with iterative steps (i.e. dynamic FCM), these calculations would otherwise be long and prone to error if conducted manually. Therefore, a code was written in Matlab, which is available in Appendix G. The aforementioned code allowed first, the creation of the interaction matrix and the state vector (i.e. first stage of

MALFCMs), and second, the multiplication and the application of the threshold function (i.e. third stage of MALFCMs). In addition, it also allowed for the comparison of two consecutive vectors, confirming when the vectors were the same and equilibrium was reached.

Table 9.4 shows the interaction matrix obtained from the historical accident data by utilising the above-mentioned program in Matlab. Table 9.5 provides the initial state vector (St.0), which was calculated by also using the aforementioned code in Matlab.

Table 9.4. Interaction matrix for grounding/stranding accidents in general cargo vessels. The first stage of the MALFCMs method. Period 2011-2016

	HF1	HF2	HF3	HF4	HF5	HF6	HF7	HF8	HF9
HF1	-	0.000	0.000	0.000	0.000	0.000	0.500	0.500	0.500
HF2	0.000	-	0.455	0.091	0.182	0.091	0.727	0.000	0.455
HF3	0.000	0.625	-	0.000	0.000	0.000	0.750	0.000	0.125
HF4	0.000	1.000	0.000	-	0.000	0.000	0.000	0.000	1.000
HF5	0.000	1.000	0.000	0.000	-	0.000	1.000	0.000	0.000
HF6	0.000	1.000	0.000	0.000	0.000	-	1.000	0.000	1.000
HF7	0.091	0.727	0.545	0.000	0.182	0.091	-	0.000	0.455
HF8	1.000	0.000	0.000	0.000	0.000	0.000	0.000	-	0.000
HF9	0.125	0.625	0.125	0.250	0.000	0.125	0.625	0.000	-

Table 9.5. Initial state vector for grounding/stranding accidents in general cargo vessels. The first stage of the MALFCMs method. Period 2011-2016

	HF1	HF2	HF3	HF4	HF5	HF6	HF7	HF8	HF9
	0.125	0.688	0.500	0.063	0.125	0.063	0.688	0.063	0.500

9.3.2 Static Analysis of the FCM Based on Historical Accident Data

The static analysis of the FCM is provided at this stage in order to observe and analyse the feedback cycles that exist in the FCM graph. Figure 9.1 provides an insight into the FCM graph, showing the relative importance of concepts and the causal effects between nodes at this time.

Cycles are formed in the model as a result of direct and indirect relationships. Thus, each cycle within the graph is accompanied by a sign, which is obtained by multiplying the sign of all the arcs that included in the cycle. Positive cycles are characterized by amplifying any change that is introduced into the system, while negative cycles counteract any initial change that is introduced into the system (Tsadiras et al., 2001). The purpose of static analyses is to show how all the factors are related to each other in a visual way. Table 9.6 and Figure 9.1

demonstrates visually all the cycles that exist in this model. However, it is not possible to establish the weighting of each factor from manual observations and calculations; hence, a dynamic analysis is needed for that purpose.

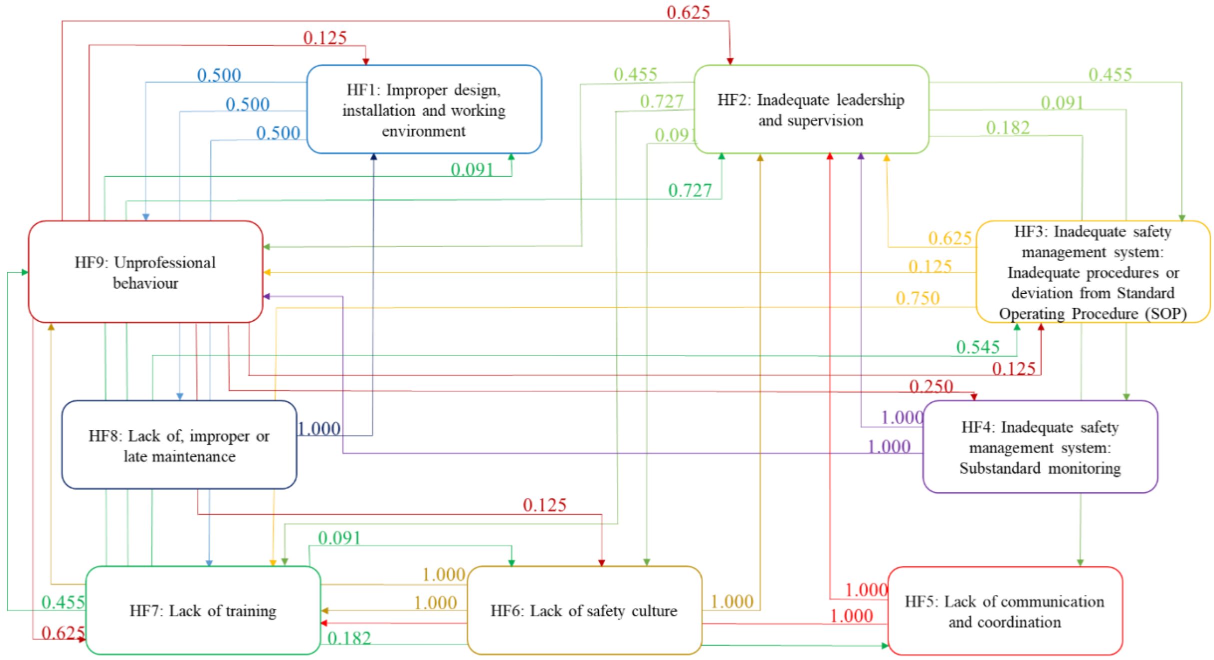


Figure 9.1. Static analysis of FCM for grounding/stranding accidents in general cargo vessels. The first stage of the MALFCMs method. Period 2011-2016

For the system being modelled in this case study, no negative cycles are identified, as all the concepts included are inadequate human actions that led to maritime accidents. Hence, no HF from the system will have any positive impact on others. An example of a cycle is the cycle HF1-HF7-HF1. This cycle indicates that HF1 influences HF7, which also has an influential effect on HF1. In addition, Table 9.6 provides as an example, all the main cycles initiated with HF1, which were identified from the static analysis of the FCM created for the historical data analysis stage. Thus, the model provided in Figure 9.1 is rich in cycles.

Table 9.6. Main cycles identified for grounding/stranding accidents in general cargo vessels. The first stage of the MALFCMs method. Period 2000-2011

No	Cycles	No	Cycles
1	HF1-HF7- HF1	14	HF1-HF9-HF1
2	HF1-HF7-HF2-HF3-HF9-HF1	15	HF1-HF9-HF2-HF3-HF7-HF1
3	HF1-HF7-HF3-HF2-HF4-HF9-HF1	16	HF1-HF9-HF2-HF5-HF7-HF1
4	HF1-HF7-HF3-HF2-HF6-HF9-HF1	17	HF1-HF9-HF2-HF6-HF7-HF1
5	HF1-HF7-HF3-HF2-HF9-HF1	18	HF1-HF9-HF2-HF7-HF1
6	HF1-HF7-HF3-HF9-HF1	19	HF1-HF9-HF3-HF2-HF5-HF7-HF1
7	HF1-HF7- HF5-HF2-HF3-HF9-HF1	20	HF1-HF9-HF3-HF2-HF6-HF7-HF1
8	HF1-HF7- HF5-HF2-HF9-HF1	21	HF1-HF9-HF3-HF2-HF7-HF1
9	HF1-HF7-HF6-HF2-HF3-HF9-HF1	22	HF1-HF9-HF3-HF7-HF1
10	HF1-HF7-HF6-HF2-HF9-HF1	23	HF1-HF9-HF6-HF2-HF5-HF7-HF1
11	HF1-HF7-HF6-HF9-HF1	24	HF1-HF9-HF6-HF2-HF7-HF1
12	HF1-HF7-HF9-HF1	25	HF1-HF9-HF6-HF7-HF1
13	HF1-HF8-HF1	26	HF1-HF9-HF7-HF1

9.4 Application of the Second Stage of MALFCMs Method to Grounding and Stranding Accidents on General Cargo Vessel

9.4.1 Participants Description

For this research study, five selected experts (which are referred to as Participant1, Participant2, Participant3, Participant4, and Participant5) completed the questionnaire, which is provided in Appendix E. Skill and experienced participants on the areas of HFs, ship operations, and accident investigations were selected in order to have a positive effect on the results. Table 9.7 provides a better description of the participants' backgrounds. In addition, Table 9.8 shows the years of experience and knowledge for each participant.

Table 9.7. Background of each participant. The second stage of the MALFCMs method

P1	P2	P3	P4	P5
Seafarer, shipping company executive, flag administrator, and accident investigator	Academic and seafarer	Academic	Independent ship and cargo surveyor and technical consultant.	Academic

Table 9.8. Years of experience and knowledge of each participant. The second stage of MALFCMs method

	P1	P2	P3	P4	P5
Years of experience	48	27	3	8	11
Q1-From 1 (lowest score) to 5: knowledge regarding accident investigations	4	4	3	4	4
Q2-From 1 (lowest score) to 5: knowledge regarding human factors	3	4	4	3	5
Q3-From 1 (lowest score) to 5: knowledge regarding ship operations	5	4	3	4	4

9.4.2 **Data Collection**

As it was explained in the previous chapters, the application of questionnaires is a popular method to collect expert opinion. As a result, many FCM related research studies reported using questionnaires to collect expert feedback (Hossain, 2006; Tsadiras et al., 2001). Similarly, in this research study also, questionnaires were utilised. Each participant was asked to complete an online questionnaire. The survey was comprehensive, and on average, it took around one and a half hours for a participant to complete the survey. The survey presented a long list of questions regarding the nine HFs that were identified within the analysis of the historical accident database (i.e. the list of HFs identified in Table 9.3).

Three types of closed questions were included in the questionnaire. The first type included general questions related to the background of each participant (i.e. years of experience, position, and level of knowledge regarding the areas of HFs, ship operations, and accident investigations). The second type of questions asked at what level a particular factor would need to be applied to have a minimum contribution to an accident. A response was selected from the alternatives “None”, “Very low”, “Low”, “Medium”, “High”, “Very high”, and “Very very high”. In addition, the answers to this set of questions would allow defining the state vector for the expert opinion stage. Finally, the last type was designed to allocate strength values to the interrelationship amongst HFs. Hence, this set of questions were typically asked in the following format: “given a change in “Factor a, what would be the effect on Factor b”. A response was selected from the alternatives “None”, “Very small”, “Small”, “Moderate”, “Big”, “Very big”, and “Very very big”. Thus, the answers to this set of questions would allow defining the interaction matrix for the expert opinion stage.

9.4.3 **Missing Data**

The data obtained from the questionnaires was analysed to identify unusual or missing data. For this specific case study, no missing data was collected due to the low number of experts taken into considerations (i.e. participants were forced to provided full answers to the questionnaire). Nevertheless, for those case studies that includes enough participants, it will be possible to include two additional answers in the questionnaire. First, for the set of questions asked at what level a particular factor would need to be applied to have a minimum contribution to an accident, an additional response will be added as “I do not know”. Secondly, for the type of questions designed to allocate strength values to the interrelationship amongst HFs, also an additional response will be added as “I do not know”.

9.4.4 **Participants’ Answers to Questionnaire Provided**

Once the questionnaire was completed, all the answers were collected and analysed. An interaction matrix was created for each participant, expressed in linguistic terms. Table 9.9 shows, as an example, the state vector created by Participant1, which was populated with his/her answers to the second type of question. In addition, Table 9.12 provides the interaction matrix created by Participant1, which was populated with his/her answers to the third type of questions, as described above. Thus, the interaction matrices and state vectors obtained from all participants are displayed in Appendix H.

Table 9.9. Initial state vector created by Participant1 by applying linguistic terms. The second stage of MALFCMs method

	HF1	**HF2**	**HF3**	**HF4**	**HF5**	**HF6**	**HF7**	**HF8**	**HF9**
	Low	Medium	Very low	Medium	None	Low	Very low	Very low	High

To be able to combine the experts’ answers to the questionnaire, the next step involved the conversion of the individual FCMs (expressed in linguistic terms) into numerical expressed FCMs. As described in the literature, a linguistic weight might be transformed into numerical values by means of a linguistic-numerical conversion. Hence, the five linguistic conversions proposed by Tsadiras et al. (2001) was adapted to include the seven linguistic terms used in the questionnaire, as explained in Chapter 7. The conversion measures applied in this research study were provided in Table 7.1 (i.e. conversion values for the state vector), and Table 7.2 (i.e. conversion values for the interaction matrix); however, it was decided to also include them below, in order to facilitate their reading.

Table 9.10. Fuzzy conversion measures for the state vector

Fuzzy linguistic terms	**None**	**Very low**	**Low**	**Medium**	**High**	**Very high**	**Very very high**
Fuzzy numerical weights	0.000	0.165	0.330	0.495	0.660	0.825	1.000

Table 9.11. Fuzzy conversion measures for the interaction matrix

Fuzzy linguistic terms	**None**	**Very small**	**Small**	**Moderate**	**Big**	**Very big**	**Very very big**
Fuzzy numerical weights	0.000	0.165	0.330	0.495	0.660	0.825	1.000

Table 9.12. Interaction matrix created by Participant1 by applying linguistic terms. The second stage of MALFCMs method

	HF1	**HF2**	**HF3**	**HF4**	**HF5**	**HF6**	**HF7**	**HF8**	**HF9**
HF1	-	Small	Very small	Small	Very small	Moderate	Very small	Moderate	Big
HF2	None	-	Big	Big	Big	Big	Moderate	Moderate	Very big
HF3	None	Small	-	Small	Small	Moderate	Very small	Very small	Moderate
HF4	None	Small	Small	-	Moderate	Moderate	Very small	Big	Moderate
HF5	None	Big	Moderate	Small	-	Big	Very small	Small	Big
HF6	None	Very big	Moderate	Moderate	Moderate	-	Big	Big	Very big
HF7	None	Very small	Small	Small	Small	Moderate	-	Small	Moderate
HF8	None	None	Very small	Moderate	Very small	Small	None	-	Moderate
HF9	None	Moderate	Very small	Moderate	Moderate	Big	Very small	Moderate	-

The aforementioned conversion measures were applied to transform the participants' FCMs into numerical expressed FCMs. Table 9.13 shows as an example, the numerical state vector created by applying the previous conversion measures to the answers provided by Participant1. In addition, Table 9.14 provides the numerical interaction matrix obtained for Participant1.

Table 9.13. Initial state vector created by Participant1 after fuzzy conversion. The second stage of MALFCMs method

	HF1	**HF2**	**HF3**	**HF4**	**HF5**	**HF6**	**HF7**	**HF8**	**HF9**
	0.330	0.495	0.165	0.495	0.000	0.330	0.165	0.165	0.660

Table 9.14. Interaction matrix created by Participant1 after fuzzy conversion. The second stage of MALFCMs method

	HF1	HF2	HF3	HF4	HF5	HF6	HF7	HF8	HF9
HF1	-	0.330	0.165	0.330	0.165	0.495	0.165	0.495	0.660
HF2	0.000	-	0.660	0.660	0.660	0.660	0.495	0.495	0.825
HF3	0.000	0.330	-	0.330	0.330	0.495	0.165	0.165	0.495
HF4	0.000	0.330	0.330	-	0.495	0.495	0.165	0.660	0.495
HF5	0.000	0.660	0.495	0.330	-	0.660	0.165	0.330	0.660
HF6	0.000	0.825	0.495	0.495	0.495	-	0.660	0.660	0.825
HF7	0.000	0.165	0.330	0.330	0.330	0.495	-	0.330	0.495
HF8	0.000	0.000	0.165	0.495	0.165	0.330	0.000	-	0.495
HF9	0.000	0.495	0.165	0.495	0.495	0.660	0.165	0.495	-

9.4.5 Analysis of Expertise Level from Experts Involved

All the FCMs have been transformed from linguistic into numeric FCMs at this stage. Thus, all the individual FCMs need to be aggregated in order to create a unique FCM, which reflects the knowledge of all participants. In this regard, relevant data is fed into Equation 7.2.

As some experts may be more credible than others, their contribution is multiplied in this study by a coefficient, w_i, before combining it with other experts' opinions. Many authors in the literature have defended the use of $w_i=1$ (Taber, 1987). Nevertheless, as the participants within this research study had various credentials and expertise areas, it was not reasonable to assume the same credibility weight for each participant. Therefore, the credibility weighting for each expert was established by adapting the method developed by Hossain (2006), which was introduced and explained in Chapter 6. In addition, in order to apply the aforementioned method, Table 7.3 showed the criteria that were considered to assign credibility weights for each expert, while Table 7.4 provided the key to the criteria table.

Table 9.8 included the answer provided by all experts regarding their level of knowledge in the areas of accident investigation (Q1), HFs (Q2), and ship operation (Q3). Hence, it is possible to define a score for Q1 to Q3 by utilizing the criteria table (i.e. Table 7.3), which provides a credibility value for each participant, as shown in Table 9.15. In addition, in Table 9.15, the total credibility value is obtained to be used in the FCM normalisation process.

Table 9.15. Credibility weights assigned to participants. The second stage of MALFCMs method

No Participant	Answer to question			Credibility value
	Score Q1	Score Q2	Score Q3	
Participant1	4	4	4	12
Participant2	4	5	4	13
Participant3	3	5	3	11
Participant4	4	4	4	12
Participant5	4	5	4	13
Total				**61**

9.4.6 Aggregation of Expert Opinion, Establishment of Interaction Matrix & State Vector

Once the credibility value for each participant has been calculated in the previous step, Equation 7.3 is applied to obtain the interaction matrix and the state vector, which results from combining the answers from all the participants by also taking into account their level of expertise. Table 9.16 shows the initial state vector (St.0) for the expert opinion stage, while Table 9.17 represents the interaction matrix obtained.

Table 9.16. Initial state vector derived from the aggregation of participants' state vectors. The second stage of MALFCMs method

	HF1	HF2	HF3	HF4	HF5	HF6	HF7	HF8	HF9
	0.406	0.728	0.733	0.563	0.603	0.730	0.655	0.495	0.628

Table 9.17. Interaction matrix derived from the aggregation of participants' interaction matrices. The second stage of MALFCMs method

	HF1	HF2	HF3	HF4	HF5	HF6	HF7	HF8	HF9
HF1	-	0.265	0.376	0.476	0.441	0.333	0.360	0.598	0.590
HF2	0.000	-	0.665	0.698	0.668	0.770	0.624	0.576	0.730
HF3	0.000	0.352	-	0.408	0.481	0.511	0.522	0.446	0.465
HF4	0.000	0.379	0.300	-	0.433	0.403	0.268	0.676	0.650
HF5	0.000	0.617	0.438	0.403	-	0.541	0.449	0.473	0.571
HF6	0.000	0.616	0.406	0.533	0.500	-	0.546	0.538	0.727
HF7	0.000	0.427	0.605	0.373	0.603	0.605	-	0.476	0.505
HF8	0.000	0.168	0.200	0.433	0.133	0.368	0.208	-	0.268
HF9	0.000	0.595	0.371	0.430	0.438	0.571	0.422	0.403	-

9.5 Application of the Third Stage of MALFCMs Method to Grounding and Stranding Accidents on General Cargo Vessel

9.5.1 Dynamic Analysis of the FCM to Obtain the Weight of Human-Contributing Factors from Historical Accident Data

As the interaction matrix and state vector for the first stage of MALFCMs have been already defined in previous sections, a dynamic analysis of the FCM is performed by applying Equation 2.1. Table 9.18 provides the initial state vector (St.0) and the dynamic evolution of the FCM until equilibrium is reached. In addition, in the dynamic FCMs, the simulation stops when the difference between two consecutive steps is small enough. Therefore, it was decided to select as a criterion a difference between two consecutive steps of 10^{-5}, which is achieved at iteration 8 in this case. In addition, Figure 9.2 shows the iterative process followed until equilibrium is reached.

Table 9.18. Calculation of steady states for grounding/stranding accidents in general cargo vessels. The third stage of the MALFCMs method. Period 2000-2011

	HF1	**HF2**	**HF3**	**HF4**	**HF5**	**HF6**	**HF7**	**HF8**	**HF9**
St.0	0.12500	0.68750	0.50000	0.06250	0.12500	0.06250	0.68750	0.06250	0.50000
St.1	0.54674	0.79819	0.67918	0.54674	0.56218	0.54674	0.80807	0.51562	0.71859
St.2	0.66349	0.95759	0.70959	0.56272	0.57250	0.55869	0.94889	0.56792	0.93869
St.3	0.68385	0.96814	0.74463	0.57974	0.58580	0.57216	0.96367	0.58218	0.95125
St.4	0.68755	0.97064	0.74737	0.58074	0.58692	0.57310	0.96633	0.58466	0.95456
St.5	0.68822	0.97089	0.74793	0.58100	0.58715	0.57332	0.96665	0.58511	0.95488
St.6	0.68833	0.97094	0.74799	0.58103	0.58717	0.57334	0.96670	0.58519	0.95494
St.7	0.68835	0.97094	0.74800	0.58103	0.58717	0.57335	0.96671	0.58520	0.95495
St.8	0.68836	0.97094	0.74801	0.58103	0.58718	0.57335	0.96671	0.58520	0.95495

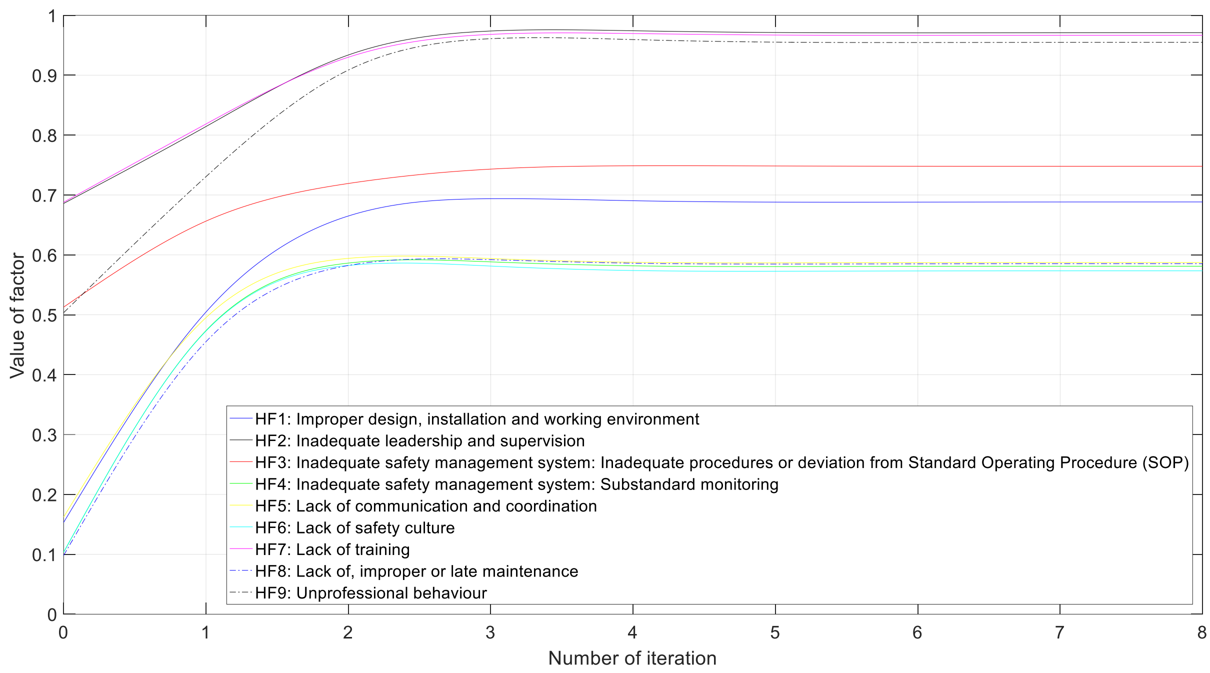


Figure 9.2. Dynamic FCM for grounding/stranding accidents in general cargo vessels from historical accident data until equilibrium is reached. The third stage of the MALFCMs method. Period 2011-2016

Finally, Table 9.19 shows the final weight obtained for all human-contributing factors after the iteration reaches equilibrium and the simulation stops. These weights are constrained to the interval [0,1], as the threshold function limits the inputs to a strict range, to maintain the stability. Additionally, these results have been normalised, and the final weights are also displayed in terms of percentage.

Table 9.19. The final weight of contributors for grounding accidents in general cargo vessels from historical accident data. The third stage of the MALFCMs method. Period 2011-2016

Human factor description	**Weights from historical accident data**	**Weights normalised (%)**
HF1: Improper design, installation, and working environment	0.688	10.342
HF2: Inadequate leadership and supervision	0.971	14.588
HF3: Inadequate safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)	0.748	11.239
HF4: Inadequate safety management system: Substandard monitoring	0.581	8.730
HF5: Lack of communication and coordination	0.587	8.822
HF6: Lack of safety culture	0.573	8.614
HF7: Lack of training	0.967	14.525
HF8: Lack of, improper or late maintenance	0.585	8.793
HF9: Unprofessional behaviour	0.955	14.348

9.5.2 Dynamic Analysis of the FCM to Obtain the Weight of Human-Contributing Factors from Expert Analysis

Following the same process described in the previous section, a dynamic analysis of the FCM obtained from the expert analysis is performed by applying Equation 2.1. Table 9.20 provides the initial state vector (St.0), and the dynamic evolution of the FCM obtained from the expert analysis until equilibrium is reached, which occurs before step 5 (St.5). In addition, Figure 9.3 shows the iterative process followed until equilibrium is reached.

Table 9.20. Calculation of steady states for grounding/stranding accidents in general cargo vessels from the expert analysis. The third stage of MALFCMs method

	HF1	HF2	HF3	HF4	HF5	HF6	HF7	HF8	HF9
St.0	0.4057	0.7276	0.7330	0.5626	0.6032	0.7298	0.6546	0.4950	0.6275
St.1	0.5000	0.8944	0.8903	0.9138	0.9139	0.9282	0.8976	0.9316	0.9435
St.2	0.5000	0.9538	0.9485	0.9620	0.9602	0.9733	0.9506	0.9726	0.9793
St.3	0.5000	0.9598	0.9552	0.9675	0.9661	0.9778	0.9572	0.9770	0.9829
St.4	0.5000	0.9605	0.9559	0.9681	0.9666	0.9782	0.9578	0.9774	0.9833
St.5	0.5000	0.9605	0.9560	0.9681	0.9667	0.9783	0.9579	0.9775	0.9833
St.6	0.5000	0.9605	0.9560	0.9681	0.9667	0.9783	0.9579	0.9775	0.9834
St.7	0.5000	0.9605	0.9560	0.9681	0.9667	0.9783	0.9579	0.9775	0.9834
St.8	0.5000	0.9605	0.9560	0.9681	0.9667	0.9783	0.9579	0.9775	0.9834

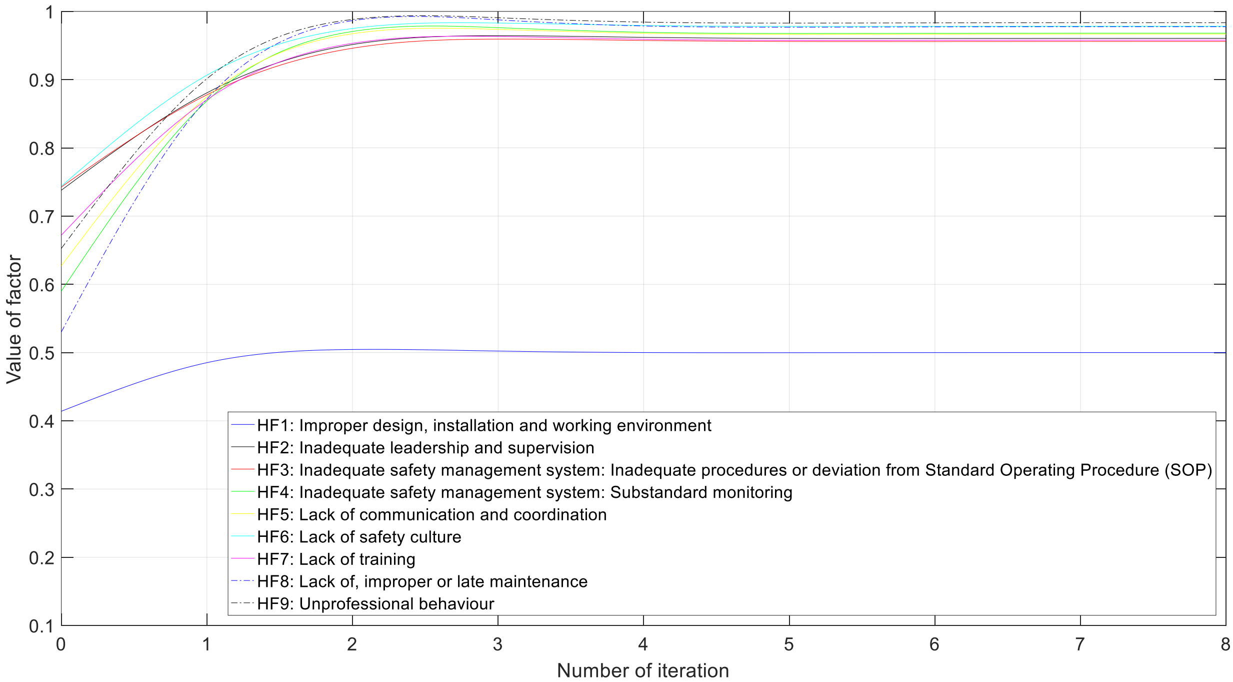


Figure 9.3. Dynamic FCM for grounding/stranding accidents in general cargo vessels from the expert analysis until equilibrium is reached. The third stage of MALFCMs method

Finally, Table 9.21 shows the final weight obtained for all human-contributing factors, after the iteration reaches equilibrium and the simulation stops. These weights are constrained to the interval [0,1] (i.e. to limit the inputs to a strict range, to maintain the stability). Additionally, these results have been normalised, and the final weights for the expert opinion stage are also displayed in terms of percentage.

Table 9.21. The final weight of contributors for grounding accidents in general cargo vessels from the expert analysis. The third stage of MALFCMs method

Human factor description	Weights from expert analysis	Weights normalised (%)
HF1: Improper design, installation, and working environment	0.500	6.062
HF2: Inadequate leadership and supervision	0.961	11.645
HF3: Inadequate safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)	0.956	11.590
HF4: Inadequate safety management system: Substandard monitoring	0.968	11.737
HF5: Lack of communication and coordination	0.967	11.720
HF6: Lack of safety culture	0.978	11.860
HF7: Lack of training	0.958	11.613
HF8: Lack of, improper or late maintenance	0.978	11.851
HF9: Unprofessional behaviour	0.983	11.922

9.6 Application of the Fourth Stage of MALFCMs Method to Grounding and Stranding Accidents on General Cargo Vessel

The fourth and final stage of MALFCMs combines the results obtained from the historical data analysis and expert analysis through sensitivity analysis. Thus, the suitability of performing a sensitivity analysis to combine the outputs from the historical data and expert opinion was discussed in Chapter 7. Finally, Table 9.22 includes the normalised weights of each human factor, which are derived by combining the historical data and the expert opinion, which were assigned to equal importance. In addition, Figure 9.4 represents the sensitivity analysis to provide a better understanding of the process.

Table 9.22. Sensitivity analysis to combine the results from the historical data analysis stage and the expert opinion stage

Human factor description	Normalised historical data results (%)	Normalised experts' results (%)	Final weights (%)
HF1: Improper design, installation, and working environment	10.342	6.062	8.202
HF2: Inadequate leadership and supervision	14.588	11.645	13.116
HF3: Inadequate safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)	11.239	11.590	11.415
HF4: Inadequate safety management system: Substandard monitoring	8.730	11.737	10.233
HF5: Lack of communication and coordination	8.822	11.720	10.271
HF6: Lack of safety culture	8.614	11.860	10.237
HF7: Lack of training	14.525	11.613	13.069
HF8: Lack of, improper or late maintenance	8.793	11.851	10.322
HF9: Unprofessional behaviour	14.348	11.922	13.135

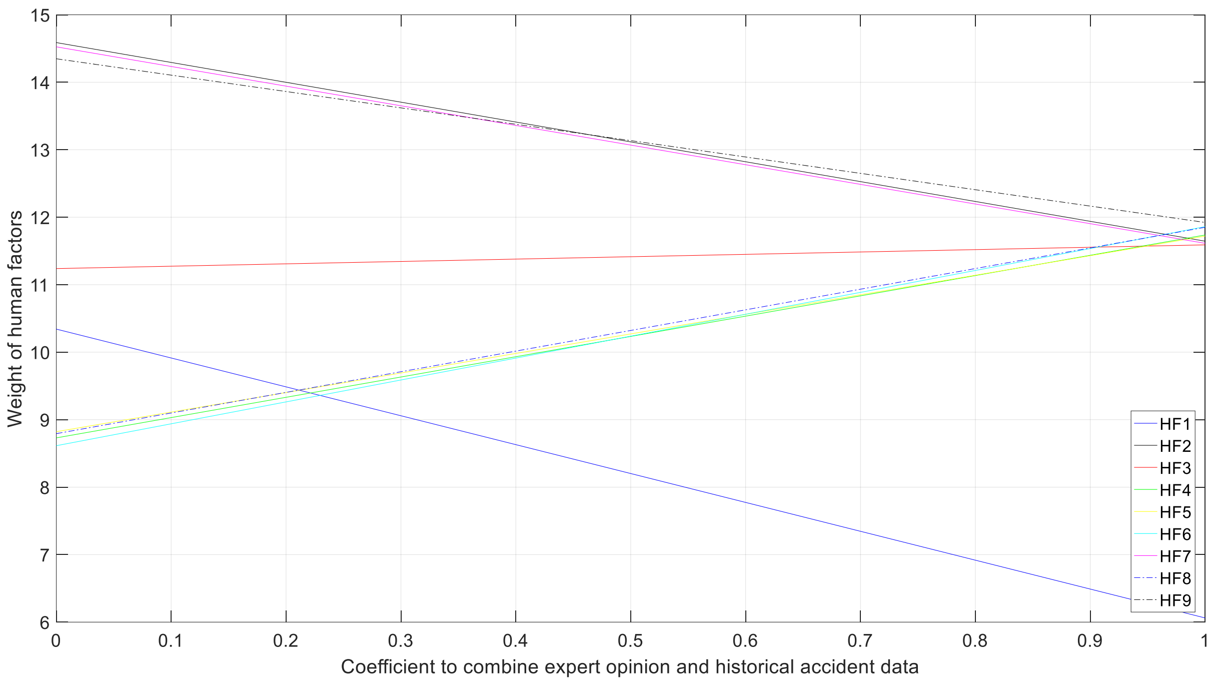


Figure 9.4. Sensitivity analysis to combine the results from the expert opinion stage and the historical data analysis stage

9.7 Discussion on the Accident Contributing Factors Results Obtained

Based on the results of the dynamic analysis of the FCM created within the historical data analysis stage, "HF2: Inadequate leadership and supervision" was identified as the most critical factor. Inadequate supervision has been consistently identified in previous studies as highly related to maritime accidents. For instance, B. M. Batalden and Sydnes (2017) applied a modified Human Factor Analysis and Classification System (HFACS) framework, identifying unsafe supervision as a main causal factor leading to very serious accidents. B.-M. Batalden and Sydnes (2014) also performed a study to investigate casualties and incidents, revealing that unsafe supervision emerges as the biggest challenge. Furthermore, a study conducted by Macrae (2009) on grounding and collision accidents revealed that a lack of supervision and team communication was reported as critical contributing factors.

In addition, also “HF7: Lack of training” was identified as an important HF within this analysis. This observation is in line with previous studies. For example, Puisa et al. (2018) analysed numerous maritime accidents, revealing that inadequate training was observable in numerous past accidents, and it was a frequent causal factor across all reports analysed. Moreover, Graziano et al. (2016) applied the Technique for Retrospective and Predictive Analysis of Cognitive Errors (TRACEr) and found that most of the failures were associated with factors like fatigue or inadequate training/instruction. Thus, a study performed by Kum and Sahin (2015) revealed that maritime accidents on extreme regions were mainly associated with inadequate quality and extension of training.

Finally, “HF9: Unprofessional behaviour” was identified as the third main contributing factor within this case study. Inadequate behaviour has been previously linked to maritime accidents in the literature. For example, a study performed by Antão, Almeida, Jacinto, and Guedes Soares (2008) highlighted that inadequate behaviour was identified within particular tasks, leading to accidents.

In addition, it is observable that the dynamic analysis of the FCM created within the expert opinion stage mainly disagrees with the findings from the historical data analysis, with the exception of “HF3: Inadequate safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)”. Thus, it is also noticeable that experts have assigned similar weightings to all factors, with the exception of “HF1: Improper design, installation, and working environment”. This observation clearly indicates that experts were not able to successfully rank the importance of the various HFs in this specific case study.

There are two possible reasons that could explain such similar weighting in the expert opinion results, the questionnaire utilised and the experts themselves. Regarding the questionnaire, special measures were taking to guarantee that the style and content of questions were clear. In addition, as the questionnaire was distributed online; hence, there was no chance to see the answers until the collection was completed, an internal meeting with three HFs experts was organised to check each question separately, aiming to determine if each question was clear and leaving no room for misinterpretation. Moreover, the conversion rates were obtained and adapted from similar studies that also collected expert data. Hence, the researcher believes that the questionnaire was not the cause of obtaining the aforementioned similar weightings.

Therefore, it seems that the problem origin lies in the experts´ answers. However, there are multiples reasons that could explain why experts were not able to rank successfully the HFs. By having a closer look into the experts´ answers (Appendix H), it is noticeable that the majority of experts have adopted a similar safe approach in their answers, i.e. they have limited their range of answers to the central range of options provided in the questionnaire. Therefore, it seems that the particular experts selected for this case study were not confident enough in their expertise area, as in general they could not defend a strong opinion.

A further analysis of the expert results reveals that "HF9: Unprofessional behaviour" was identified as the main human-contributing factor, followed by "HF6: Lack of safety culture", and "HF8: Lack of, improper or late maintenance". Although the weightings for the previous factors was very similar as it was discussed before.

The major disagreement observed between both FCM created (i.e. historical data and expert opinion) occurs for "HF1: Improper design, installation, and working environment", which was identified by participants as the less influential factor in maritime accidents, while it has medium importance according to with the weights from the historical data analysis stage. And for "HF6: Lack of safety culture", which has the lowest contribution based on the database analysis, but it was ranked second place by experts. The aforementioned disagreements are a clear example of the subjectivity that may be associated with the use of expert judgement in the MALFCM approach. For instance, it is a fact that a lack of safety culture has been a traditional critical cause of maritime accidents in the past decades; however, it is currently being addressed by shipping companies, as it is suggested from its low weighting obtained from the analysis of the database. On the other hand, experts still consider it as highly contributing to shipping accidents. Historically a lack of safety culture has been a key factor for maritime accidents; hence, it seems that experts are often reluctant to change their opinion about this factor. In addition, an alternative explanation is that a lack of safety culture is a very abstract concept; hence, it is very difficult for accident investigators to adequately capture if this factor is influencing or not a maritime accident. Thus, accident investigators are often provided with a checklist to identify HFs, which often lack a definition for each HF. Hence, if adequate training is not provided it is very difficult to successfully select the right HFs, and by extension, this affect negatively the recording process on the accident database, as some factors are assigned wrongly or not assigned at all.

Finally, in the last stage, the two sets of weights obtained are mixed together to reach more reliable weights for each HF. It should be noticed that equal coefficients (i.e. both coefficients are 0.5) are used for the weights derived from historical data and participants' views). Nevertheless, a sensitivity analysis has been further proposed to examine how important are the coefficients used to reach a mixed weight. Figure 9.4 showed the changes in final weights by changing the coefficient from 0.1 to 0.9, which has been used to combine both FCMs results. It is possible to observe that "HF1: Improper design, installation, and working environment" is the most sensitive factor to changing the coefficients "expert opinion-historical accident data", as there is a 4.280% difference between the maximum and the minimum value of this factor (i.e. the weight of this factors is in the interval 6.062-10.342 depending on the coefficients' distribution). In addition, the least sensitive factor to changes in its value is "HF3: Inadequate safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)", which remains almost insensitive to changing the coefficients' distribution. Thus, this insensitivity is a good indicator of the ability to compare together historic accident data and expert opinion.

Based on the results demonstrated in this chapter, it can be said that the proposed MALFCMs approach is suitable to combine historical data and expert judgement successfully. However, there are two critical factors to consider when combining both sources of data. First, to ensure that enough data is collected and available for the historical data analysis. Second, to ensure that experts with the right background are adequately selected. Overall, both historical data and expert judgement often identifies similar factors; nevertheless, for specific cases, it is observed a discrepancy amongst both analysis. For those cases, it is important to conduct a sensitivity analysis, as shown in this chapter, as it will be key to combine the results obtained from both data sets.

9.8 Chapter Summary

In this chapter, weightings for each human accident-contributing factor involved in grounding/stranding accidents in general cargo vessels were obtained by combining the findings from two different data sources. The first source was a historical accident database, from where sixteen accidents between 2011 and 2016 were examined and analysed, aiming to identify those HFs leading to maritime accidents. Thus, the aforementioned accident data was used as an input to calculate the weight for each HF by means of the FCMs method. The second source was data collected from questionnaires. The questionnaire contained a long list of questions regarding the nine HFs that were identified within the analysis of the historical accident database. Five experts answered the aforementioned questionnaire in a way that they could utilize linguistic values to measure the impact of each HF. In addition, each expert had a diverse background from the maritime industry (i.e. seafarers, academics, or accident investigators). Thus, for constructing a second FCMs from the second source of data, the linguistic values provided were converted into numeric values. Then, all experts' views were combined by assigning a different credibility weight to each expert, based on his/her knowledge regarding the areas of HFs, ship operations, and accident investigations.

Chapter 10 will include the development of the second output of this research study, the so-called resilience assessment framework, which will allow assessing the resilience level in a shipping company as a final output.

10 RESILIENCE ASSESSMENT FRAMEWORK

10.1 Overview

It was stated in the literature review that, for a system to be safe, it must be resilient. A most accepted way for resilience engineering was to consider the four abilities or cornerstones (i.e. learning, anticipating, monitoring and responding), as none of them can be left out if we want a system to be resilient. Nevertheless, many authors have extended the aforementioned resilience cornerstones to incorporate additional resilience factors. Thus, a new concept known as Integrated Resilience Engineering (IRE) was defined by A. Azadeh, Salehi, Ashjari, et al. (2014), which includes additional resilience engineering abilities (e.g. teamwork, redundancy or fault tolerance). Subsequently, developing a tool based on resilience engineering precepts and concepts that allow measuring the resilience factors included in the aforementioned IRE is judged of great importance. Therefore, this chapter first provides in Section 10.2 the context and objectives of developing a resilience assessment framework. In addition, this chapter describes the overall resilience assessment framework, which is proposed with the aim of assessing the resilience level within a shipping company, based on how the company performs on certain resilience abilities, which are linked to common human causes of accidents.

The aforementioned resilience assessment framework consists of six phases. Section 10.3 describes the first phase, which aims to identify and quantify the importance of those HF threats that could adversely affect the performance and safety on board by applying the MALFCMs method. Section 10.4 explains the second phase, which includes the identification of major resilience abilities. Moreover, Section 10.5 analyses the third phase, which aims to establish a link between HF threats and resilience abilities. Thus, this section also includes the criteria for the selection of participants, the design of a questionnaire for data collection, and the criteria to analyse and aggregate the data collected. Section 10.6 describes the fourth phase, which is related to the procedure of establishing weightings for all resilience abilities. In addition, Section 10.7 analyses the fifth phase, which included the development and distribution of a Resilience Assessment Questionnaire (RAQ). Finally, Section 10.8 explains the sixth phase, which comprised the analysis of the RAQ results, the establishment of a resilience score, and recommendation for resilience improvement. A general overview of the proposed resilience assessment framework is provided in Figure 10.1. In addition, Figure 10.2 aims to provide a clearer picture regarding how the different resilience assessment phases are interrelated amongst them and with the content of previous chapters.

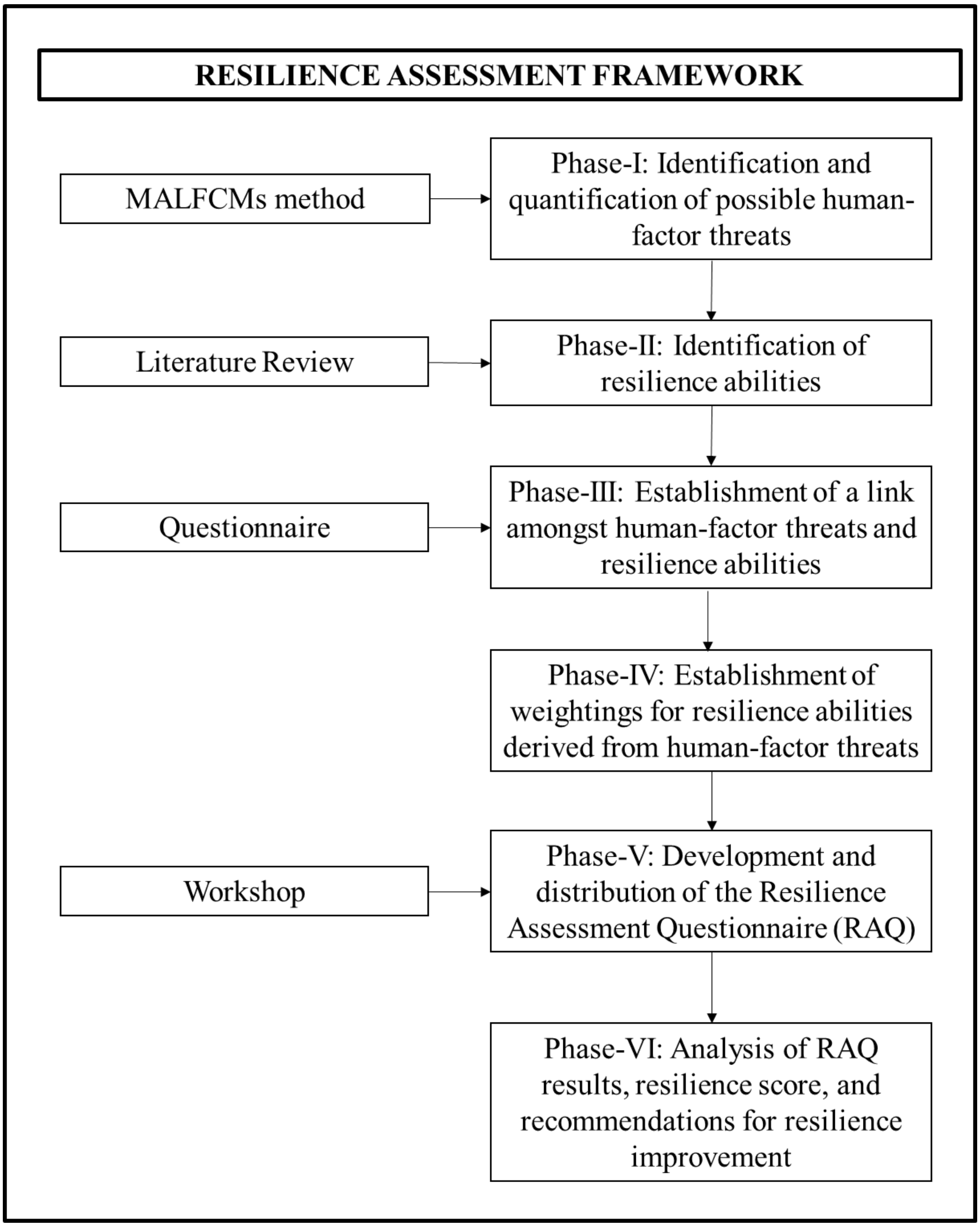


Figure 10.1. Overview of the proposed resilience assessment framework

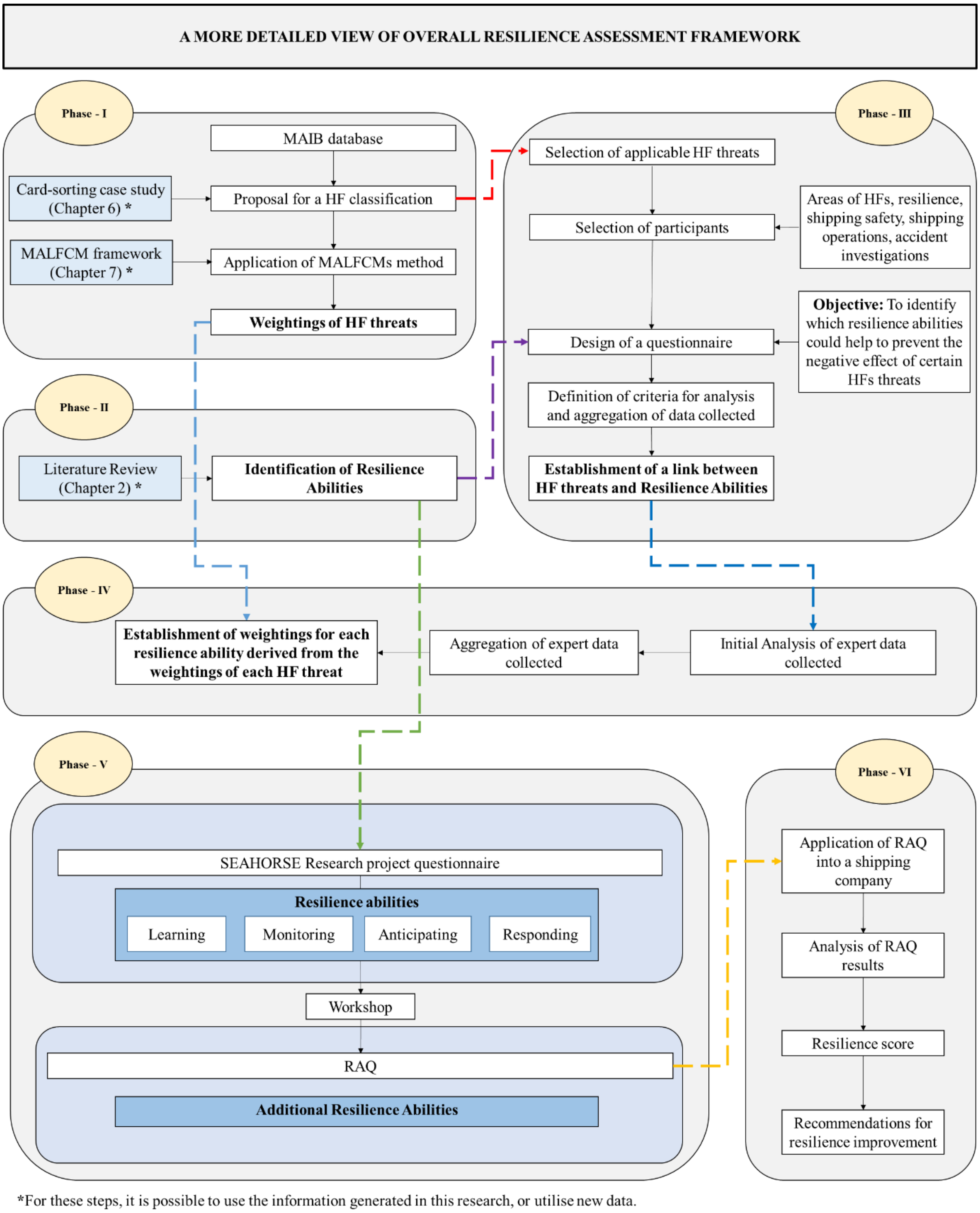


Figure 10.2. A more detailed overview of the content of each phase in the proposed resilience assessment framework

10.2 Context and Objective of Developing a Resilience Assessment Framework

Maritime accidents remain a major concern in our society, as they are frequently related to undesirable accidental outcomes such as injuries to personnel, damage to property or environmental impact. Thus, the maritime industry is also facing numerous emerging challenges that illustrate the complexity of maritime operations as follows:

- More regulations and increasing demand on crew to comply with new regulations and associated procedures.
- International crews are often the result of supply shortages and wage pressure from ship owners. This situation increases risks on-board due to varying (and often substandard) training regimes.
- Design of modern vessels with increased automation: Often, more automation means less physical work; hence it leads to crew reductions. However, when the system is designed without proper consideration given to human capabilities and needs, automation can result in additional risks. For example, if human-machine interaction is not carefully considered and properly designed, it can cause additional cognitive load and fatigue.

There are abilities and strengths that exist in an organisation which help to maintain the safety of its operations when challenges arise. These challenges may be known to operators and management already, or they may occur unexpectedly. Thus, by properly addressing and managing the influence of those factors that mostly affect maritime accidents (i.e. HFs), it is possible to contribute to a safer maritime industry.

The main aim of developing and applying a resilience assessment framework is to help ship operators and maritime companies to increase the safety of their operations and improve workers' work experience and well-being by enhancing overall resilience of ship operation. In order to realise the aforementioned aim, this research will develop and apply a Resilience Assessment Questionnaire (RAQ), which presents a similar structure to the questionnaire created as an outcome of the FP 7 Research project called Safety Enhancement in Transport by Achieving Human Orientated Resilient Shipping Environment (SEAHORSE).

The SEAHORSE resilience framework is built on four resilience levels (i.e. individual, crew, multi-party and organization) based on the four major resilience cornerstones (i.e. learning, monitoring, anticipating and responding) (Turan et al., 2016). Resilience assessment approach of this research study evolved from the original resilience assessment framework developed in SEAHORSE Project, therefore naturally there are similarities in the survey methodology but the main differences are as follows:

- SEAHORSE resilience questionnaire was focused on assessing resilience at four different levels (i.e. individual, team, organization, and multi-party levels) while this research although uses similar resilience statements, it does not calculate the resilience at the aforementioned levels, but obtains one overall results to represent the company overall resilience.
- SEAHORSE project incorporated the four traditional resilience abilities, while this research also incorporates additional resilience abilities that were identified from the literature review analysis as indicated before. The eleven resilience abilities that are considered in this research are indicated and defined on Table 10.1.
- SEAHORSE project aimed to address various operational demands or challenges (e.g. extreme weather conditions, faulty design, etc.) while this research aims to assess the resilience level in a shipping company, based on how the company performs on certain resilience abilities, which are linked to common human causes of accidents (i.e. HF threats).

10.3 Phase-I: Identification and Quantification of Possible Human-Factor Threats

The identification and quantification of possible HF threats are fulfilled by applying the MALFCMs method. A comprehensive description of the MALFCMs method was provided in Chapter 7. In addition, Chapter 8 demonstrated the historical data analysis stage from the above-mentioned MALFCMs method, and Chapter 9 demonstrated the overall MALFCMs method through a case study on grounding and stranding accidents on cargo ships.

10.4 Phase-II: Identification of Resilience Abilities

As it was discussed before, there are four resilience abilities or resilience cornerstones, which have been applied traditionally to establish if a system is resilient (Erik Hollnagel, 2011) as shown in Figure 10.3:

- Respond and/or react: Recognize when and how to react in both expected and unexpected conditions.

- Monitor: Perceive significant changes in performance, covering what happens in both, the system and the environment
- Anticipate: Detect threats and opportunities beyond the current operation.
- Learn: Facilitate and enhance learning the right lessons from the right experiences, including both successes and failures.

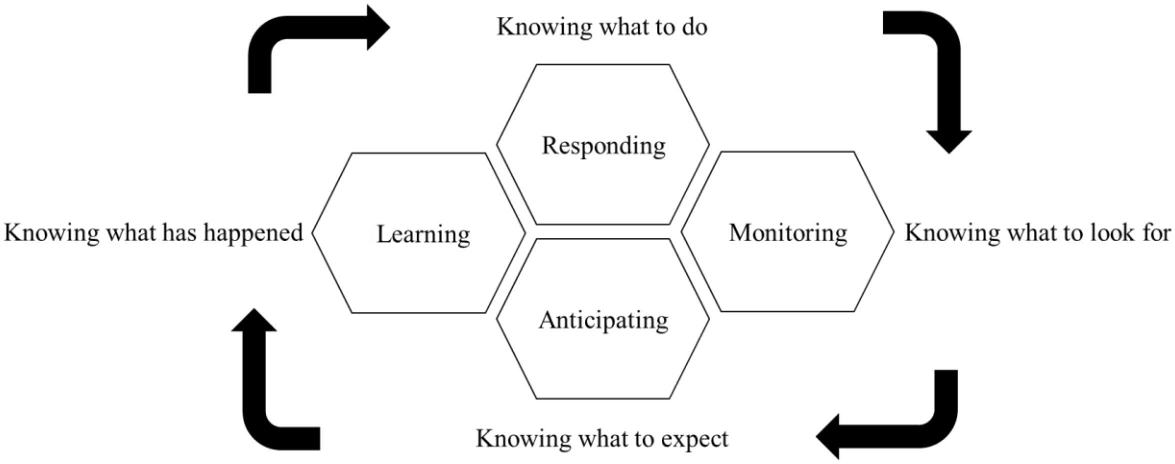


Figure 10.3. Four traditional resilience abilities

The above-mentioned abilities have been widely recognized as the major resilience cornerstones. Nevertheless, numerous authors have extensively defined and applied additional factors when addressing resilience engineering, as it was summarized in Table 2.4. This PhD study will assess the additional resilience factors that were identified from previous studies and combine them with the traditional resilience abilities that are commonly used. The aim is to establish a complete list of resilience abilities which can be linked to HF threats in maritime accidents. Therefore, Table 10.1 summarises the resilience abilities that are initially included in this research study, together with the scope of each ability.

Table 10.1. Resilience abilities initially addressed in the resilience-engineering framework

No	Resilience ability	Description
RA-1	Learning	The ability associated with knowing what happened in the past, receiving knowledge from past events
RA-2	Responding	Ability to behave and respond when an unfolding event takes place
RA-3	Anticipating	Ability to predict a future outcome and take actions to prevent it
RA-4	Monitoring	Ability to detect and respond in consequence when an unexpected event takes place
RA-5	Management commitment	The ability that recognizes and addresses the human performance concerns by top management
RA-6	Reporting culture	The ability that involves reporting the issues up through the organization
RA-7	Awareness	Gathering data and information that makes management insightful about what is going on at a company
RA-8	Flexibility	The ability of a system to adapt to new challenges or complex problems
RA-9	Teamwork	Work is done by persons working as a team
RA-10	Redundancy	Duplication of systems' critical components or resources to increase the reliability of the system
RA-11	Fault-tolerance	The ability that enables a system to continue operating properly in the event of the failure of some of its components

10.5 Phase-III: Establishment of a Link between Human-Factor Threats and Resilience Abilities

10.5.1 Selection of Human Factors

The HFs that are considered in this study were included in Table 6.7. These HFs were obtained from the results of performing a set of qualitative analysis (i.e. topic normalisation and expert analysis) and quantitative analysis (i.e. statistical analysis and co-occurrence analysis) that were described in detail in Chapter 6.

10.5.2 Selection of Participants

An adequate selection of participants is considered one of the first and critical steps to obtain reliable results. Hence, skill and experienced participants in the areas of HFs, resilience, shipping safety, shipping operations, and accident investigation are a desirable target in order to have a positive effect on the results.

10.5.3 Design of a Questionnaire for Data Collection

To establish a link between HFs and resilience abilities, a questionnaire is developed, which followed the same card-sorting method that was introduced in Chapter 6. The objective of the questionnaire is to identify which resilience abilities could help to prevent the negative effect of certain HFs identified from past maritime accidents. The choice of collecting data by means of a questionnaire was actually made to overcome the lack of data availability, as there are no previous studies trying to establish a similar relation between HFs and resilience abilities. Thus, the design of the required tool in the form of a questionnaire was the next logical step.

The methodology that has been adopted to design the questionnaire includes sorting a list of items (i.e. resilience abilities) that could help to prevent and reduce the negative effect of a second element (i.e. HFs). Thus, a number of principles were taken into account during this design phase, which were similar to the principles followed during the design of the MALFCMs questionnaire for expert data-collection. First, to keep sentences as short as possible by providing clear and concise statements. Second, to limit the number of words in a sentence, without exceeding twenty words. Third, to utilize active rather than passive voice, specific rather than general words, and to use adverbs of frequency (Lietz, 2010).

Regarding the questionnaire structure, questions were organised under two separate sections. The first section includes general questions related to the background of each participant (i.e. years of experience, position, and level of knowledge regarding the areas of HFs, resilience, shipping safety, shipping operations, and accident investigations). The second section typically asks experts to select those resilience abilities from the list defined in Table 10.1 that could help to prevent or reduce the negative effect of a specific human accident-contributing factor. Finally, the questionnaire was made available in two formats, namely, web-based online survey, and paper format. For the web-based version, the questionnaire was developed with the Qualtrics Survey Software. The complete questionnaire form is included in Appendix I.

10.5.4 **Criteria to Analyse and Aggregate the Data Collected**

After experts sorted which resilience abilities could help to prevent or to reduce the negative effect of each human contributing factor, the next step involves the process of aggregating each individual expert response to form one main, which reflects the knowledge of all experts includes in this study. Thus, some participants may be more credible due to their level of expertise. Hence, it is possible to weigh each expert with a different credibility weight, as shown in Equation 10.1 (Kandasamy & Smarandache, 2003; Bart Kosko, 1992).

$$R_{HF_j} = \sum_{i=1}^{n} w_i R_i$$

Equation 10.1. Credibility weight applied to determine resilience abilities for each human-factor threat.

Where R_{HFj} represents the resilience abilities associated with each HF threat, R_i represents the resilience abilities selected by $expert_i$, n provides the number of participants and w_i is equal to the credibility weight of $expert_i$.

Many authors in the literature had defended the use of w_i=1 (Taber, 1987). Nevertheless, as different experts may have various credentials and expertise areas, it is not reasonable to assume the same credibility weight for each participant. Therefore, the credibility weighting for each expert was established by first adapting the method developed by Hossain (2006), following similar criteria than in the aggregation of expert opinion step that was followed during the second stage of the MALFCMs method, which was further described in Chapter 6. And second, by following a normalisation step (Tsadiras et al., 2001), where the previous resilience abilities associated with each HF threat are divided by the total credibility weight, as shown in Equation 10.2.

$$R_{HF_j} = \frac{\sum_{i=1}^{n} w_i \, R_i}{\sum_{i=1}^{n} w_i}$$

Equation 10.2. Formula to determine resilience abilities for each human-factor threat resulting from combining all experts' results.

Where R_{HFj} indicates the resilience abilities associated with each HF threat, R_i represents the resilience abilities for $expert_i$, n is equal to the number of experts, and w_i is equal to the credibility weight of $expert_i$.

Table 10.2 shows the criteria that were considered to assign credibility weights for each expert. In addition, Table 10.3 provides the key to the criteria table, which was adapted from Hossain (2006).

Table 10.2. Criteria to assign credibility weights. Adapted from Hossain (2006)

No	Criteria to be used for participants	Why is this criterion important to determine the credibility of each participant for this specific research?	The numerical value associated with these criteria
1	The participant possesses a solid background on human factors	The participant has a low/standard/high level of human factors understanding. The participant is able to offer insight and information to this research based on its own expertise/academic level.	3 to 5
2	The participant possesses a solid background on resilience	The participant has a low/standard/high level of resilience understanding. The participant is able to offer insight and information to this research based on its own expertise/academic level.	3 to 5
3	The participant possesses a solid background on shipping safety	The participant has a low/standard/high level of shipping safety understanding. The participant is able to offer insight and information to this research based on its own expertise/academic level.	2 to 4
2	The participant possesses a solid background on shipping operations	The participant has a low/standard/high level of understanding of how ships are operated. The participant is able to offer insight and information to this research based on its own expertise/academic level.	2 to 4
3	The participant possesses a solid background on accident investigation	The participant has a low/standard/high level of understanding of how maritime accidents are investigated. The participant is able to offer insight and information to this research based on its own expertise/academic level.	3 to 5

Table 10.3. Key to criteria table. Adapted from Hossain (2006)

Factor assessed	Expert answer	The score for credibility weight
Q1: Knowledge level regarding human factors	1 to 2	3
	3	4
	4 to 5	5
Q2: Knowledge level regarding resilience	1 to 2	3
	3	4
	4 to 5	5
Q3: Knowledge level regarding accident investigation	1 to 2	2
	3	3
	4 to 5	4
Q4: Knowledge level regarding shipping safety	1 to 2	2
	3	3
	4 to 5	4
Q5: Knowledge level regarding shipping operation	1 to 2	3
	3	4
	4 to 5	5

On the above key to criteria table, it was decided to merge the answers with the lowest score provided by the experts under the same credibility weight, following a similar approach that the study conducted by Hossain (2006). Thus, the same approach was followed to merge the answers with the highest score. Once the credibility values for all participants have been calculated in the previous step, Equation 10.2 is applied to obtain the main resilience abilities for each HF threat, which results from combining the answers from all the experts by also taking into account their level of expertise.

10.6 Phase-IV: Establishment of Weightings for Resilience Abilities Derived from Human-Factor Threats

After the weighting for each HF threat has been obtained on Phase-I, the next step includes utilizing the aforementioned HFs weightings to derive the weighting for each resilience ability.

10.6.1 **Initial Analysis of Expert Data Collected**

As discussed above, with regard to the questionnaire structure, experts were asked to sort those resilience abilities that could help to prevent and to reduce the negative effects of a specific HF threat. Thus, to determine the most influential resilience abilities for each HF threat, the results from the questionnaire were accounted to determine how often a certain resilience ability was sorted within each HF threat. To better illustrate the above-described process, a conceptual example is shown in Table 10.4.

Table 10.4. Analysis of data collected. Conceptual example

HF	Expert1	Expert2	Expert3	…	Expertn	Ra most often sorted	No Times
HF1	RA-x	RA-z	RA-x	…	RA-x	RA-x	4
	RA-y	RA-y	RA-k	…	RA-z	RA-k	3
	RA-k	RA-x	RA-z	…	RA-k	RA-z	3
	…	…	…	…	…	…	…
HF2	RA-y	RA-k	RA-y	…	RA-z	RA-x	4
	RA-x	RA-x	RA-x	…	RA-y	RA-y	4
	RA-k	RA-y	RA-k	…	RA-x	RA-k	3
	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…

10.6.2 **Aggregation of Expert Data Collected**

The next step includes the aggregation of expert data by following the process described in the previous section. Therefore, each expert is assigned a credibility weight based on his/her background, following the criteria described in Table 10.2. Thus, Equation 10.1 is applied to rank the most influential resilience abilities for each HF threat. A preliminary example regarding how the credibility weight for each expert is taken into account is shown in Table 10.5.

Table 10.5. Aggregation of data collected. Preliminary numerical example

HF	Expert1 (c.w.=10)	Expert2 (c.w.=15)	…	Expertn (c.w.=20)	Ra most influential	Cred. Weighting	Certainty value [0, 1]
HF1	RA-x	RA-z	…	RA-x	RA-x	45	1.000
	RA-y	RA-y	…	RA-z	RA-z	35	0.778
	RA-k	RA-x	…	RA-k	RA-k	30	0.667
	…	…	…	…	…	…	…
HF2	RA-y	RA-k	…	RA-z	RA-x	45	1.000
	RA-x	RA-x	…	RA-y	RA-y	45	1.000
	RA-k	RA-y	…	RA-x	RA-k	25	0.556
	…	…	…	…	…	…	
…	…	…	…	…	…	…	…

It is important to notice that in the preliminary example proposed in Table 10.5, the maximum contributing weighting for a resilience ability would not exceed the total credibility weight of all experts (i.e. 45 in the previous example). Thus, a maximum value in the certainty value for any resilience ability would only indicate that all experts agreed to link that specific resilience ability with a specific HF threat (i.e. the certainty value will be equal to 1.000).

10.6.3 Establishment of Weightings for each Resilience Ability

Lastly, after the most influential resilience abilities for each HF threat were identified, the next step includes to derive the weighing for each resilience ability associated with each HF threat. Therefore, the credibility weighting value defined in Table 10.5 is utilized as a criterion to distribute the weighting of a specific HF threat into its resilience abilities. For instance, if all sorted resilience abilities have the same contributing weighting value for a specific HF threat, the weighting of that specific HF threat will be divided equally amongst the aforementioned resilience abilities. In order to clarify the above-described process, Table 10.6 provides a preliminary numerical example regarding how to derive the weighting for each resilience ability in a specific HF threat, by incorporating the calculated credibility weights.

Table 10.6. Derived weighting for each resilience ability in a specific HF. Preliminary numerical example

HF	Expert1 (c.w.=10)	Expert2 (c.w.=15)	…	Expertn (c.w.=20)	RA most influential	Normalised Cred. Weighting	RA weighting
HF1	RA-x	RA-z	…	RA-x	RA-x	0.41	0.082
W=0.2	RA-y	RA-y	…	RA-z	RA-z	0.32	0.064
	RA-k	RA-x	…	RA-k	RA-k	0.27	0.054
	…	…	…	…	…	…	…
	…	…	…	…	…	…	Total w=0.2
HF2	RA-y	RA-k	…	RA-z	RA-x	0.39	0.117
W=0.3	RA-x	RA-x	…	RA-y	RA-y	0.39	0.117
	RA-k	RA-y	…	RA-x	RA-k	0.22	0.065
	…	…	…	…	…	…	…
	…	…	…	…	…	…	Total w=0.3
…	…	…	…	…	…		
Total w=1.000	…	…	…	…	…		Total w=1.000

Finally, once the weightings for each resilience ability associated with each HF threat have been obtained in the previous step, the final weight for each resilience ability is calculated. The above-mentioned final weight for a particular resilience ability is obtained by totalling all partial resilience values for that specific ability, which are obtained from each HF threat, as shown in Equation 10.3. It is important to notice that the final weighting for each resilience ability will indicate the maximum value that each resilience ability could reach.

$$W_{RA_i} = \sum_{j=1}^{n} W_{RA_{i}{}_{HF_j}}$$

Equation 10.3.Formula to obtain the final weighting for each resilience ability

10.7 Phase-V: Development and Distribution of a Resilience Assessment Questionnaire (RAQ)

After a link has been established amongst each HF threat and certain resilience abilities, a Resilience Assessment Questionnaire (RAQ) is used to assess the resilience level in a shipping company, based on how the company performs on certain resilience abilities, which are linked to common human causes of accidents. In addition, by assessing its resilience level, it will be possible to identify weaknesses in the company and propose a set of measures to overcome these weaknesses and increase the overall safety level.

10.7.1 **RAQ Structure**

With the aim to develop the aforementioned RAQ, a workshop was held at the University of Strathclyde on the 21st of November, 2019.). Skill and experienced people were selected in order to have a positive effect on the results. Thus, a seafarer, a Health, Safety, Quality, and Environment (HSQE) Manager, and two academics/researchers, each with a background on the areas of HFs and resilience engineering, participated in the workshop. In addition, a workshop description was provided to the participants at the beginning of the workshop, to explain the objectives and the activities planned for the workshop.

The workshop consisted of three parts or steps. First, an introduction section, in which a description of the workshop's aim was provided to each participant. The objective of the above-mentioned workshop was to identify if a list of predefined resilience topics and statements would be suitable to assess the resilience level of a shipping company. Second, a presentation to the participants of a list of proposed topics, their statements and the resilience abilities that each topic would address. Thus, the above-mentioned proposed topics and their statements were extracted from the EU FP 7 SEAHORSE Research project questionnaire (SEAHORSE, 2016a, 2016b). Finally, the workshop concluded with the feedback provided by each participant, which included amendments to the proposed questionnaire, further comments, and suggestions.

After the introduction section, the participants were asked to identify if a list of proposed topics and their statements would be able to capture the resilience level on a shipping company. Two hours were allocated for the group.

Table 10.7 provides the list of RAQ topics and their allocated resilience abilities that were initially presented to the workshop participants. Thus, it is important to mention that Table 10.7 provides all resilience abilities that are allocated to at least one statement in each topic; it does not indicate that all resilience abilities listed in a topic are linked to each statement, as it will be disclosed below.

Table 10.7. Initially proposed RAQ topics and their resilience abilities

No	Topic	Resilience abilities
1	Lessons learned during operation	Learning, Reporting culture
2	Learn from other's experiences & accidents	Learning, Awareness
3	Learn from own experiences & accidents	Learning, Awareness
4	Communication between team members	Responding, Flexibility, Monitoring, Teamwork
5	Handling of exceptions (beyond the day to day operations)	Responding, Flexibility
6	Criteria for safe operation well defined and understood	Responding, Management commitment
7	Understanding and willingness to use external support	Responding
8	Performance of roles, tasks, and responsibilities	Responding, Monitoring
9	Training (simulators, table-top, preparedness)	Responding, Teamwork, Flexibility
10	Ability to make (correct) decisions	Responding, Management commitment
11	Ability to deal with unforeseen operational demands	Responding, Flexibility, Management commitment, Anticipating, Monitoring
12	System knowledge	Anticipating, Awareness
13	Communicating risk at all levels of the organization	Anticipating, Management commitment, Awareness
14	Monitoring of resources	Monitoring
15	Changes; technical, organizational, external	Monitoring, Management commitment
16	Focus on safety	Monitoring
17	Process disturbances; control and safety system actuations	Monitoring, Reporting culture
18	Bypass of control and safety functions	Monitoring
19	Activity level / simultaneous operations	Monitoring, Flexibility

In addition, Table 10.8 provides further insight into the statements that comprised each RAQ topic.

Table 10.8. Initially proposed RAQ statements and their resilience abilities

No	Statements	Topic No	Resilience abilities
1	Crew members use lessons learned in their operations	1	Learning, Reporting culture
2	Crew members document lessons learned in their operations	1	Learning, Reporting culture
3	Crew members share lessons learned in their operations	1	Learning, Reporting culture
4	Crew members evaluate lessons learned in their operations	1	Learning, Reporting culture
5	Crew members use incident/accident information from other companies	2	Learning, Awareness
6	Crew members use success stories from outside the company	2	Learning, Awareness
7	Crew members use their own incident/accident information	3	Learning, Awareness
8	Crew members use their success stories (e.g. what went right)	3	Learning, Awareness
9	There is a sufficient level of communications between crew members	4	Responding, Monitoring, Teamwork
10	Crew members have sufficient communication skills	4	Responding, Monitoring, Teamwork
11	There is a sufficient level of communications between crew members during unexpected situations	4	Responding, Flexibility
12	Information and communication systems are always available and reliable during unexpected situations	4	Responding, Flexibility, Teamwork
13	The information provided by other actors (e.g. company, coastguard) during unexpected situations is understandable for all crew involved	4	Responding, Flexibility
14	Crew members use a common language (e.g. English the official language) during unexpected situations	4	Responding, Flexibility, Teamwork
15	The information is communicated to all actors during unexpected situations in a timely manner	4	Responding, Flexibility, Teamwork

No	Statements	Topic No	Resilience abilities
16	Information systems work properly during unexpected situations	4	Responding, Flexibility Redundancy, Fault-tolerance
17	Crew members respond well to exceptions during normal operations	5	Responding, Flexibility
18	Crew members conduct exercises for handling exceptions	5	Responding, Flexibility
19	Crew members are well prepared for handling exceptions	5	Responding, Flexibility
20	Crew members have sufficient resources to respond to exceptions	5	Responding, Flexibility, Management commitment
21	Crew members have established who does what during exceptions	5	Responding, Flexibility
22	Criteria for safe operations are clearly defined	6	Responding, Management commitment
23	Crew members understand well the criteria for safe operations	6	Responding
24	Crew members understand that they can ask for external support if needed	7	Responding
25	Crew members are willing to use external support if needed	7	Responding
26	Crew members perform their roles, tasks and take responsibilities as described	8	Responding, Monitoring
27	Crew members have sufficient authority for the execution of their tasks	8	Responding, Monitoring
28	Crew members know what is important when working	8	Responding, Anticipating
29	Crew members have experience doing the work	8	Responding, Anticipating
30	Crew members know the important safety procedures	8	Responding, Anticipating
31	Crew members know the risks of their work	8	Responding, Anticipating
32	Crew members have sufficient redundancy and diversity in skills	8	Responding, Redundancy, Anticipating
33	Roles, tasks, and responsibilities of crew members are clearly defined	8	Anticipating, Management commitment
34	Crew members know who does what and when	8	Anticipating
35	Crew members know who is formally responsible for what	8	Anticipating
36	Crew members follow a shared training program	9	Responding, Teamwork
37	Crew members are trained to respond to foreseen risk scenarios	9	Responding
38	Crew members are trained to respond to unforeseen risk scenarios	9	Responding, Flexibility, Fault-tolerance
39	Crew members are trained to respond to emergency scenarios	9	Responding, Flexibility, Fault-tolerance
40	Crew members receive sufficient support when making critical decisions	10	Responding, Management commitment
41	Crew members receive sufficient training to make critical decisions	10	Responding, Management commitment
42	Crew members are able to deal with unforeseen operational demands	11	Responding, Flexibility, Monitoring, Fault-tolerance
43	Crew members conduct exercises to handle unforeseen operational demands at the ship	11	Responding, Flexibility, Monitoring, Fault-tolerance
44	Crew members work with an up-to-date plan for handling unforeseen operational demands	11	Responding, Flexibility, Monitoring, Fault-tolerance
45	Crew members are well prepared for unforeseen operational demands	11	Responding, Flexibility, Monitoring, Fault-tolerance
46	Crew members have established ' who does what ' during unforeseen operational demands	11	Responding, Flexibility, Monitoring, Fault-tolerance
47	Crew members have sufficient resources to respond to unforeseen operational demands	11	Responding, Flexibility, Monitoring, Fault-tolerance
48	Crew members are sufficiently capable of handling a variety of disturbances and perturbations	11	Responding, Flexibility, Fault-tolerance
49	Crew members know how the technical system works	12	Anticipating, Awareness
50	Crew members have insight into how technical systems may fail	12	Anticipating, Awareness
51	Crew members have knowledge about design assumptions of the technical systems	12	Anticipating, Awareness
52	Crewmember have knowledge about (possible) operational conditions of the technical systems	12	Anticipating, Awareness
53	Crewmember have knowledge about (possible) interactions between the technical systems	12	Anticipating, Awareness
54	Risk information is properly communicated with crew members	13	Anticipating, Management commitment, Awareness
55	Risk information is available through various channels e.g. meetings, safety alerts, bulletins, etc.	13	Anticipating, Management commitment, Awareness

No	Statements	Topic No	Resilience abilities
56	Risk information is easily accessible by all crew members	13	Anticipating, Management commitment, Awareness
57	Risk information can be easily understood by all crew members	13	Anticipating, Management commitment, Awareness
58	The presence of crew resources (e.g. time, means, people) is monitored during the operation	14	Monitoring
59	The quality of crew resources (e.g. means, people) is monitored during the operation	14	Monitoring
60	Any changes in the operation (e.g. technological, organizational, external) are well prepared	15	Monitoring, Management commitment
61	Any changes in the operation (e.g. technological, organizational, external) are well thought out and planned	15	Monitoring, Management commitment
62	Any changes in the operation (e.g. technological, organizational, external) are implemented with care for the safety	15	Monitoring, Management commitment
63	Any changes in the operation (e.g. technological, organizational, external) are actively monitored for potential negative effects	15	Monitoring, Management commitment
64	Any changes in the operation (e.g. technological, organizational, external) are prepared by people with the right expertise	15	Monitoring, Management commitment
65	Any changes in the operation (e.g. technological, organizational, external) are well directed and controlled	15	Monitoring, Management commitment
66	Any changes in the operation (e.g. technological, organizational, external) come as a surprise in the workplace	15	Monitoring, Management commitment
67	Any changes in the operation (e.g. technological, organizational, external) are carried out in a safe manner	15	Monitoring, Management commitment
68	Crew members are committed to the safety	16	Monitoring
69	Crew members take safety seriously	16	Monitoring
70	Crew members are committed to a safe and healthy working	16	Monitoring
71	Crew members make careful trade-offs between safety and other goals	16	Monitoring
72	Crew members actively share information about (potential) technical failures of equipment (e.g. DP-systems, power systems, sensor systems)	17	Monitoring, Reporting culture
73	Crew members actively share information about (potential) loss of control during operational activities	17	Monitoring, Reporting culture
74	Compliance to safety functions (e.g. safety procedures) is monitored during the operation	18	Monitoring
75	By-passing or disabling safety functions/barriers/defences is actively monitored	18	Monitoring, Redundancy
76	By-passing or disabling safety functions/barriers/defences is actively controlled and corrected	18	Monitoring, Redundancy
77	In periods with high activity or a high number of simultaneous operations crew members are highly vigilant on the possibility that something might go wrong	19	Monitoring, Flexibility
78	In periods with high activity or a high number of simultaneous operations crewmembers perform additional risk assessments to control for potential negative side effects	19	Monitoring, Flexibility
79	In periods with high activity or a high number of simultaneous operations crew members monitor (potential) unexpected interactions between operations and/ or activities	19	Monitoring, Flexibility

Within the time allocated for the workshop, participants raised some concerns related to the provided RAQ. First, participants identified that specific topics from above RAQ were missing some important statements that would help to establish if the equipment is available on board for allowing the register of specific information (i.e. lesson learned and incident/accident information). By including the abovementioned statements, it will be possible to observe if the company under study has a resilience culture on board, which will allow enhancing the resilience level on the shipping company under study. Hence, specific questions were added to the RAQ based on participants' feedback, as displayed in Table 10.9.

Table 10.9. Statements added to proposed RAQ

Added statements based on participants' feedback	**Topic No**	**Resilience abilities**
There is a system in place for crew members to register lesson learned	1	Learning, Awareness, Reporting culture
There is a system in place for crew members to share successes and failures	2	Learning, Awareness, Reporting culture
There is a system in place for crew members to register incident/accident information	3	Learning, Awareness, Reporting culture
Crew members are aware of the type of critical decisions they are responsible to make and the potential consequences of incorrect decisions	10	Responding, Awareness
There are enough crew members available to respond appropriately to unforeseen operational demands	11	Responding, Monitoring, Management commitment

In addition, participants discussed that numerous statements should be rephrased to avoid misinterpretation from final respondents. Hence, Table 10.10 provides those statements which were amended based on the participants' feedback.

Table 10.10. Amendments to proposed RAQ

No	**Statement**	**Amended statement**
11	There is a sufficient level of communications between crew members during unexpected situations	A well-defined communication system and its SOP exists in the organization for any unexpected situation
18	Crew members conduct exercises for handling exceptions	Crew members conduct regular drills for the most likely exceptional situation
32	Crew members have sufficient redundancy and diversity in skills	Crew members have sufficient redundancy (e.g. back-up, substitute, etc.) and diversity in skills when manning levels are compromised
49	Crew members know how the technical system works	Crew members know the functioning of onboard technical systems
51	Crew members have knowledge about design assumptions of the technical systems	Crew members have knowledge about design limitations of the technical systems
52	Crewmember have knowledge about (possible) operational conditions of the technical systems	Crewmember understand how critical systems operate in both normal and emergency situations
53	Crewmember have knowledge about (possible) interactions between the technical systems	Crewmember have knowledge about interactions and interfaces between technical systems
67	Any changes in the operation (e.g. technological, organizational, external) are carried out in a safe manner	Any changes in the operation (e.g. technological, organizational, external) are carried out in a safe manner, with due care
68	Crew members are committed to the safety	Crew members are committed and take safety seriously
71	Crew members make careful trade-offs between safety and other goals	Crew members make well-deliberated trade-offs between safety and other goals
72	Crew members actively share information about (potential) technical failures of equipment (e.g. DP-systems, power systems, sensor systems)	Crew members actively share information about (potential) technical failures of equipment (e.g. control systems, power systems, sensor systems)

Moreover, after the workshop was conducted, expert opinion was requested to select the most representative resilience ability for each statement. Thus, three highly qualified experts were selected. Two of the aforementioned experts have been working in the areas of maritime safety, HFs and resilience for more than ten years. In addition, the third expert was a PhD researcher with four years of experience in HFs and resilience. Therefore, Table 10.11 displays the complete list of statements from the RAQ together with their most representative resilience ability for each statement.

Table 10.11. Complete list of statements from the proposed RAQ and their most influential resilience abilities

No	Statements	Expert 1	Expert 2	Expert 3	Final RA
1	Crew members use lessons learned in their operations	Learning	Learning	Learning	Learning
2	Crew members document lessons learned in their operations	R. Culture	R. Culture	R. Culture	R. Culture
3	Crew members share lessons learned in their operations	Learning	Learning	Learning	Learning
4	Crew members evaluate lessons learned in their operations	Learning	Learning	Learning	Learning
5	There is a system in place for crew members to register lesson learned	R. Culture	R. Culture	R. Culture	R. Culture
6	Crew members use incident/accident information from other companies	Awareness	Learning	Learning	Learning
7	Crew members use success stories from outside the company	Learning	Learning	Learning	Learning
8	There is a system in place for crew members to share successes and failures	R. Culture	R. Culture	Learning	R. Culture
9	Crew members use their own incident/accident information	Learning	Learning	Learning	Learning
10	Crew members use their success stories (e.g. what went right)	Learning	Learning	Learning	Learning
11	There is a system in place for crew members to register incident/accident information	R. Culture	R. Culture	R. Culture	R. Culture
12	There is a sufficient level of communications between crew members	Teamwork	Teamwork	Teamwork	Teamwork
13	Crew members have sufficient communication skills	Teamwork	Teamwork	Teamwork	Teamwork
14	A well-defined communication system and its SOP exists in the organization for any unexpected situation	Flexibility	Flexibility	Flexibility	Flexibility
15	Information and communication systems are always available and reliable during unexpected situations	Flexibility	Flexibility	Flexibility	Flexibility
16	The information provided by other actors (e.g. company, coastguard) during unexpected situations is understandable for all crew involved	Flexibility	Flexibility	Flexibility	Flexibility
17	Crew members use a common language (e.g. English the official language) during unexpected situations	Teamwork	Teamwork	Teamwork	Teamwork
18	The information is communicated to all actors during unexpected situations in a timely manner	Teamwork	Teamwork	Responding	Teamwork
19	Information systems work properly during unexpected situations	Redundancy	Redundancy	Flexibility	Redundancy
20	Crew members respond well to exceptions during normal operations	Responding	Responding	Responding	Responding
21	Crew members conduct regular drills for the most likely exceptional situation	Flexibility	Responding	Responding	Responding
22	Crew members are well prepared for handling exceptions	Flexibility	Flexibility	Flexibility	Flexibility
23	Crew members have sufficient resources to respond to exceptions	Flexibility	Flexibility	Flexibility	Flexibility
24	Crew members have established who does what during exceptions	Responding	Responding	Responding	Responding

No	Statements	Expert 1	Expert 2	Expert 3	Final RA
25	Criteria for safe operations are clearly defined	M. Commit.	M. Commit.	Anticipation	M. Commit.
26	Crew members understand well the criteria for safe operations	Responding	Responding	Responding	Responding
27	Crew members understand that they can ask for external support if needed	Responding	Responding	Responding	Responding
28	Crew members are willing to use external support if needed	Responding	Responding	Responding	Responding
29	Crew members perform their roles, tasks and take responsibilities as described	Responding	Responding	Responding	Responding
30	Crew members have sufficient authority for the execution of their tasks	Responding	Responding	Responding	Responding
31	Crew members know what is important when working	Anticipating	Anticipating	Anticipating	Anticipating
32	Crew members have experience doing the work	Anticipating	Anticipating	Anticipating	Anticipating
33	Crew members know the important safety procedures	Responding	Responding	Anticipating	Responding
34	Crew members know the risks of their work	Anticipating	Anticipating	Anticipating	Anticipating
35	Crew members have sufficient redundancy (e.g. back-up, substitute, etc.) and diversity in skills when manning levels are compromised	Redundancy	Redundancy	Redundancy	Redundancy
36	Roles, tasks, and responsibilities of crew members are clearly defined	M. Commit.	M. Commit.	M. Commit.	M. Commit.
37	Crew members know who does what and when	Anticipating	Anticipating	Anticipating	Anticipating
38	Crew members know who is formally responsible for what	Anticipating	Anticipating	Anticipating	Anticipating
39	Crew members follow a shared training program	Teamwork	Teamwork	Teamwork	Teamwork
40	Crew members are trained to respond to foreseen risk scenarios	Responding	Responding	Responding	Responding
41	Crew members are trained to respond to unforeseen risk scenarios	Responding	Responding	Responding	Responding
42	Crew members are trained to respond to emergency scenarios	Responding	Responding	Responding	Responding
43	Crew members receive sufficient support when making critical decisions	M. Commit.	M. Commit.	M. Commit.	M. Commit.
44	Crew members are aware of the type of critical decisions they are responsible to make and the potential consequences of incorrect decisions	Responding	Responding	Awareness	Responding
45	There are enough crew members available to respond appropriately to unforeseen operational demands	Responding	Responding	Redundancy	Responding
46	Crew members receive sufficient training to make critical decisions	Responding	Responding	Responding	Responding
47	Crew members are able to deal with unforeseen operational demands	Responding	Responding	Fault-Tolerance	Responding
48	Crew members conduct exercises to handle unforeseen operational demands at the ship	Fault-tolerance	Fault-tolerance	Responding	Fault-tolerance
49	Crew members work with an up-to-date plan for handling unforeseen operational demands	Fault-tolerance	Fault-tolerance	Responding	Fault-tolerance
50	Crew members are well prepared for unforeseen operational demands	Fault-tolerance	Fault-tolerance	Flexibility	Fault-tolerance
51	Crew members have established ' who does what ' during unforeseen operational demands	Flexibility	Flexibility	Flexibility	Flexibility
52	Crew members have sufficient resources to respond to unforeseen operational demands	Flexibility	Flexibility	Redundancy	Flexibility
53	Crew members are sufficiently capable of handling a variety of disturbances and perturbations	Fault-tolerance	Fault-tolerance	Fault-Tolerance	Fault-tolerance
54	Crew members know the functioning of on board technical systems	Awareness	Awareness	Awareness	Awareness
55	Crew members have insight into how technical systems may fail	Awareness	Awareness	Awareness	Awareness
56	Crew members have knowledge about design limitations of the technical systems	Awareness	Awareness	Awareness	Awareness
57	Crewmember understand how critical systems operate in both normal and emergency situations	Awareness	Awareness	Awareness	Awareness

No	Statements	Expert 1	Expert 2	Expert 3	Final RA
58	Crewmember have knowledge about interactions and interfaces between technical systems	Awareness	Awareness	Awareness	Awareness
59	Risk information is properly communicated with crew members	M. Commit.	M. Commit.	Awareness	M. Commit.
60	Risk information is available through various channels e.g. meetings, safety alerts, bulletins, etc.	M. Commit.	M. Commit.	Anticipating	M. Commit.
61	Risk information is easily accessible by all crew members	M. Commit.	M. Commit.	Anticipating	M. Commit.
62	Risk information can be easily understood by all crew members	Anticipating	Anticipating	Anticipating	Anticipating
63	The presence of crew resources (e.g. time, means, people) is monitored during the operation	Monitoring	Monitoring	Monitoring	Monitoring
64	The quality of crew resources (e.g. means, people) is monitored during the operation	Monitoring	Monitoring	Monitoring	Monitoring
65	Any changes in the operation (e.g. technological, organizational, external) are well prepared	M. Commit.	M. Commit.	M. Commit.	M. Commit.
66	Any changes in the operation (e.g. technological, organizational, external) are well thought out and planned	M. Commit.	M. Commit.	M. Commit.	M. Commit.
67	Any changes in the operation (e.g. technological, organizational, external) are implemented with care for the safety	M. Commit.	M. Commit.	M. Commit.	M. Commit.
68	Any changes in the operation (e.g. technological, organizational, external) are actively monitored for potential negative effects	Monitoring	Monitoring	Monitoring	Monitoring
69	Any changes in the operation (e.g. technological, organizational, external) are prepared by people with the right expertise	M. Commit.	M. Commit.	M. Commit.	M. Commit.
70	Any changes in the operation (e.g. technological, organizational, external) are well directed and controlled	M. Commit.	M. Commit.	M. Commit.	M. Commit.
71	Any changes in the operation (e.g. technological, organizational, external) come as a surprise in the workplace	M. Commit.	M. Commit.	M. Commit.	M. Commit.
72	Any changes in the operation (e.g. technological, organizational, external) are carried out in a safe manner, with due care	M. Commit.	M. Commit.	M. Commit.	M. Commit.
73	Crew members are committed and take safety seriously	Monitoring	Monitoring	Monitoring	Monitoring
74	Crew members take safety seriously	Monitoring	Monitoring	Monitoring	Monitoring
75	Crew members are committed to a safe and healthy working	Monitoring	Monitoring	Monitoring	Monitoring
76	Crew members make well-deliberated trade-offs between safety and other goals	Monitoring	Monitoring	Monitoring	Monitoring
77	Crew members actively share information about (potential) technical failures of equipment (e.g. control systems, power systems, sensor systems)	R. Culture	R. Culture	R. Culture	R. Culture
78	Crew members actively share information about (potential) loss of control during operational activities	R. Culture	R. Culture	R. Culture	R. Culture
79	Compliance to safety functions (e.g. safety procedures) is monitored during the operation	Monitoring	Monitoring	Monitoring	Monitoring
80	By-passing or disabling safety functions/barriers/defences is actively monitored	Redundancy	Monitoring	Monitoring	Monitoring
81	By-passing or disabling safety functions/barriers/defences is actively controlled and corrected	Redundancy	Redundancy	Redundancy	Redundancy
82	In periods with high activity or a high number of simultaneous operations crew members are highly vigilant on the possibility that something might go wrong	Monitoring	Monitoring	Monitoring	Monitoring
83	In periods with high activity or a high number of simultaneous operations crewmembers perform additional risk assessments to control for potential negative side effects	Flexibility	Flexibility	Anticipating	Flexibility

No	Statements	Expert 1	Expert 2	Expert 3	Final RA
84	In periods with high activity or a high number of simultaneous operations crew members monitor (potential) unexpected interactions between operations and/ or activities	Monitoring	Monitoring	Monitoring	Monitoring

Finally, the questionnaire was made available in two formats, namely, web-based online survey, and paper format. For the web-based version, the questionnaire was developed with the Qualtrics Survey Software. Thus, the paper format questionnaire is displayed in Appendix J.

10.8 Phase-VI: Analysis of RAQ Results, Resilience Score, and Recommendations for Resilience Improvement

10.8.1 RAQ Analysis of the results

On the aforementioned questionnaire, anonymity was treated as a crucial aspect to get results that are more reliable. A Likert scale was applied, and answers were organized either strongly disagree-disagree-agree or disagree-agree-strongly agree and do not know. Thus, in the calculation processes, each statement had a score that varied between 1(strongly disagree) and 5 (strongly agree) where 1 represented the minimum score and 5 represented the highest score.

After the conversion of the verbal statements into mathematical numbers was completed, the average score of each statement was calculated as shown in Equation 10.4, where the constant 100/5 was added to represent the results out of 100 as a percentage.

$$Statement_i = \sum_{j=1}^{n} \frac{Participant_j}{n} * \frac{100}{5}$$

Equation 10.4. RAQ, conversion of the verbal statements into mathematical numbers.

After the questionnaire is completed, the questionnaire responses are analysed and the resilience level of the company is calculated. Thus, the results are an indicator of the state of the resilience level in a specific shipping company, based on how that company performs on certain resilience abilities, which are linked to common human causes of accidents.

The output of the resilience assessment questionnaire is first qualitative, as it indicates which resilience abilities are linked to each specific HF but also quantitative, as it provides a snapshot of the company’s performance against the resilience abilities that were introduced before.

10.8.2 Recommendations for Resilience Improvement

Finally, the proposed methodology includes to identify possible weaknesses in the system and to propose a set of measures to overcome them, increasing overall safety level.

10.9 Chapter Summary

This chapter provided the context and objectives of developing a resilience assessment framework. In addition, this chapter describes the six phases of the developed resilience assessment framework, which is proposed with the aim of assessing the resilience level within a shipping company.

Chapter 11 will include a detail case study to assess the resilience level in a shipping company.

11 CASE STUDY TO ASSESS THE RESILIENCE LEVEL IN A SHIPPING COMPANY

11.1 Overview

This chapter fully applies the resilience assessment framework that was demonstrated in the previous chapter to a real case study. This case study is used to indicate how the proposed methodology can be implemented in a shipping company.

11.2 Human-factor threats customization and quantification (Phase-I)

The customization of the HF threats includes the establishment of the model's variables with respect to the goal of the research. Given that the data regarding these influencing variables might differ for each vessel category, it is necessary to first define the target of this research. The shipping company under study contains only passenger ships, which are usually defined as ships carrying more than twelve passengers (IMO, 2019). Thus, once the target of this study has been defined, the next task includes the quantification of those HF threats that are related to passenger ships. As identified in the methodology section, the aforementioned task is fulfilled by applying the MALFCMs method, which has extensively described in the literature (de Maya et al., 2019). MALFCMs method is a Fuzzy Cognitive Map-based technique, which has been designed to combine expert knowledge with lessons learned from past accident experiences, aiming to provide more reliable results. Thus, the MALFCMs method could be described in four main stages: 1) Historical data analysis stage, 2) Expert opinion analysis stage, 3) Dynamic FCM stage, and 4) Consolidation of results stage.

11.2.1 **Historical Data Analysis Stage**

For the purpose of this case study, maritime accidents on passenger ships involving UK vessels worldwide and all vessels operating in UK territorial waters between 2011 and 2016 were analysed. Thus, nineteen maritime accidents on passenger ships were scrutinized and analysed, aiming to identify those HF threats that were involved in the above-mentioned accidents. Identified HF threats are displayed in Table 11.1.

Table 11.1. Human-factor threats involved in accidents in passenger ships. Period 2011-2016

No HF	Human factor description
HF threat 1	Commercial pressure
HF threat 2	Effect of environmental and external factors
HF threat 3	Improper design, installation, and working environment
HF threat 4	Inadequate leadership and supervision
HF threat 5	Lack of communication and coordination
HF threat 6	Lack of training
HF threat 7	Safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)
HF threat 8	Unprofessional behaviour

Once all HF threats were identified, an interaction matrix and a state vector were created from the historical accident data, by following the process described in Chapter 6. Table 11.2 shows the interaction matrix obtained from the historical accident data. In addition, Table 11.3 provides the initial state vector (St.0).

Table 11.2. Interaction matrix for passenger ships. The first stage of the MALFCMs method. Period 2011-2016

	HF threat 1	**HF threat 2**	**HF threat 3**	**HF threat 4**	**HF threat 5**	**HF threat 6**	**HF threat 7**	**HF threat 8**
HF threat 1	-	0.000	1.000	0.000	0.000	1.000	1.000	0.000
HF threat 2	0.000	-	0.000	0.000	0.000	0.333	0.667	0.000
HF threat 3	0.250	0.000	-	0.250	0.000	0.750	0.750	0.250
HF threat 4	0.000	0.000	0.200	-	0.200	0.400	0.600	0.400
HF threat 5	0.000	0.000	0.000	0.333	-	0.333	1.000	0.333
HF threat 6	0.091	0.091	0.273	0.182	0.091	-	0.727	0.273
HF threat 7	0.071	0.143	0.214	0.214	0.214	0.571	-	0.429
HF threat 8	0.000	0.000	0.167	0.333	0.167	0.500	1.000	-

Table 11.3. Initial state vector for passenger ships. The first stage of the MALFCMs method. Period 2011-2016

	HF threat 1	**HF threat 2**	**HF threat 3**	**HF threat 4**	**HF threat 5**	**HF threat 6**	**HF threat 7**	**HF threat 8**
	0.053	0.158	0.211	0.263	0.158	0.579	0.737	0.316

11.2.2 **Expert Opinion Analysis Stage**

For this research study, five selected experts (which are referred to as Participant1, Participant2, Participant3, Participant4, and Participant5) completed an online questionnaire. Participants with complementary expertise were selected covering the areas of HFs, ship operations, and accident investigations in order to have a positive effect on the results. The aforementioned online questionnaire presented a long list of questions regarding the HF threats that were identified within the analysis of the historical accident database (i.e. the HFs listed in Table 11.1). Three types of closed questions were included in the questionnaire. The first type included general questions related to the background of each participant. The second type typically asked at what level a particular factor would need to be applied to have a contribution to an accident. Finally, the last type was designed to allocate strength values to the interrelationship amongst HFs. Hence, this set typically asked, given a change in “Factor a”, what would be the effect on “Factor b”. In addition, the above-described questionnaire is included in Appendix E. Once the online questionnaire was completed, all the answers were collected and analysed. Thus, the interaction matrices and state vectors obtained from all participants are displayed in Appendix K.

In order to be able to combine the experts’ answers to the questionnaire, the next step involved the conversion of the individual FCMs (expressed in linguistic terms) into numerical expressed FCMs (the procedure was described in Chapter 6). The conversion measures applied for the linguistic input were provided in Table 7.2 (i.e. conversion values for the interaction matrix), and Table 7.2 (i.e. conversion values for the state vector). Therefore, the aforementioned conversion measures were applied to transform the participants’ FCMs into numerical expressed FCMs. Table 11.4 shows as an example numerical state vector created by applying the previous conversion measures to the answers provided by Participant1. In addition, Table 11.5 provides the numerical interaction matrix obtained for Participant1.

Table 11.4. Initial state vector created by Participant1 after fuzzy conversion. The second stage of MALFCMs method

	HF threat 1	**HF threat 2**	**HF threat 3**	**HF threat 4**	**HF threat 5**	**HF threat 6**	**HF threat 7**	**HF threat 8**
	0.495	0.495	0.330	0.660	0.495	0.660	0.825	0.330

Table 11.5. Interaction matrix created by Participant1 after fuzzy conversion. The second stage of MALFCMs method

	HF threat 1	HF threat 2	HF threat 3	HF threat 4	HF threat 5	HF threat 6	HF threat 7	HF threat 8
HF threat 1	0.000	0.000	0.000	0.000	0.000	0.330	0.165	0.825
HF threat 2	0.000	0.000	0.000	0.000	0.000	0.000	0.165	0.495
HF threat 3	0.000	0.000	0.000	0.330	0.165	0.165	0.165	0.660
HF threat 4	0.330	0.000	0.000	0.000	0.660	0.495	0.660	0.825
HF threat 5	0.495	0.000	0.000	0.660	0.000	0.165	0.495	0.660
HF threat 6	0.000	0.000	0.000	0.165	0.330	0.000	0.330	0.495
HF threat 7	0.000	0.000	0.000	0.330	0.330	0.165	0.000	0.495
HF threat 8	0.495	0.000	0.000	0.495	0.495	0.165	0.165	0.000

All the FCMs have been transformed from linguistic into numeric FCMs at this stage. Thus, all the individual FCMs need to be aggregated in order to create a unique FCM, which reflects the knowledge of all participants. In this regard, relevant data is substituted into Equation 7.2. The credibility weighting for each expert was established by adapting the method developed by Hossain (2006), which was introduced and explained in Chapter 6. The aforementioned method allowed to obtain a credibility value for each participant, as shown in Table 11.6.

Table 11.6. Credibility weights assigned to participants. The second stage of MALFCMs method

No Participant	Answer to question			Credibility value
	Score Q1	Score Q2	Score Q3	
Participant1	4	4	4	12
Participant2	4	5	4	13
Participant3	3	5	3	11
Participant4	4	4	4	12
Participant5	4	5	4	13
Total				**61**

Once the credibility value for each participant has been calculated in the previous step, Equation 7.3 is applied to obtain the interaction matrix and the state vector, which results from combining the answers from all the participants by also taking into account their level of expertise. Table 11.7 shows the initial state vector (St.0) for the expert opinion stage, while Table 11.8 represents the interaction matrix obtained.

Table 11.7. Initial state vector resulting from the aggregation of participants' state vectors. The second stage of MALFCMs method

HF threat 1	HF threat 2	HF threat 3	HF threat 4	HF threat 5	HF threat 6	HF threat 7	HF threat 8
0.600	0.536	0.406	0.728	0.603	0.655	0.733	0.628

Table 11.8. Interaction matrix resulting from the aggregation of participants' interaction matrices. The second stage of MALFCMs method

	HF threat 1	HF threat 2	HF threat 3	HF threat 4	HF threat 5	HF threat 6	HF threat 7	HF threat 8
HF threat 1	0.000	0.000	0.000	0.333	0.330	0.395	0.200	0.590
HF threat 2	0.165	0.000	0.000	0.162	0.368	0.295	0.371	0.422
HF threat 3	0.133	0.000	0.000	0.265	0.441	0.360	0.376	0.590
HF threat 4	0.362	0.000	0.000	0.000	0.668	0.624	0.665	0.730
HF threat 5	0.357	0.000	0.000	0.617	0.000	0.449	0.438	0.571
HF threat 6	0.211	0.000	0.000	0.427	0.603	0.000	0.605	0.505
HF threat 7	0.105	0.000	0.000	0.352	0.481	0.522	0.000	0.465
HF threat 8	0.330	0.000	0.000	0.595	0.438	0.422	0.371	0.000

11.2.3 **Dynamic FCM Stage**

As the interaction matrix and state vector for the first stage of MALFCMs have been already defined in previous sections, a dynamic analysis of the FCM is performed by applying Equation 2.1. Table 11.9 provides the initial state vector (St.0) and the dynamic evolution of the FCM obtained from the historical data until equilibrium is reached, which occurs before step 5 (St.5).

In addition, Figure 11.1 shows the iterative process followed until equilibrium is reached. It can be seen that after a few iterations it is possible to observe that importance values for each factor is stabilised. Although each factor is important and known to be attributed to passenger vessel accidents in the past, HF threat 7: "Safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)" and HF threat 6: "Lack of training" clearly stand out as the most important two factors. Therefore, this graph can provide an initial relative importance of each factor at a glance. Inadequate procedures or unsafe deviation from defined procedures is an important issue and training can be one way to reduce its occurrence or consequence.

Table 11.9. Calculation of steady states for accidents in passenger ships from historical data. The third stage of the MALFCMs method. Period 2000-2011

	HF threat 1	HF threat 2	HF threat 3	HF threat 4	HF threat 5	HF threat 6	HF threat 7	HF threat 8
St.0	0.05263	0.15789	0.21053	0.26316	0.15789	0.57895	0.73684	0.31579
St.1	0.53939	0.53939	0.61626	0.61626	0.57830	0.73106	0.79712	0.66468
St.2	0.56892	0.54496	0.75834	0.70519	0.61569	0.91747	0.97085	0.75664
St.3	0.58476	0.55530	0.78488	0.73534	0.63613	0.93933	0.98136	0.79301
St.4	0.58703	0.55616	0.79092	0.74148	0.63990	0.94385	0.98365	0.79886
St.5	0.58754	0.55634	0.79194	0.74263	0.64061	0.94464	0.98403	0.80005
St.6	0.58762	0.55637	0.79214	0.74285	0.64075	0.94479	0.98410	0.80026
St.7	0.58764	0.55638	0.79218	0.74289	0.64077	0.94482	0.98412	0.80030
St.8	0.58764	0.55638	0.79219	0.74290	0.64078	0.94482	0.98412	0.80031

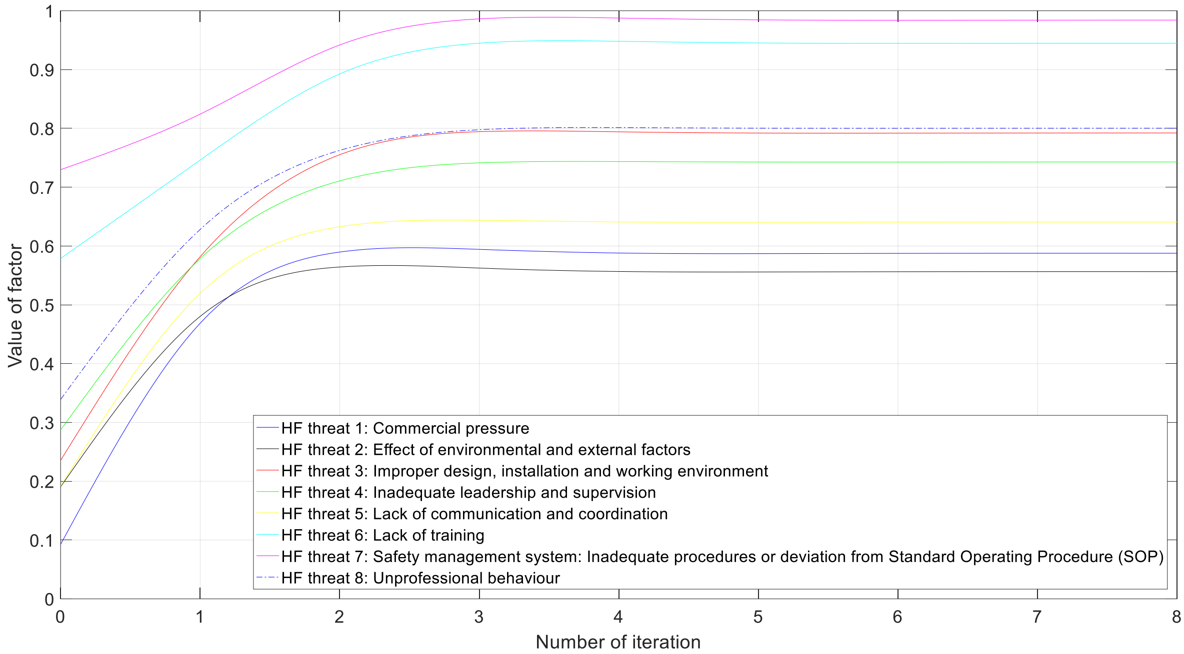


Figure 11.1. Dynamic FCM for passenger ships from historical accident data until equilibrium is reached. The third stage of the MALFCMs method. Period 2011-2016

Finally, Table 11.10 shows the final weight obtained for all HF threats, after the iteration reaches equilibrium and the simulation stops. These weights are constrained to the interval [0,1], as the threshold function limits the inputs to a strict range, to maintain the stability. Additionally, these results have been normalised, and the final weights are also displayed in terms of percentage.

Table 11.10. The final weight of contributors for passenger ships from historical accident data. The third stage of the MALFCMs method. Period 2011-2016

Human-factor threat description	**Weights from historical accident data**	**Weights normalised (%)**
Commercial pressure	0.588	9.715
Effect of environmental and external factors	0.556	9.198
Improper design, installation, and working environment	0.792	13.096
Inadequate leadership and supervision	0.743	12.281
Lack of communication and coordination	0.641	10.593
Lack of training	0.945	15.619
Safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)	0.984	16.269
Unprofessional behaviour	0.800	13.230

Following the same process that was described before, a dynamic analysis of the FCM obtained from the expert analysis is performed by applying Equation 2.1. Table 11.11 provides the initial state vector (St.0) and the dynamic evolution of the FCM obtained from the expert analysis until equilibrium is reached, which occurs before step 5 (St.5). In addition, Figure 11.2 shows the iterative process followed until equilibrium is reached.

Table 11.11. Calculation of steady states for grounding/stranding accidents in passenger ships from the expert analysis. The third stage of MALFCMs method

	HF threat 1	**HF threat 2**	**HF threat 3**	**HF threat 4**	**HF threat 5**	**HF threat 6**	**HF threat 7**	**HF threat 8**
St.0	0.60049	0.53557	0.40574	0.72762	0.60320	0.65459	0.73303	0.62754
St.1	0.73960	0.50000	0.50000	0.84250	0.88920	0.87140	0.86400	0.91420
St.2	0.79390	0.50000	0.50000	0.90280	0.92780	0.91540	0.91200	0.94820
St.3	0.80370	0.50000	0.50000	0.91100	0.93560	0.92390	0.92020	0.95470
St.4	0.80540	0.50000	0.50000	0.91250	0.93680	0.92530	0.92150	0.95580
St.5	0.80560	0.50000	0.50000	0.91270	0.93700	0.92550	0.92180	0.95600
St.6	0.80570	0.50000	0.50000	0.91280	0.93710	0.92560	0.92180	0.95600
St.7	0.80570	0.50000	0.50000	0.91280	0.93710	0.92560	0.92180	0.95600
St.8	0.80570	0.50000	0.50000	0.91280	0.93710	0.92560	0.92180	0.95600

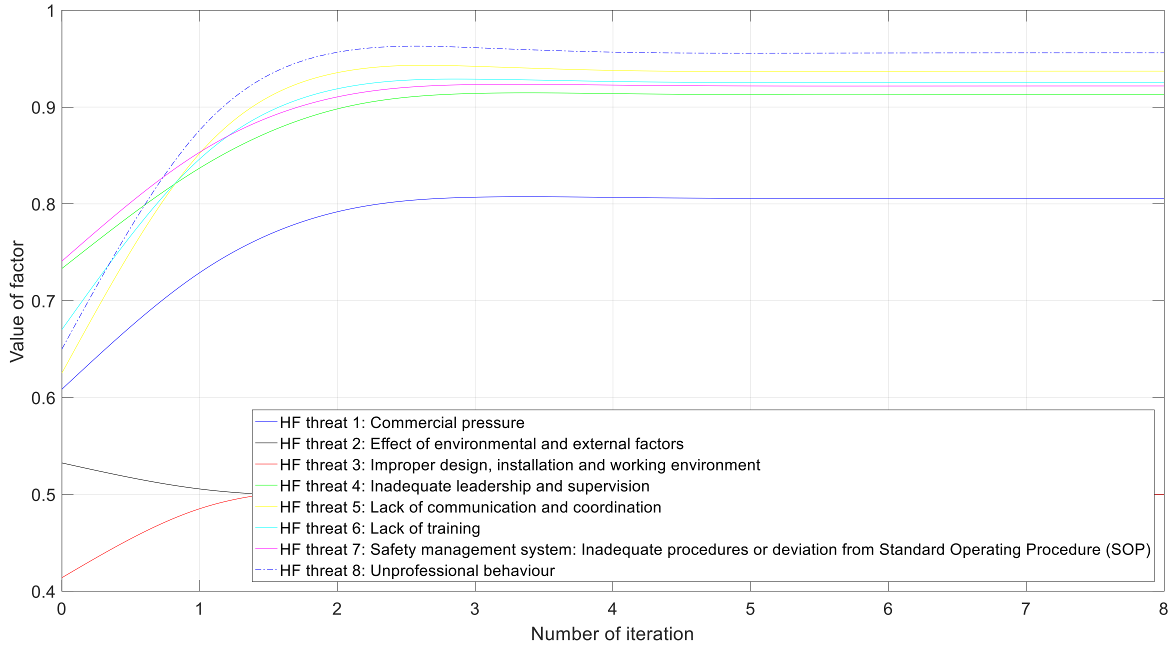


Figure 11.2. Dynamic FCM for passenger ships from the expert analysis until equilibrium is reached. The third stage of MALFCMs method

It can be seen from Figure 11.2 that specific HF threats (i.e. HF threat 8: "Unprofessional behaviour" and HF threat 5: "Lack of communication and coordination") clearly stand out as the most important two factors from the expert analysis. In addition, the HF threat 2:" Effect of environmental and external factors" and the HF threat 3: "Improper design, installation, and working environment" presents the lowest value (i.e. 0.500).

Finally, Table 11.12 shows the final weight obtained for all HF threats, after the iteration reaches equilibrium and the simulation stops. These weights are constrained to the interval [0,1] (i.e. to limit the inputs to a strict range, to maintain the stability). Additionally, these results have been normalised, and the final weights for the expert opinion stage are also displayed in terms of percentage.

Table 11.12. The final weight of contributors for passenger ships from the expert analysis. The third stage of MALFCMs method

Human-factor threat description	Weights from historical accident data	Weights normalised (%)
Commercial pressure	0.806	12.474
Effect of environmental and external factors	0.500	7.741
Improper design, installation, and working environment	0.500	7.741
Inadequate leadership and supervision	0.913	14.132
Lack of communication and coordination	0.937	14.508
Lack of training	0.926	14.330
Safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)	0.922	14.272
Unprofessional behaviour	0.956	14.801

11.2.4 **Consolidation of Results Stage**

Lastly, the fourth stage of MALFCMs combines the results obtained from the historical data analysis and expert analysis through a sensitivity analysis. The purpose of a sensitivity analysis is to understand how the uncertainty in the output of a mathematical model or system can be divided and allocated to different sources of uncertainty in its inputs. Hence, as the aim of this stage is to combine the outputs from the historical data and expert opinion analyses, a sensitivity analysis seems adequate to perform this task.

Hence, Table 11.13 includes the weights of each HF normalised from both, the historical data and the expert opinion, and the final weights proposed, in which the same importance has been assigned to both sources of data. In addition, Figure 11.3 represents the sensitivity analysis to provide a better understanding of the process, in which the two sets of data were mixed together to prevent results being biased towards one source of data. It should be noticed that equal coefficients (i.e. both coefficients are 0.5) are used for the weights derived from historical data and experts' views) in Table 11.13.

Table 11.13. Sensitivity analysis to combine the results from the historical data analysis stage and the expert opinion stage

Human factor description	Normalised historical data results (&)	Normalised experts' results (%)	Final weights (%)
Commercial pressure	9.715	12.474	11.094
Effect of environmental and external factors	9.198	7.741	8.469
Improper design, installation, and working environment	13.096	7.741	10.419
Inadequate leadership and supervision	12.281	14.132	13.207
Lack of communication and coordination	10.593	14.508	12.551
Lack of training	15.619	14.330	14.975
Safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)	16.269	14.272	15.270
Unprofessional behaviour	13.230	14.801	14.016

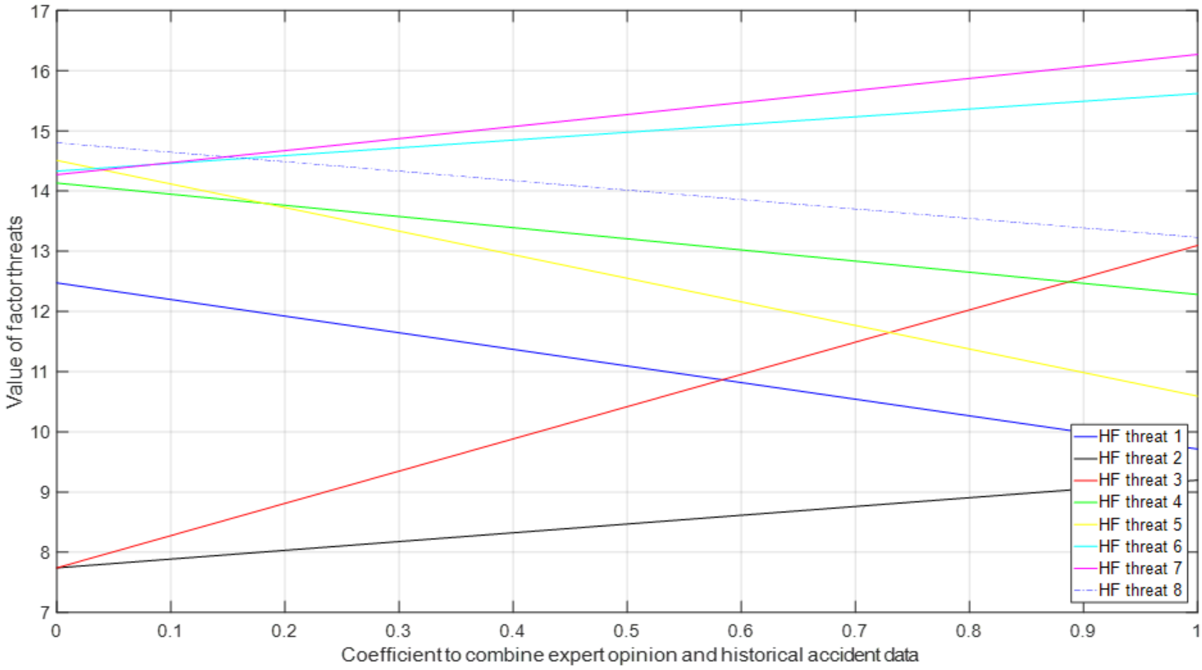


Figure 11.3. Sensitivity analysis to combine the results from the expert opinion stage and the historical data analysis stage

In Fig 11.3 there are three factors that are getting a more significant influence from the weightings used, while the other factors have less slop, which means that the difference between using historical data or expert opinion is not that significant. The sensitivity analysis provides confidence in the sense that the majority of the factors do not get significantly affected when utilising different sources of data. In order to minimise the factors being affected, it was decided to assign the same value to historical data and expert opinion.

11.3 Identification of Resilience Abilities (Phase-II)

As described in previous chapters, there are four traditional resilience abilities, which are named as responding, monitoring, anticipating and learning. Moreover, additional resilience abilities were identified from the extensive literature review that was conducted in Chapter 2. As a result, eleven resilience abilities have been taken into consideration in this case study. Descriptions of the aforementioned resilience abilities were provided in Table 10.1.

11.4 Establishment of a link between human-factor threats and resilience abilities (Phase-III)

After the weightings for all human factor threats have been obtained and the resilience abilities have been identified, the next logical step included establishing a link between the HF threats listed in Table 11.1, and the resilience abilities described in Table 10.1. The aforementioned link was established by collecting data by means of a questionnaire. The mode of data collection and the structure of the questionnaire were described in detail in Chapter 10. Furthermore, the questionnaire that was utilized to establish the aforementioned link amongst human factor threats and resilience abilities is included in Appendix I.

Regarding the selection of participants, seventeen experts on the areas of HFs, resilience, shipping safety, shipping operations, and accident investigation were selected to complete the above-mentioned questionnaire, aiming to provide results that are more reliable. The answers provided by all participants are displayed in Appendix L.

11.4.1 **Analysis and Aggregation of the Data Collected**

After experts sorted which resilience abilities could help to prevent and to reduce the negative effect of each human contributing factor, the next step involved the process of aggregating each individual expert response to form one main, which reflects the knowledge of all experts included in this study. Some participants may be more credible due to their level of expertise. In order to address this, it is possible to weigh each expert with a different credibility weight as shown in Equation 7.2.Therefore, the credibility weighting for each expert was established by adapting the method developed by Hossain (2006), which was detailed in Chapter 6.

Table 10.2 included the criteria that were considered for assigning a credibility weight to each expert. The answer provided by all experts regarding their level of knowledge in the areas of HF (Q1), resilience (Q2), shipping safety (Q3), shipping operations (Q4), and accident investigations (Q5) would be used to define an individual credibility weight, which is unique for each participant. Thus, it is possible to define a score for Q1 to Q5 by utilizing the key to the criteria table (i.e. Table 10.3), which allows obtaining a credibility value for each participant, as shown in Table 11.14.

Table 11.14. Knowledge of each participant and credibility score to link human factors and resilience abilities

	Q1	Q2	Q3	Q4	Q5	Credibility score
Participant1	5	4	4	4	4	21
Participant2	4	3	4	4	4	19
Participant3	5	3	3	3	4	18
Participant4	5	5	4	4	4	22
Participant5	5	5	3	2	4	19
Participant6	5	5	4	4	4	22
Participant7	5	5	4	4	4	22
Participant8	5	3	4	4	3	19
Participant9	3	3	4	4	4	18
Participant10	4	3	4	4	4	19
Participant11	5	5	4	4	4	22
Participant12	4	3	4	4	4	19
Participant13	5	3	4	4	4	20
Participant14	4	4	3	3	3	17
Participant15	5	5	4	4	4	22
Participant16	5	4	4	4	4	21
Participant17	5	5	4	4	4	22

Once the credibility values for each participant has been calculated, Equation 10.2 is applied to obtain the main resilience abilities for each HF threat, which results from combining the answers from all the experts by also taking into account their level of expertise.

11.5 Establishment of weightings for resilience abilities (Phase-IV)

After establishing the weighting for each HF threat as shown in Table 11.13, the next logical step included utilizing the aforementioned weightings to derive the weighting for each resilience ability. As established in the previous section, a questionnaire was distributed to collect experts' opinions regarding which resilience abilities could help to prevent and to reduce the negative effect of a specific HF threat. Thus, the answers provided by all experts are displayed in Appendix L.

In order to determine the weighting for each resilience ability in a specific HF category, a three stage procedure was followed. First, an initial analysis was performed on the expert data collected, to identify how often experts sorted certain resilience abilities within each HF. A conceptual example of the aforementioned initial analysis was displayed in Table 10.4. Thus, Table 11.15 provides a preliminary analysis of the data collected for this case study. From this preliminary analysis, it is possible to obtain an initial interpretation of the results. For instance, when the HF threat "commercial pressure" was investigated, anticipation, management commitment and awareness were the resilience abilities most often sorted by the participants as resilience abilities able to work together to reduce the impact of that specific HF threat.

Second, the expert data collected was aggregated in order to reflect more reliable results. Hence, each expert was assigned a credibility weight as displayed in Table 11.14, which was based on each expert background regarding the areas of HFs (Q1), resilience (Q2), shipping safety (Q3), shipping operations (Q4), and accident investigations (Q5). Then, Equation 7.2 was applied to rank the most influential resilience abilities for each HF threat. A preliminary example regarding how the credibility weight for each expert was taken into account was displayed in Table 10.5. Table 11.16 provides the aggregation of the data collected for this case study.

Table 11.15. Preliminary analysis of data collected

HF	RA most often sorted	No Times	RA most often sorted	No Times	RA most often sorted	No Times
Commercial pressure	Anticipating	10	Teamwork	8	Flexibility	4
	Management commitment	9	Monitoring	6	Redundancy	4
	Awareness	9	Reporting culture	5	Fault-tolerance	0
	Learning	8	Responding	4		
Effect of environmental and external factors	Monitoring	14	Responding	6	Reporting culture	2
	Awareness	8	Flexibility	6	Teamwork	2
	Learning	7	Redundancy	6	Management commitment	0
	Anticipating	7	Fault-tolerance	3		
Improper design, installation, and working environment	Learning	14	Team work	8	Fault-tolerance	5
	Management commitment	12	Monitoring	7	Anticipating	4
	Reporting culture	11	Responding	5	Flexibility	2
	Awareness	11	Redundancy	5		
Inadequate leadership and supervision	Management commitment	12	Awareness	4	Flexibility	2
	Reporting culture	10	Fault-tolerance	3	Anticipating	0
	Teamwork	10	Learning	2	Redundancy	0
	Monitoring	4	Responding	2		
Lack of communication and coordination	Teamwork	14	Learning	8	Flexibility	2
	Reporting culture	12	Awareness	7	Redundancy	2
	Management commitment	11	Responding	5	Fault-tolerance	1
	Monitoring	9	Anticipating	2		
Lack of training	Learning	11	Team work	3	Fault-tolerance	1
	Management commitment	10	Responding	2	Anticipating	0
	Awareness	9	Monitoring	2	Flexibility	0
	Reporting culture	3	Redundancy	1		
Safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)	Learning	9	Monitoring	6	Teamwork	2
	Management commitment	9	Anticipating	5	Redundancy	0
	Reporting culture	8	Responding	3	Fault-tolerance	0
	Awareness	7	Flexibility	2		
Unprofessional behaviour	Learning	10	Responding	4	Fault-tolerance	1
	Reporting culture	9	Awareness	4	Flexibility	0
	Management commitment	8	Team work	4	Redundancy	0
	Monitoring	5	Anticipating	2		

Table 11.16. Aggregation of data collected

HF	RA most influential	Cred. score	Certainty value	RA most influential	Cred. score	Certainty value
Commercial pressure	Anticipating	206	0.602	Monitoring	121	0.354
	Management commitment	183	0.535	Flexibility	83	0.243
	Awareness	180	0.526	Responding	80	0.234
	Teamwork	164	0.480	Redundancy	79	0.231
	Learning	161	0.471	Reporting culture	77	0.225
Effect of environmental and external factors	Monitoring	282	0.825	Flexibility	123	0.360
	Awareness	157	0.459	Redundancy	123	0.360
	Learning	139	0.406	Fault-tolerance	60	0.175
	Anticipating	139	0.406	Teamwork	44	0.129
	Responding	126	0.368	Reporting culture	40	0.117
Improper design, installation and working environment	Learning	282	0.825	Redundancy	102	0.298
	Management commitment	240	0.702	Fault-tolerance	102	0.298
	Reporting culture	238	0.696	Responding	97	0.284
	Awareness	226	0.661	Anticipating	77	0.225
	Teamwork	161	0.471	Flexibility	37	0.108
	Monitoring	139	0.406			
Inadequate leadership and supervision	Management commitment	239	0.699	Fault-tolerance	59	0.173
	Teamwork	204	0.596	Learning	41	0.120
	Reporting culture	198	0.579	Flexibility	40	0.117
	Monitoring	82	0.240	Responding	35	0.102
	Awareness	78	0.228			
Lack of communication and coordination	Teamwork	282	0.825	Responding	100	0.292
	Reporting culture	238	0.696	Anticipating	44	0.129
	Management commitment	223	0.652	Flexibility	41	0.120
	Monitoring	182	0.532	Redundancy	39	0.114
	Learning	165	0.482	Fault-tolerance	19	0.056
	Awareness	136	0.398			
Lack of training	Learning	216	0.632	Responding	37	0.108
	Management commitment	202	0.591	Monitoring	37	0.108
	Awareness	184	0.538	Redundancy	22	0.064
	Reporting culture	63	0.184	Fault-tolerance	22	0.064
	Teamwork	63	0.184			
Safety management system: Inadequate	Management commitment	187	0.547	Anticipating	103	0.301

HF	RA most influential	Cred. score	Certainty value	RA most influential	Cred. score	Certainty value
procedures or deviation from Standard Operating Procedure (SOP)	Learning	176	0.515	Responding	65	0.190
	Reporting culture	163	0.477	Flexibility	39	0.114
	Awareness	141	0.412	Teamwork	36	0.105
	Monitoring	114	0.333			
Unprofessional behaviour	Learning	200	0.585	Responding	78	0.228
	Reporting culture	183	0.535	Teamwork	76	0.222
	Management commitment	159	0.465	Anticipating	40	0.117
	Monitoring	103	0.301	Fault-tolerance	22	0.064
	Awareness	84	0.246			

It is important to notice that the only objective of the certainty value presented in Table 11.16 is to indicate the level of agreement amongst all experts. Hence, a certainty value of 1.000 in a resilience ability in a specific HF would only indicate that all experts agreed to include that resilience ability.

The final step included deriving the weighing for each resilience ability. Hence, the credibility weighting values displayed in Table 11.14 were used as a criterion to distribute the weighting of a specific HF threat into its resilience abilities. Table 11.17 provides a spreadsheet with the derived weighting for each resilience ability in a specific HF for this case study. It is important to mention that the weighting for each HF threat which is displayed in Table 11.17 has been drawn from Table 11.13, which were obtained after applying the MALFCMs method.

Table 11.17. Derived weighting for each resilience ability in a specific HF

HF	**RA most influential**	**Normalised Cred. Weighting**	**RA weighting**	**RA most influential**	**Normalised Cred. Weighting**	**RA weighting**
Commercial pressure	Anticipating	0.154	1.713	Monitoring	0.091	1.006
	Management commitment	0.137	1.522	Flexibility	0.062	0.690
	Awareness	0.135	1.497	Responding	0.060	0.665
HF weighting:	Teamwork	0.123	1.364	Redundancy	0.059	0.657
11.094	Learning	0.121	1.339	Reporting culture	0.058	0.640
Effect of environmental and external factors	Monitoring	0.229	1.937	Flexibility	0.100	0.845
	Awareness	0.127	1.078	Redundancy	0.100	0.845
	Learning	0.113	0.955	Fault-tolerance	0.049	0.412
HF weighting:	Anticipating	0.113	0.955	Teamwork	0.036	0.302
8.469	Responding	0.102	0.865	Reporting culture	0.032	0.275
Improper design, installation and working environment	Learning	0.166	1.727	Redundancy	0.060	0.625
	Management commitment	0.141	1.470	Fault-tolerance	0.060	0.625
	Reporting culture	0.140	1.458	Responding	0.057	0.594
	Awareness	0.133	1.384	Anticipating	0.045	0.472
HF weighting:	Teamwork	0.095	0.986	Flexibility	0.022	0.227
10.419	Monitoring	0.082	0.851			
Inadequate leadership and supervision	Management commitment	0.245	3.234	Fault-tolerance	0.060	0.798
	Teamwork	0.209	2.760	Learning	0.042	0.555
	Reporting culture	0.203	2.679	Flexibility	0.041	0.541
HF weighting:	Monitoring	0.084	1.110	Responding	0.036	0.474
13.207	Awareness	0.080	1.055			
Lack of communication and coordination	Teamwork	0.192	2.409	Responding	0.068	0.854
	Reporting culture	0.162	2.033	Anticipating	0.030	0.376
	Management commitment	0.152	1.905	Flexibility	0.028	0.350

HF	RA most influential	Normalised Cred. Weighting	RA weighting	RA most influential	Normalised Cred. Weighting	RA weighting
	Monitoring	0.124	1.555	Redundancy	0.027	0.333
HF weighting:	Learning	0.112	1.410	Fault-tolerance	0.013	0.162
12.551	Awareness	0.093	1.162			
	Learning	0.255	3.823	Responding	0.044	0.655
Lack of training	Management commitment	0.239	3.576	Monitoring	0.044	0.655
	Awareness	0.217	3.257	Redundancy	0.026	0.389
HF weighting:	Reporting culture	0.074	1.115	Fault-tolerance	0.026	0.389
14.975	Teamwork	0.074	1.115			
Safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)	Management commitment	0.183	2.789	Anticipating	0.101	1.536
	Learning	0.172	2.625	Responding	0.063	0.969
	Reporting culture	0.159	2.431	Flexibility	0.038	0.582
HF weighting:	Awareness	0.138	2.103	Teamwork	0.035	0.537
15.270	Monitoring	0.111	1.700			
	Learning	0.212	2.966	Responding	0.083	1.157
Unprofessional behaviour	Reporting culture	0.194	2.714	Teamwork	0.080	1.127
	Management commitment	0.168	2.358	Anticipating	0.042	0.593
HF weighting:	Monitoring	0.109	1.528	Fault-tolerance	0.023	0.326
14.016	Awareness	0.089	1.246			

Finally, once the weightings for each resilience ability associated with each HF threat have been obtained in the previous step, the final weight for each resilience ability was calculated by following Equation 10.3. Hence, Table 11.18 displays the final weighting for each resilience ability for this case study.

Table 11.18. Final weighting for each resilience ability

No	Resilience ability	Final Weighting (%)
RA-1	Learning	15.400
RA-2	Responding	6.234
RA-3	Anticipating	5.645
RA-4	Monitoring	10.342
RA-5	Management commitment	16.854
RA-6	Reporting culture	13.346
RA-7	Awareness	12.783
RA-8	Flexibility	3.235
RA-9	Teamwork	10.601
RA-10	Redundancy	2.849
RA-11	Fault-tolerance	2.713
	Total	**100.000**

11.6 Assessment of resilience level (Phase-V)

A link has been established amongst each HF threat and certain resilience abilities, and the weighting for each resilience ability has been established as shown in Table 11.18. The next logical step included adapting and utilizing the Resilience Assessment Questionnaire (RAQ) to the specific needs of the company under study, in order to assess its resilience level. By assessing the resilience level in the company, it will be possible to identify weaknesses and propose a set of measures to overcome these weaknesses and increase the overall safety level. A complete description of the initial RAQ design and structure was provided in Chapter 10 In addition, the company under study observed that certain topics presented redundant or unnecessary statements. Thus, by eliminating those statements, the questionnaire would be reduced, which ideally would be translated into more reliable results from the company, as the final respondents would not feel discouraged by filling an unnecessary long questionnaire. Therefore, specific questions were removed to the RAQ based on company's feedback as displayed in Table 11.19.

Table 11.19. Statements removed from proposed RAQ and reasons for removal

Removed statements based on participants' feedback	Topic No	Reasons
Crew members use a common language (e.g. English the official language) during unexpected situations	4	The statement is unnecessary as the HSQE Manager has assured that English is spoken by all crew members in the case study company.
Any changes in the operation (e.g. technological, organizational, external) are implemented with care for the safety	15	The HSQE Manager considered this statement unnecessary, as obviously all changes aim to be safe.
Crew members take safety seriously	16	Similar to other statements, it has been suggested to remove it and combine it with statement No 73.
Crew members are committed to a safe and healthy working	16	The statement is unnecessary as it might be more representative of a safety culture questionnaire.

In addition, it needs to be mentioned that some of the statements that were removed from this case study can be added for another case where multinational crew are involved.

An email was sent to the shipping company on the 4th of December, 2019 for internal distribution. The aforementioned email included three main components. First, an introduction letter, which provided the background for the RAQ. The aforementioned letter is included in Appendix M. Second, a link to the online version of the RAQ, as it was agreed with the company that it would be easier to collect the results by utilizing the online version of the RAQ. Finally, the two main objectives that were aimed to be completed with the RAQ. Aforementioned objectives are as follows:

- First and main objective: To assess the resilience level on board specific vessels on the company under study.
- Second objective: To assess the differences between expected resilience on board (i.e. by collecting relevant onshore responses to the questionnaire) and real resilience on board (i.e. by collecting relevant crew members' responses). The objective was to capture deficiencies in terms of resilience. For example, if a vessel has a system in place to record past accidents and learn from them, but crew members are not aware of the above-mentioned system, then crew members will not be able to use it. Therefore, there will be a difference between the "expected resilience" (i.e. measured from the collected onshore answers) and the "objective resilience" (i.e. from the collected measured on board answers).

To complete the previous objectives, the target audience of the aforementioned email were five specific vessels selected by the company under study and shore personnel.

In addition, a second email was sent on the 8th of January 2020, which included the same information and attachments as the first email. The goal of sending a second email one month after the first email was to obtain additional answers, and therefore, aiming to contribute to get a more reliable resilience assessment of the company under study.

11.7 Analysis of RAQ Results and Recommendations for Resilience Improvement (Phase-VI)

The online version of the questionnaire was closed on the 22nd of January 2020, and the results of the aforementioned RAQ were analysed to determine the resilience level of the company under study.

11.7.1 RAQ Data Collection

The RAQ was distributed to all crewmember from five vessels and all shore-personnel in a passenger shipping company. The detailed return rates from different groups are displayed in Table 11.20.

Table 11.20. RAQ return rates

Position	Number of Responses
Crew members	15
Shore personnel	10

11.7.2 RAQ Missing Data

The data obtained from the online version of the RAQ was analysed to identify unusual or missing data. The questionnaire consisted of 19 topics covering 80 statements in total, as shown in Appendix J. In total, there were 25 responses to the RAQ, from where 20 responses were completed responses and 5 included partial responses. The questionnaire also included an optional demographic questions such as the rank or position of the crew members in the company. The company being investigated under this case study suggested including the aforementioned demographic question to compare RAQ answers; however, the majority of the participant did not provide such information. Therefore, it was decided that for future questionnaires such questions would not be included which may potentially cause more concern at a participant level than the benefits that they may bring.

11.7.3 **RAQ Demographics**

This section includes the results of the demographics section of the RAQ questionnaire in order to provide background information about the participants. A total of 25 questionnaires were obtained, from where 15 (60.00%) were completed by crew members and the remaining 10 (40.00%) where completed by shore personnel. Regarding the questionnaires filled by crew members, 3 (20.00%) were completed by Masters, 2 (13.33%) were completed by Chief Officers, 2 (13.33%) were completed by 2nd Officers, 1 (6.67%) was completed by a 3rd Officer, 3 (20.00%) were completed by Chief Engineers, and 4 (26.67%) did not provide their rank or position. Table 11.21 provides further insight into the demographic distribution in terms of rank or position.

Table 11.21. RAQ, crew members rank distribution

Crew members rank	**Number of Responses**
Master	3
Chief Officer	2
2nd Officer	2
3rd Officer	1
Chief Engineer	3
Others	4
Total	**15**

11.7.4 **RAQ, Resilience Abilities Results**

This section presents the resilience perception results of the employees within the passenger company under study. In total, 15 crew members and 10 shore personnel completed the RAQ questionnaire and all responses are taken into account in the following analysis.

The average scores of each resilience ability in the RAQ were calculated by including all statements related to each resilience ability, as shown in Table 10.11. The results revealed that as an average, the highest score was obtained in the “anticipating” resilience ability, while the lowest score was received in the “management commitment” resilience ability. It can be seen from Table 11.23 that the biggest difference between crew members and shore personnel was recorded on the “fault-tolerance” resilience ability with a 7.99% difference value. The values for crew members were obtained as an average of the combined results provided by all crew members. Thus, the values for shore personnel were obtained by combining the results provided by all shore workers. The aforementioned difference between responses amongst crew members and shore personnel clearly identifies that both groups have a different perception in terms of the resilience level within the company.

Although there is not an agreed metric for measuring success in a company in terms of its resilience level, similar approaches and studies in the safety culture field have defined and applied scales that can be useful for the scope of this research. Therefore, the scale created by Arslan (2018) has been adopted in this study as shown in Table 11.22.

Table 11.22. RAQ, scale adapted from Arslan (2018)

Scale	Resilience level
X>80	Excellent resilience level
70<X<80	Adequate resilience level
60<X<70	Lower than desirable resilience level
X<60	Inadequate resilience level

The labels for each range have been defined by maintaining a positive language when possible. It is important to notice that the aforementioned resilience labels only show the resilience capability of a company. Therefore, it should not be perceived as a direct indicator of safety performance.

Scores which are lower than 60, are usually not desirable within organizations. Thus, while statements between 60 and 70 (in yellow) reflect a lower than desirable resilience perception, all statements under 60 (in red) reflect an inadequate resilience perception. Hence, relevant efforts should be invested to strengthen the identified vulnerabilities. In the calculation process, each statement has a score that varies between 0 and 100, where 0 shows the minimum score and 100 represents the highest score.

Table 11.23. RAQ, resilience abilities results. Crew members and shore personnel results

Resilience ability	**Scores for Crew members (%)**	**Scores for Shore personnel (%)**	**Average results (%)**	**Difference value (%)**
Learning	68.20	63.87	66.04	4.33
Responding	74.48	75.99	75.23	1.51
Anticipating	80.26	78.78	79.52	1.48
Monitoring	72.93	73.33	73.13	0.40
Management commitment	62.54	68.72	65.63	6.18
Reporting culture	71.91	70.67	71.29	1.24
Awareness	73.85	78.53	76.19	4.69
Flexibility	67.81	75.02	71.42	7.21
Teamwork	77.01	70.00	73.51	7.01
Redundancy	68.44	68.83	68.63	0.40
Fault-tolerance	68.85	76.83	72.84	7.99

Regarding the resilience abilities on board each vessel, the average scores for each ability were also calculated by including all statements related to each resilience ability. Table 11.24 shows that as an average, “vessel3” obtained the highest score in the “anticipating” resilience ability, while the lowest score was reported in the “management commitment” ability by “vessel4”. Thus, the differences amongst vessels clearly identify that each vessel has a different perception in terms of the resilience level on board.

Table 11.24. RAQ, resilience abilities results. Crew members result by vessel

Resilience ability	**Vessel 1 (%)**	**Vessel 2 (%)**	**Vessel 3 (%)**	**Vessel 4 (%)**	**Vessel 5 (%)**
Learning	70.00	65.71	72.86	74.29	71.43
Responding	76.88	73.75	76.25	72.50	72.50
Anticipating	80.00	73.33	86.67	80.00	78.33
Monitoring	70.00	67.50	78.75	75.00	63.75
Management commitment	56.67	56.67	65.00	46.67	61.67
Reporting culture	68.33	73.33	61.67	73.33	76.11
Awareness	80.00	76.00	82.00	60.00	70.00
Flexibility	65.00	67.50	72.50	67.50	61.25
Teamwork	72.50	60.00	82.50	65.00	77.50
Redundancy	62.50	60.00	70.00	65.00	75.00
Fault-tolerance	60.00	80.00	80.00	75.00	55.00

11.7.4.1 Learning Statements

The resilience ability of “learning” consisted of seven statements. The average score of each statement for all crew members within each vessel analysed is provided in Table 11.25, while Table 11.26 provides the average score of each statement for all crew members and shore personnel. There are various statements with the lowest score (i.e. 40.00%) recorded in almost all the vessels. Thus, the statements “Crew members use success stories from outside the company” present the lowest score for almost all vessels analysed. On the contrary, “vessel4” does not present any statement under a 60.00% value for the resilience ability learning, which shows that there is room for improvement for sharing good practices in the rest of the vessels within the company under study, which is a one of the important indicators of resilient organisational behaviour. It needs to be noted that this is a common concern in maritime and not specific to the case study company.

In addition, for the average of all crew members, the statement with the lowest score is also “Crew members use success stories from outside the company”, while the statement with the lowest score for shore personnel is “Crew members use incident/accident information from other companies”.

Table 11.25. RAQ, Statements for resilience ability learning. Crew members result by vessel

No	Statements for the ability learning	Vessel 1 (%)	Vessel 2 (%)	Vessel 3 (%)	Vessel 4 (%)	Vessel 5 (%)
1	Crew members use lessons learned in their operations	80.00	80.00	80.00	80.00	80.00
3	Crew members share lessons learned in their operations	90.00	80.00	80.00	80.00	93.33
4	Crew members evaluate lessons learned in their operations	80.00	60.00	80.00	80.00	86.67
6	Crew members use incident/accident information from other companies	40.00	80.00	60.00	80.00	50.00
7	Crew members use success stories from outside the company	40.00	40.00	50.00	60.00	40.00
9	Crew members use their own incident/accident information	80.00	80.00	80.00	80.00	80.00
10	Crew members use their success stories (e.g. what went right)	80.00	40.00	80.00	60.00	70.00

Table 11.26. RAQ, Statements for resilience ability learning. Crew members and shore personnel results

No	Statements for the ability learning	Crew members (%)	Shore personnel (%)
1	Crew members use lessons learned in their operations	78.67	71.11
3	Crew members share lessons learned in their operations	81.33	64.00
4	Crew members evaluate lessons learned in their operations	76.00	72.00
6	Crew members use incident/accident information from other companies	57.14	52.50
7	Crew members use success stories from outside the company	45.71	57.50
9	Crew members use their own incident/accident information	78.57	72.50
10	Crew members use their success stories (e.g. what went right)	60.00	57.50

It can be observed from the above information that employees disagree with the fact that accidental data and external sources of information are used to learn from past experiences.

The maritime sector has traditionally presented a reactive approach to accidents, as regulations are generally developed to prevent reoccurrence rather than to avoid accident scenarios. However, it is a known fact that accidents are rare events and during a higher percentage of the time the system is safe, so it is possible to obtain additional useful information when focusing on the positive events and by learning from them. Nowadays, most companies have developed their own databases containing information on near-miss incidents and accidents. In general, near miss information and unreportable incidents are collected by the companies and never shared due to commercial sensitivity. Therefore, there is a clear need for establishing a sector wide system to overcome this barrier and enable companies to share and promote learning not only from reportable accidents but also from near misses, as near misses can provide informalities which safety barriers are effectively preventing the accidents from occurring.

Nevertheless, investigated accidents are publicly available, hence, accessible online. Crew members normally do not access the aforementioned information themselves. Therefore, the company needs to filter this information and inform their crew members about potential lessons learn from external sources which clear contextual information about the incident, its development and consequences so that crew can appreciate that this is a real accident and not just an additional training topic that the company has identified.

11.7.4.2 **Responding Statements**

The resilience ability "responding" consisted of sixteen statements. The average score of each statement for all crew members within each vessel analysed is provided in Table 11.27, while Table 11.28 provides the average score of each statement for all crew members and shore personnel. Most of the vessels agree when identifying the statements with lower scores, especially for the statement "Crew members receive sufficient training to make critical decisions", which has been ranked under 50.00% by at least four of the vessels analysed. In addition, the aforementioned statements is also the statement with the lowest score for crew members and shore personnel.

Table 11.27. RAQ, Statements for the resilience ability responding. Crew members result by vessel

No	Statements for the ability responding	Vessel 1 (%)	Vessel 2 (%)	Vessel 3 (%)	Vessel 4 (%)	Vessel 5 (%)
19	Crew members respond well to exceptions during normal operations	90.00	100.00	80.00	100.00	90.00
20	Crew members conduct regular drills for the most likely exceptional situation	90.00	100.00	90.00	80.00	70.00
23	Crew members have established who does what during exceptions	80.00	80.00	90.00	100.00	80.00
25	Crew members understand well the criteria for safe operations	80.00	80.00	90.00	80.00	80.00
26	Crew members understand that they can ask for external support if needed	80.00	60.00	80.00	60.00	80.00
27	Crew members are willing to use external support if needed	80.00	40.00	60.00	60.00	60.00
28	Crew members perform their roles, tasks and take responsibilities as described	80.00	80.00	80.00	80.00	80.00
29	Crew members have sufficient authority for the execution of their tasks	70.00	80.00	80.00	80.00	80.00
32	Crew members know the important safety procedures	80.00	80.00	90.00	80.00	80.00
39	Crew members are trained to respond to foreseen risk scenarios	80.00	80.00	70.00	80.00	60.00
40	Crew members are trained to respond to unforeseen risk scenarios	80.00	40.00	70.00	80.00	60.00
41	Crew members are trained to respond to emergency scenarios	80.00	80.00	80.00	80.00	90.00
43	Crew members receive sufficient training to make critical decisions	60.00	40.00	80.00	80.00	60.00
44	Crew members are aware of the type of critical decisions they are responsible to make and the potential consequences of incorrect decisions	80.00	80.00	70.00	N/A	60.00
45	There are enough crew members available to respond appropriately to unforeseen operational demands	40.00	80.00	40.00	40.00	50.00
46	Crew members are able to deal with unforeseen operational demands	80.00	80.00	70.00	80.00	80.00

Table 11.28. RAQ, Statements for the resilience ability responding. Crew members and shore personnel results

No	Statements for the ability responding	Crew members (%)	Shore personnel (%)
19	Crew members respond well to exceptions during normal operations	84.62	74.29
20	Crew members conduct regular drills for the most likely exceptional situation	87.69	82.86
23	Crew members have established who does what during exceptions	83.08	80.00
25	Crew members understand well the criteria for safe operations	81.54	80.00
26	Crew members understand that they can ask for external support if needed	71.67	80.00
27	Crew members are willing to use external support if needed	66.67	70.00
28	Crew members perform their roles, tasks and take responsibilities as described	80.00	80.00
29	Crew members have sufficient authority for the execution of their tasks	78.46	80.00
32	Crew members know the important safety procedures	81.54	83.33
39	Crew members are trained to respond to foreseen risk scenarios	80.00	76.67
40	Crew members are trained to respond to unforeseen risk scenarios	81.54	83.33
41	Crew members are trained to respond to emergency scenarios	70.00	83.33
43	Crew members receive sufficient training to make critical decisions	69.23	72.00
44	Crew members are aware of the type of critical decisions they are responsible to make and the potential consequences of incorrect decisions	80.00	80.00
45	There are enough crew members available to respond appropriately to unforeseen operational demands	55.38	76.00
46	Crew members are able to deal with unforeseen operational demands	61.54	72.00

11.7.4.3 Anticipating Statements

The resilience ability "anticipating" consisted of six statements. The average score of each statement for all crew members within each vessel analysed is provided in Table 11.29, while Table 11.30 provides the average score of each statement for all crew members and shore personnel. Overall, the various vessels have replied positively to this set of statements, as there is only one statement that present a score of 40.00% in one vessel (i.e. "Risk information can be easily understood by all crew members" by vessel 2).

Overall, most vessels analysed fear that risk information is not accessible and understood by all crew members. The access, understanding, and adherence to risk and safety operations are of paramount importance to achieve the appropriate levels of resilience and safety in a shipping company. Therefore, the company should facilitate employees' appreciation and knowledge about risk on an individual and organizational level, while also encouraging all crew members to share risk information since a lack of awareness can result in incidents or accidents in the company.

Table 11.29. RAQ, Statements for the resilience ability anticipating. Crew members result by vessel

No	Statements for the ability anticipating	Vessel 1 (%)	Vessel 2 (%)	Vessel 3 (%)	Vessel 4 (%)	Vessel 5 (%)
30	Crew members know what is important when working	80.00	80.00	90.00	80.00	80.00
31	Crew members have experience doing the work	80.00	80.00	100.00	80.00	90.00
33	Crew members know the risks of their work	80.00	80.00	90.00	80.00	80.00
36	Crew members know who does what and when	80.00	80.00	80.00	80.00	80.00
37	Crew members know who is formally responsible for what	80.00	80.00	90.00	80.00	80.00
61	Risk information can be easily understood by all crew members	80.00	40.00	70.00	80.00	60.00

Table 11.30. RAQ, Statements for the resilience ability anticipating. Crew members and shore personnel results

No	Statements for the ability anticipating	Crew members (%)	Shore personnel (%)
30	Crew members know what is important when working	81.54	80.00
31	Crew members have experience doing the work	84.62	76.67
33	Crew members know the risks of their work	83.08	80.00
36	Crew members know who does what and when	80.00	76.67
37	Crew members know who is formally responsible for what	81.54	83.33
61	Risk information can be easily understood by all crew members	70.77	76.00

11.7.4.4 Monitoring Statements

The resilience ability “monitoring” consisted of eight statements. The average score of each statement for all crew members within each vessel analysed is provided in Table 11.31, while Table 11.32 provides the average score of each statement for all crew members and shore personnel. Most of the vessels agree when identifying “Any changes in the operation (e.g. technological, organizational, and external) are actively monitored for potential negative effects” as the statement with the lowest score. In addition, above-statement was also identified by crew members as the statement with the lowest score. On the other hand, the statement with the lowest score for shore personnel was “Crew members make well-deliberated trade-offs between safety and other goals”.

Table 11.31. RAQ, Statements for the resilience ability monitoring. Crew members result by vessel

No	Statements for the ability monitoring	Vessel 1 (%)	Vessel 2 (%)	Vessel 3 (%)	Vessel 4 (%)	Vessel 5 (%)
62	The presence of crew resources (e.g. time, means, people) is monitored during the operation	60.00	80.00	80.00	80.00	40.00
63	The quality of crew resources (e.g. means, people) is monitored during the operation	60.00	60.00	80.00	80.00	40.00
66	Any changes in the operation (e.g. technological, organizational, external) are actively monitored for potential negative effects	50.00	40.00	40.00	80.00	40.00
71	Crew members are committed and take safety seriously	90.00	80.00	100.00	80.00	80.00
72	Crew members make well-deliberated trade-offs between safety and other goals	60.00	60.00	80.00	40.00	80.00
75	Compliance to safety functions (e.g. safety procedures) is monitored during operations	80.00	80.00	90.00	80.00	80.00
78	In periods with high activity or a high number of simultaneous operations crew members are highly vigilant on the possibility that something might go wrong	80.00	80.00	80.00	80.00	80.00
80	In periods with high activity or a high number of simultaneous operations crew members monitor (potential) unexpected interactions between operations and/ or activities	80.00	60.00	80.00	80.00	70.00

Table 11.32. RAQ, Statements for the resilience ability monitoring. Crew members and shore personnel results

No	Statements for the ability monitoring	Crew members (%)	Shore personnel (%)
62	The presence of crew resources (e.g. time, means, people) is monitored during the operation	73.33	76.00
63	The quality of crew resources (e.g. means, people) is monitored during the operation	71.67	84.00
66	Any changes in the operation (e.g. technological, organizational, external) are actively monitored for potential negative effects	50.77	53.33
71	Crew members are committed and take safety seriously	84.62	83.33
72	Crew members make well-deliberated trade-offs between safety and other goals	70.77	50.00
75	Compliance to safety functions (e.g. safety procedures) is monitored during operations	81.54	76.67
78	In periods with high activity or a high number of simultaneous operations crew members are highly vigilant on the possibility that something might go wrong	78.46	80.00
80	In periods with high activity or a high number of simultaneous operations crew members monitor (potential) unexpected interactions between operations and/ or activities	72.31	83.33

It can be observed from the above information that shore personnel is concerned that crew members may not be able to make well-considered trade-offs between safety and other goals. It is important to check whether there are additional resources or tools are in place for shore management to better monitor these safety trade-offs and be able to take timely action. Crew members should also be more aware of the consequences of safety trade-offs, and they may be provided with a system to conduct such trade-offs to prevent single point of failure. It is known that to be resilient in terms of safety are companies and employee should not see operational efficiency and safety as mutually exclusive.

11.7.4.5 Management Commitment Statements

The resilience ability "management commitment" consisted of twelve statements. The average score of each statement for all crew members within each vessel analysed is provided in Table 11.33, while Table 11.34 provides the average score of each statement for all crew members and shore personnel. Overall, most of the vessels agree when identifying the statements with a lower score. Thus, the statements with a lower score for management commitment are, "Any changes in the operation (e.g. technological, organizational, external) are well prepared", "Any changes in the operation (e.g. technological, organizational, external) are well thought out and planned", "Any changes in the operation (e.g. technological, organizational, external) are prepared by people with the right expertise" and "Any changes in the operation (e.g. technological, organizational, external) are well directed and controlled", which have been ranked with a 40.00% or below by at least three of the vessels analysed. In addition, the aforementioned statements also present the lowest score for crew members and shore personnel.

It is important to take into account that in the RAQ tables, responses marked with the answer "N/A" indicates that the respondent did not have a clear opinion about the specific statement, and preferred not to answer.

Table 11.33. RAQ, Statements for the resilience ability management commitment. Crew members result by vessel

No	Statements for the ability management commitment	Vessel 1 (%)	Vessel 2 (%)	Vessel 3 (%)	Vessel 4 (%)	Vessel 5 (%)
24	Criteria for safe operations are clearly defined	50.00	80.00	90.00	100.00	100.00
35	Roles, tasks, and responsibilities of crew members are clearly defined	80.00	80.00	70.00	100.00	80.00
42	Crew members receive sufficient support when making critical decisions	50.00	40.00	60.00	60.00	60.00
58	Risk information is properly communicated with crew members	70.00	80.00	80.00	80.00	80.00
59	Risk information is available through various channels e.g. meetings, safety alerts, bulletins, etc.	80.00	80.00	80.00	80.00	80.00
60	Risk information is easily accessible to all crew members	60.00	20.00	70.00	80.00	40.00
64	Any changes in the operation (e.g. technological, organizational, external) are well prepared	40.00	40.00	50.00	N/A	50.00
65	Any changes in the operation (e.g. technological, organizational, external) are well thought out and planned	40.00	40.00	50.00	N/A	50.00
67	Any changes in the operation (e.g. technological, organizational, external) are prepared by people with the right expertise	40.00	40.00	60.00	N/A	40.00
68	Any changes in the operation (e.g. technological, organizational, external) are well directed and controlled	40.00	40.00	40.00	N/A	40.00
69	Any changes in the operation (e.g. technological, organizational, external) come as a surprise in the workplace	70.00	80.00	50.00	60.00	70.00
70	Any changes in the operation (e.g. technological, organizational, external) are carried out in a safe manner, with due care	60.00	60.00	80.00	N/A	50.00

Table 11.34. RAQ, Statements for the resilience ability management commitment. Crew members and shore personnel results

No	Statements for the ability management commitment	Crew members (%)	Shore personnel (%)
24	Criteria for safe operations are clearly defined	81.54	83.33
35	Roles, tasks, and responsibilities of crew members are clearly defined	78.46	83.33
42	Crew members receive sufficient support when making critical decisions	55.38	76.00
58	Risk information is properly communicated with crew members	75.38	76.00
59	Risk information is available through various channels e.g. meetings, safety alerts, bulletins, etc.	76.92	86.67
60	Risk information is easily accessible to all crew members	60.00	76.67
64	Any changes in the operation (e.g. technological, organizational, external) are well prepared	51.67	53.33
65	Any changes in the operation (e.g. technological, organizational, external) are well thought out and planned	48.33	53.33
67	Any changes in the operation (e.g. technological, organizational, external) are prepared by people with the right expertise	48.33	56.00
68	Any changes in the operation (e.g. technological, organizational, external) are well directed and controlled	45.00	56.67
69	Any changes in the operation (e.g. technological, organizational, external) come as a surprise in the workplace	66.15	56.67
70	Any changes in the operation (e.g. technological, organizational, external) are carried out in a safe manner, with due care	63.33	66.67

11.7.4.6 Reporting Culture Statements

The resilience ability "reporting culture" consisted of six statements. The average score of each statement for all crew members within each vessel analysed is provided in Table 11.35, while Table 11.36 provides the average score of each statement for all crew members and shore personnel. Overall, the various vessels have reply positively to this set of statements, as there is only one statement that presents a score of 40.00% or below according to at least three vessels, which is "There is a system in place for crew members to share successes and failures".

In addition, the aforementioned statement is also the statement with the lowest score for crew members and shore personnel. Therefore, it seems that either the system is not installed on board the company's vessels, or the aforementioned system might be installed on board vessels, but not all crew members are aware of it. In that case, the company should provide crew members with adequate training regarding how to report information through this system.

Moreover, the most obvious and accessible source of information on 'what may go wrong, and therefore how to treat those situations', is the company's own experience from incidents and accidents. It is in the interest of shipping companies to avoid the reoccurrence of negative events and multiply good practices. Hence, the company can investigate providing its employees with an effective system to record and share both successes and failures.

Table 11.35. RAQ, Statements for the resilience ability reporting culture. Crew members result by vessel

No	Statements for the ability reporting culture	Vessel 1 (%)	Vessel 2 (%)	Vessel 3 (%)	Vessel 4 (%)	Vessel 5 (%)
2	Crew members document lessons learned in their operations	60.00	80.00	40.00	60.00	80.00
5	There is a system in place for crew members to register lesson learned	60.00	80.00	40.00	80.00	66.67
8	There is a system in place for crew members to share successes and failures	40.00	40.00	40.00	60.00	60.00
11	There is a system in place for crew members to register incident/accident information	90.00	80.00	90.00	80.00	90.00
73	Crew members actively share information about (potential) technical failures of equipment (e.g. control systems, power systems, sensor systems)	80.00	80.00	80.00	80.00	80.00
74	Crew members actively share information about (potential) loss of control during operational activities	80.00	80.00	80.00	80.00	80.00

Table 11.36. RAQ, Statements for the resilience ability reporting culture. Crew members and shore personnel results

No	Statements for the ability reporting culture	Crew members (%)	Shore personnel (%)
2	Crew members document lessons learned in their operations	62.67	58.00
5	There is a system in place for crew members to register lesson learned	70.67	66.00
8	There is a system in place for crew members to share successes and failures	54.29	57.50
11	There is a system in place for crew members to register incident/accident information	90.00	82.50
73	Crew members actively share information about (potential) technical failures of equipment (e.g. control systems, power systems, sensor systems)	76.92	80.00
74	Crew members actively share information about (potential) loss of control during operational activities	76.92	80.00

Most of the participants have discussed that apparently there is not a system in place for crew members to share successes and failures and this issue has been already identified before as a main concern within the company. In addition, both crew members and shore personnel seem to acknowledge that crew members do not utilize stories or information about incidents and accidents from other parties. The manifestation of potential events in real occurrences constitutes only a small percentage of the potential events that might occur. Thus, it is important to learn as much as possible not only from the company's own experiences but also from other companies' accidental data. Accessing information and sharing information is very easy and it is important that shipping companies establish this ability to share good and bad practices between each other.

11.7.4.7 Awareness Statements

The resilience ability "awareness" consisted of five statements. The average score of each statement for all crew members within each vessel analysed is provided in Table 11.37, while Table 11.38 provides the average score of each statement for all crew members and shore personnel. Overall, the various vessels replied positively to this set of statements, as there is only one statement that present a score of 40.00% (i.e. statement "Crew members have insight into how technical systems may fail" as reported by "vessel 4").

Table 11.37. RAQ, Statements for the resilience ability awareness. Crew members result by vessel

No	Statements for the ability awareness	Vessel 1 (%)	Vessel 2 (%)	Vessel 3 (%)	Vessel 4 (%)	Vessel 5 (%)
53	Crew members know the functioning of onboard technical systems	80.00	80.00	80.00	60.00	80.00
54	Crew members have insight into how technical systems may fail	80.00	80.00	90.00	40.00	60.00
55	Crew members have knowledge about design limitations of the technical systems	80.00	80.00	80.00	60.00	70.00
56	Crewmember understand how critical systems operate in both normal and emergency situations	80.00	80.00	80.00	80.00	70.00
57	Crewmember have knowledge about interactions and interfaces between technical systems	80.00	60.00	80.00	60.00	70.00

Table 11.38. RAQ, Statements for the resilience ability awareness. Crew members and shore personnel results

No	Statements for the ability awareness	Crew members (%)	Shore personnel (%)
53	Crew members know the functioning of onboard technical systems	76.92	83.33
54	Crew members have insight into how technical systems may fail	72.31	80.00
55	Crew members have knowledge about design limitations of the technical systems	72.31	76.67
56	Crewmember understand how critical systems operate in both normal and emergency situations	76.92	76.67
57	Crewmember have knowledge about interactions and interfaces between technical systems	70.77	76.00
57	Crewmember have knowledge about interactions and interfaces between technical systems	70.77	76.00

11.7.4.8 Flexibility Statements

The resilience ability "flexibility" consisted of eight statements. The average score of each statement for all crew members within each vessel analysed is provided in Table 11.39, while Table 11.40 provides the average score of each statement for all crew members and shore personnel. Overall, most of the vessels agree when identifying the statements with a lower score. Thus, the statements with a lower score are "Information and communication systems are always available and reliable during unexpected situations" and "Crew members have sufficient resources to respond to unforeseen operational demands", which have been ranked with a 40.00% or below by at least three of the vessels analysed.

In addition, the statement with the lowest score for crew members is also "Information and communication systems are always available and reliable during unexpected situations", while all statements for shore personnel have been rated over 60.00%.

Table 11.39. RAQ, Statements for the resilience ability flexibility. Crew members result by vessel

No	Statements for the ability flexibility	Vessel 1 (%)	Vessel 2 (%)	Vessel 3 (%)	Vessel 4 (%)	Vessel 5 (%)
14	A well-defined communication system and its SOP exists in the organization for any unexpected situation	60.00	80.00	80.00	80.00	60.00
15	Information and communication systems are always available and reliable during unexpected situations	40.00	20.00	40.00	80.00	50.00
16	The information provided by other actors (e.g. company, coastguard) during unexpected situations is understandable for all crew involved	60.00	80.00	80.00	60.00	80.00
21	Crew members are well prepared for handling exceptions	90.00	80.00	80.00	80.00	80.00
22	Crew members have sufficient resources to respond to exceptions	60.00	80.00	80.00	60.00	80.00
50	Crew members have established ' who does what ' during unforeseen operational demands	80.00	80.00	90.00	60.00	40.00
51	Crew members have sufficient resources to respond to unforeseen operational demands	50.00	60.00	60.00	40.00	40.00
79	In periods with high activity or a high number of simultaneous operations crewmembers perform additional risk assessments to control for potential negative side effects	80.00	60.00	70.00	80.00	60.00

Table 11.40. RAQ, Statements for the resilience ability flexibility. Crew members and shore personnel results

No	Statements for the ability flexibility	Crew members (%)	Shore personnel (%)
14	A well-defined communication system and its SOP exists in the organization for any unexpected situation	70.77	83.33
15	Information and communication systems are always available and reliable during unexpected situations	50.77	71.43
16	The information provided by other actors (e.g. company, coastguard) during unexpected situations is understandable for all crew involved	76.36	70.00
21	Crew members are well prepared for handling exceptions	80.00	71.43
22	Crew members have sufficient resources to respond to exceptions	72.31	96.00
50	Crew members have established ' who does what ' during unforeseen operational demands	67.69	80.00
51	Crew members have sufficient resources to respond to unforeseen operational demands	55.38	68.00
79	In periods with high activity or a high number of simultaneous operations crewmembers perform additional risk assessments to control for potential negative side effects	69.23	60.00

Overall, most of the vessels acknowledge that there are not sufficient resources to respond to unforeseen operational demands. The ability to deal with unforeseen operational demands is a resource that plays an important role when dealing with operations that cannot be fully planned in advance. Hence, the company should have the willingness and ability to appropriately resource all operations, most especially unforeseen operational demands.

In addition, most of the crewmembers agree that information and communication systems are not always available and reliable during unexpected situations. Adequate knowledge about all the technical systems work and the interaction between systems is important in a company, including knowledge about design assumptions and operational conditions. This knowledge provides flexibility to the company, as it facilitates insight into how systems may fail and the potential consequences. Communication is of key importance, especially during unexpected or emergency situations, hence, all systems on board should always be reliable, but specifically during the aforementioned unexpected or emergency situations.

11.7.4.9 Teamwork Statements

The resilience ability “teamwork” consisted of four statements. The average score of each statement for all crew members within each vessel analysed are provided in Table 11.41, while Table 11.42 provides the average score of each statement for all crew members and shore personnel. Overall, most of the vessels and crewmembers agree when identifying that “There is a sufficient level of communications between crew members” is the statement with the lower score. In addition, the statement with the lowest score for shore personnel is “Crew members have sufficient communication skills”.

Moreover, from the four statements listed in Table 11.42, it seems that the statement Nº13 is the strongest statement from the perspective of crew members (with an 89.23% agreement). However according to shore personnel, the same statement has the lowest score. Therefore, it seems that shore personnel is concerned about specific ship shore communication that they expect to improve in the future. In addition, such level of change between two groups should be further investigated by the company.

Effective communication is a fundamental resource to achieve highly effective and safer operations. Thus, good communication is obtained when all crew members have good communication skills and when there is a proper definition of the people responsible for communicating relevant information in the company.

Table 11.41. RAQ, Statements for the resilience ability teamwork. Crew members result by vessel

No	Statements for the ability teamwork	Vessel 1 (%)	Vessel 2 (%)	Vessel 3 (%)	Vessel 4 (%)	Vessel 5 (%)
12	There is a sufficient level of communications between crew members	80.00	80.00	90.00	100.00	80.00
13	Crew members have sufficient communication skills	90.00	80.00	100.00	100.00	80.00
17	The information is communicated to all actors during unexpected situations in a timely manner	60.00	40.00	80.00	60.00	60.00
38	Crew members follow a shared training program	60.00	40.00	60.00	N/A	90.00

Table 11.42. RAQ, Statements for the resilience ability teamwork. Crew members and shore personnel results

No	Statements for the ability teamwork	Crew members (%)	Shore personnel (%)
12	There is a sufficient level of communications between crew members	81.54	76.00
13	Crew members have sufficient communication skills	89.23	56.67
17	The information is communicated to all actors during unexpected situations in a timely manner	67.27	64.00
38	Crew members follow a shared training program	70.00	83.33

Most of the crewmembers agree that information and communication systems are not always available and reliable during unexpected situations. Communication is of key importance, especially during unexpected or emergency situations. A quick response to an unexpected situation is often dependant on information from other crew members, hence, it is essential that information and communication flow smoothly between crew members throughout the duration of the situation until control has been regained. Therefore, adequate communication skills amongst all crew members must be guaranteed by the company. In addition, the use of different languages on board has been identified extensively in the literature as a huge communication barrier, hence to avoid communication-related accidents, and since all the maritime communication is held in English, maritime companies should bring all the seafarers to a sufficient level of English in order to address language barriers amongst different nationalities. With regards to the company studied under this case study, the majority of crew is locals; hence, multinational crew concerns do not apply to them.

11.7.4.10 Redundancy Statements

The resilience ability "redundancy" consisted of four statements. The average score of each statement for all crew members within each vessel analysed is provided in Table 11.43, while Table 11.44 provides the average score of each statement for all crew members and shore personnel. Overall, most of the vessels and crew members agree when identifying the statements with a lower score. Thus, the statements with a lower score for redundancy are "Information systems work properly during unexpected situations", and "Crew members have sufficient redundancy (e.g. back-up, substitute, etc.) and diversity in skills when manning levels are compromised". In addition, all statements for shore personnel have been rated over 60.00%.

Table 11.43. RAQ, Statements for the resilience ability redundancy. Crew members result by vessel

No	Statements for the ability redundancy	Vessel 1 (%)	Vessel 2 (%)	Vessel 3 (%)	Vessel 4 (%)	Vessel 5 (%)
18	Information systems work properly during unexpected situations	40.00	40.00	40.00	40.00	60.00
34	Crew members have sufficient redundancy (e.g. back-up, substitute, etc.) and diversity in skills when manning levels are compromised	50.00	40.00	60.00	60.00	60.00
76	By-passing or disabling safety functions / barriers/ defences is actively monitored	80.00	80.00	90.00	80.00	90.00
77	By-passing or disabling safety functions / barriers/ defences is actively controlled and corrected	80.00	80.00	90.00	80.00	90.00

Table 11.44. RAQ, Statements for the resilience ability redundancy. Crew members and shore personnel results

No	Statements for the ability redundancy	Crew members (%)	Shore personnel (%)
18	Information systems work properly during unexpected situations	53.33	63.33
34	Crew members have sufficient redundancy (e.g. back-up, substitute, etc.) and diversity in skills when manning levels are compromised	56.92	68.00
76	By-passing or disabling safety functions / barriers/ defences is actively monitored	81.82	72.00
77	By-passing or disabling safety functions / barriers/ defences is actively controlled and corrected	81.67	72.00

From the responses obtained, it can be observed that participants feel that it will be difficult to respond to unforeseen operational demands with current manning levels. It is common in maritime that manning levels are designed for normal operations and there is lack of redundancy for unusual conditions. This issue may cause more significant concern for long distance shipping companies as fatigue will play more significant role and ship is operating in a remote location which makes it more difficult to transfer more resources on ships whenever needed. Regardless of the nature of operations, results show that additional attention can be given to understand sufficiency of resources during unexpected conditions to achieve more resilient operations. Therefore, insufficient manning levels should be investigated adequately within the company, especially since insufficient manning levels lead other crew members to increase their workload, which often results in fatigue. Fatigue is known as one of the main underlying reasons for many maritime accidents as numerous studies have indicated in the literature (Graziano et al., 2016). It affects both crew members and shore personnel, who often lose their attention to safety when they are under stress or fatigue. Hence, the company should design manning levels which are adequate during all ship operations, especially by taking into account unforeseen operational demands. In addition, crew members perceive that changes in the operation are not well prepared, planned, monitored and controlled. Any changes in the operation, whether they are deliberate or not, may cause unintentional effects on safety. Hence, close attention should be paid to changes with respect to potential negative effects. Therefore, the company should facilitate tools and training for all employees to encourage a share of information in the organization.

11.7.4.11 Fault-tolerance Statements

Lastly, the resilience ability "fault-tolerance "consisted of four statements. The average score of each statement for all crew members within each vessel analysed are provided in Table 11.45, while Table 11.46 provides the average score of each statement for all crew members and shore personnel. Overall, most of the vessels and crew members agree when identifying the statement with the lowest score. Thus, the statement with the lowest score for the resilience ability fault-tolerance is "Crew members work with an up-to-date plan for handling unforeseen operational demands". In addition, all statements for shore personnel have been rated over 60.00%.

Table 11.45. RAQ, Statements for the resilience ability fault-tolerance. Crew members result by vessel

No	Statements for the ability fault-tolerance	Vessel 1 (%)	Vessel 2 (%)	Vessel 3 (%)	Vessel 4 (%)	Vessel 5 (%)
47	Crew members conduct exercises to handle unforeseen operational demands at the ship	40.00	80.00	80.00	80.00	40.00
48	Crew members work with an up-to-date plan for handling unforeseen operational demands	40.00	80.00	80.00	80.00	40.00
49	Crew members are well prepared for unforeseen operational demands	80.00	80.00	80.00	60.00	50.00
52	Crew members are sufficiently capable of handling a variety of disturbances and perturbations	80.00	80.00	80.00	80.00	90.00

Table 11.46. RAQ, Statements for the resilience ability fault-tolerance. Crew members and shore personnel results

No	Statements for the ability fault-tolerance	Crew members (%)	Shore personnel (%)
47	Crew members conduct exercises to handle unforeseen operational demands at the ship	64.62	84.00
48	Crew members work with an up-to-date plan for handling unforeseen operational demands	63.08	80.00
49	Crew members are well prepared for unforeseen operational demands	69.23	70.00
52	Crew members are sufficiently capable of handling a variety of disturbances and perturbations	78.46	73.33

Most of the vessels acknowledge that there is no up-to-date plan for handling unforeseen operational demands. The ability to deal with unforeseen operational demands is a resource that plays an important role when dealing with operations that cannot be fully planned in advance. Thus, the ability to respond effectively to changes in the operational demands can significantly improve the outcomes in this context. The ability to handle unforeseen operational demands is a critical aspect of any resilient company, as it must be ready to respond adequately during unexpected operations. Hence, the company should provide employees with accurate and updated instructions and procedures to be used during any unexpected situation.

11.7.5 **Resilience Score**

Finally, once the RAQ results have been analysed in the previous sections, it is possible to assess the resilience level of the shipping company under study. For this purpose, the final weightings for each resilience ability displayed in Table 11.18 are used to reflect the maximum score that is possible to obtain for each resilience ability. Table 11.47 shows the resilience score that is obtained for each resilience ability from the crew members' perspective. In addition, Table 11.48 provides the resilience score that is obtained for each resilience ability from the shore personnel's perspective.

Table 11.47. Resilience score. Crew members 'perspective

Resilience ability	**Max. Weighting (%)**	**Scores for Crew members (%)**	**Resilience score (%)**
Learning	15.40	68.20	10.50
Responding	6.23	74.48	4.64
Anticipating	5.65	80.26	4.53
Monitoring	10.34	72.93	7.54
Management commitment	16.85	62.54	10.54
Reporting culture	13.35	71.91	9.60
Awareness	12.78	73.85	9.44
Flexibility	3.24	67.81	2.20
Team work	10.60	77.01	8.16
Redundancy	2.85	68.44	1.95
Fault-tolerance	2.71	68.85	1.87
Total	**100.00**	**Total Resilience Score**	**70.97**

From Table 11.47, it is possible to observe that the highest score for crew members in any resilience category was obtained for the ability "anticipating" (80.26%), while the lowest score was received in the "management commitment" resilience ability (62.54%). Overall, the company under analysis from the crew members' perspective has a resilience score of 70.97%. Results over 70.00% indicates that the company under study has an adequate resilience level. However, it is still possible to increase this level, aiming to achieve an excellent resilience level. Hence, a set of recommendations and actions will be proposed in the next sections to raise the resilience level from the crew members' perspective.

Table 11.48. Resilience score. Shore personnel's perspective

Resilience ability	Max. Weighting (%)	Scores for Shore personnel (%)	Resilience score (%)
Learning	15.40	63.87	9.84
Responding	6.23	75.99	4.73
Anticipating	5.65	78.78	4.45
Monitoring	10.34	73.33	7.58
Management commitment	16.85	68.72	11.58
Reporting culture	13.35	70.67	9.43
Awareness	12.78	78.53	10.04
Flexibility	3.24	75.02	2.43
Team work	10.60	70.00	7.42
Redundancy	2.85	68.83	1.96
Fault-tolerance	2.71	76.83	2.08
Total	**100.00**	**Total Resilience Score**	**71.55**

It is noticeable that the highest score for shore personnel in any resilience category was also obtained for the ability "anticipating" (78.78%), while the lowest score was received in the "learning" ability (63.87%). In resilience engineering, the learning ability is not limited to just investigating accidents but also require more systematic approach to capture positive and negative events from both inside and outside the company to ensure that expected levels of resilience are reached. Therefore, it is expected that the majority of companies would not score well in this ability, as the maritime approach is limited to monitoring accidental occurrences reactively. So even though the company under study is known to have an effective proactive learning approach, it was expected to have a low score in the learning resilience ability.

Overall, the company under analysis from the shore personnel's perspective has a resilience score of 71.55%. Although this value is slightly higher than the resilience score that was obtained for crew members, there is still room for improvement.

In addition, Table 11.49 displays the resilience score for each vessel, which was derived from the RAQ results for each vessel displayed in Table 11.24.

Table 11.49. Resilience score. Crew members 'perspective by vessel

Resilience ability	Vessel 1 (%)	Vessel 2 (%)	Vessel 3 (%)	Vessel 4 (%)	Vessel 5 (%)
Learning	10.78	10.12	11.22	11.44	11.00
Responding	4.79	4.59	4.75	4.52	4.52
Anticipating	4.52	4.14	4.90	4.52	4.43
Monitoring	7.24	6.98	8.14	7.76	6.59
Management commitment	9.55	9.55	10.95	7.86	10.39
Reporting culture	9.12	9.79	8.23	9.79	10.16
Awareness	10.22	9.71	10.48	7.67	8.95
Flexibility	2.11	2.19	2.35	2.19	1.98
Teamwork	7.69	6.36	8.75	6.89	8.22
Redundancy	1.78	1.71	2.00	1.85	2.14
Fault-tolerance	1.63	2.17	2.17	2.03	1.49
Total Resilience Score (%)	**69.42**	**67.31**	**73.93**	**66.52**	**69.86**

It can be observed that the resilience score that was obtained for "vessel1", "vessel2", "vessel4"and "vessel5" is under 70.00% which reflects a lower than desirable resilience culture perception on those specific vessels as discussed before. Thus, "vessel4" reached the highest resilience score between the vessels under analyses, nevertheless, its value is still under the desirable 80.00% target.

11.7.6 **Comparison of the Results**

It is important to generate a benchmark amongst results to compare the level of performance amongst various groups as the workplace (i.e. sea or shore) or different vessels.

11.7.6.1 Comparison amongst Crew Members and Shore Personnel

To assess the differences between expected resilience on board (i.e. answer provided by shore personnel) and resilience on board (i.e. answer provided by crew members) a benchmark is created for each resilience ability. In total, 25 questionnaires were completed, from where 15 (60.00%) were completed by crew members and the remaining 10 (40.00%) were completed by shore personnel. The average results of crew members and shore personnel for each resilience ability are shown in Table 11.50. Moreover, Figure 11.4 displays the comparison of the results between crew members and shore personnel.

Table 11.50. Comparison amongst crew members and shore personnel

No	Resilience ability	Average Crew members (%)	Average Shore personnel (%)	Average (%)
RA-1	Learning	68.20	63.87	66.04
RA-2	Responding	74.48	75.99	75.23
RA-3	Anticipating	80.26	78.78	79.52
RA-4	Monitoring	72.93	73.33	73.13
RA-5	Management commitment	62.54	68.72	65.63
RA-6	Reporting culture	71.91	70.67	71.29
RA-7	Awareness	73.85	78.53	76.19
RA-8	Flexibility	67.81	75.02	71.42
RA-9	Teamwork	77.01	70.00	73.51
RA-10	Redundancy	68.44	68.83	68.63
RA-11	Fault-tolerance	68.85	76.83	72.84

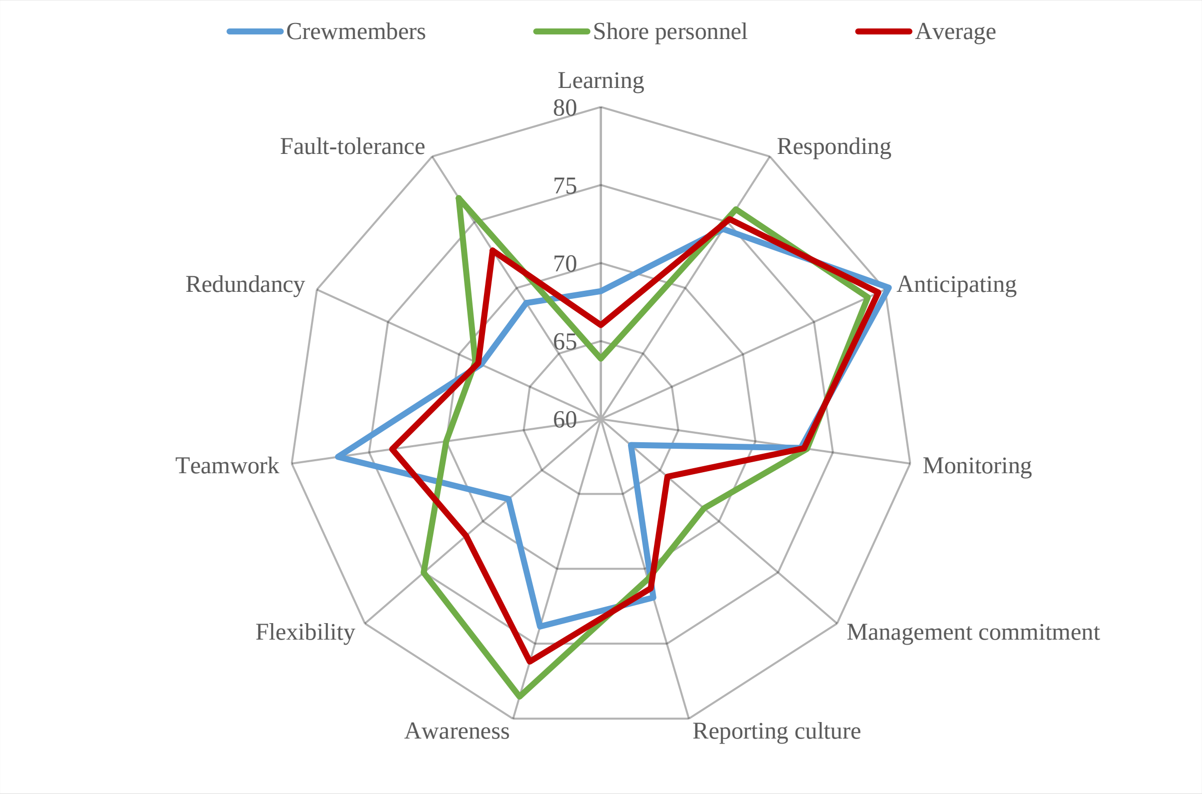


Figure 11.4. Comparison amongst crew members and shore personnel

The resilience attitude and perceptions of crew members are smaller than the average on every resilience ability except the abilities “learning”, “reporting culture”, “anticipating”, and “teamwork”. As the company has a lower resilience score from the crew members' perspective, efforts should be invested to increase the resilience perception within crew members. On the other hand, the resilience attitude and perceptions of shore personnel are mostly higher than the benchmark on the rest of resilience abilities.

11.7.6.2 Comparison amongst Vessels

To assess the differences between resilience perceptions on board different vessels a benchmark is created. The average results of each vessel for each resilience ability are shown in Table 11.51. Moreover, Figure 11.5 displays the comparison of the results between vessels.

Table 11.51. Comparison amongst vessels

No	Resilience ability	Average Vessel 1 (%)	Average Vessel 2 (%)	Average Vessel 3 (%)	Average Vessel 4 (%)	Average Vessel 5 (%)	Average (%)
RA-1	Learning	70.00	65.71	72.86	74.29	71.43	70.86
RA-2	Responding	76.88	73.75	76.25	72.50	72.50	74.38
RA-3	Anticipating	80.00	73.33	86.67	80.00	78.33	79.67
RA-4	Monitoring	70.00	67.50	78.75	75.00	63.75	71.00
RA-5	Management commitment	56.67	56.67	65.00	46.67	61.67	57.33
RA-6	Reporting culture	68.33	73.33	61.67	73.33	76.11	70.56
RA-7	Awareness	80.00	76.00	82.00	60.00	70.00	73.60
RA-8	Flexibility	65.00	67.50	72.50	67.50	61.25	66.75
RA-9	Team work	72.50	60.00	82.50	65.00	77.50	71.50
RA-10	Redundancy	62.50	60.00	70.00	65.00	75.00	66.50
RA-11	Fault-tolerance	60.00	80.00	80.00	75.00	55.00	70.00
	Average	69.26	68.53	75.29	68.57	69.32	

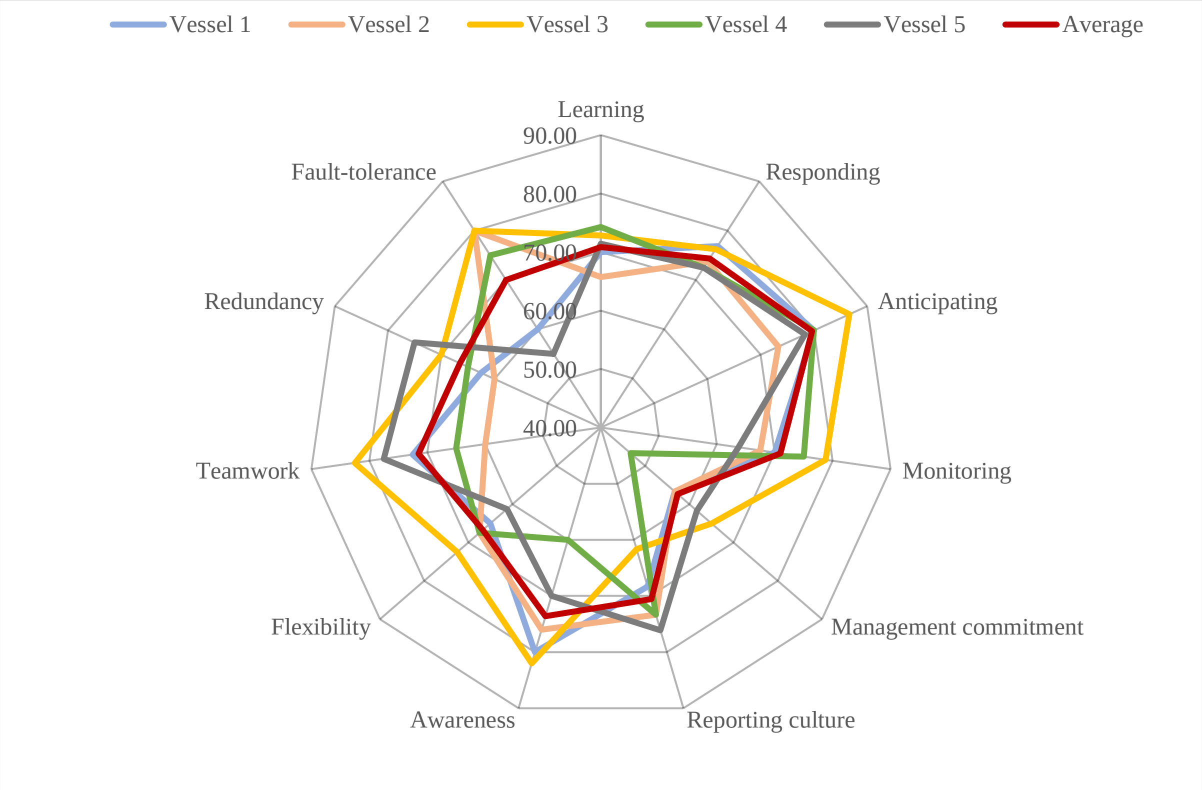


Figure 11.5. Average amongst vessels

It is observable that the resilience attitude and perceptions vary amongst vessels. For instance, “Vessel1” has a smaller perception than the average on every resilience ability except the abilities “responding”, “anticipating”, “awareness”, and “teamwork”.

On the other hand, “Vessel3” has a higher resilience perception than the average on every resilience ability except learning and reporting culture. In addition, “Vessel4” has a higher resilience perception than the average on every resilience ability except anticipating and redundancy. Lastly, “Vessel5” has also a smaller resilience perception than the average on every resilience ability except “reporting culture”. Thus, the average value for the resilience ability management commitment (57.33%) indicates an inadequate resilience perception of this ability.

11.7.7 **Recommendations for Resilience Improvement**

The first part of the resilience assessment framework has been successfully conducted in the shipping company via the collection and analysis of the questionnaires. The resilience assessment identified several areas and statements that require further improvements to enhance overall resilience within the company. The major problems identified within the passenger company under this case study together with possible recommendations for improvement are given below:

1. Combination of statements No 6 and 7: “Crew members use success stories from outside the company” and “Crew members use incident/accident information from other companies”

Most of the answers collected from both crewmembers and shore personnel acknowledged that crew members do not utilize stories or information about incidents and accidents from other parties. The manifestation of potential events in real occurrences constitutes only a small percentage of the potential events that might occur. Thus, it is important to learn as much as possible not only from the company's own experiences but also from other companies' successes and failures. Since the previous information can be mostly accessed online through near-miss reports, or it can be requested from maritime companies, it should be utilized as a resource to avoid potential negative outcomes. Nowadays accessibility of information knows no borders, hence, there is no excuse for avoiding to learn from other companies' experiences.

Suggested solution: The company should encourage employees to utilize both success stories and incidents and accident information from outside the company as a learning source to prevent their own accidents in the company Crew members normally do not accidental information themselves. Therefore, the company should filter accidental information and inform their crew members about potential lessons learn from external sources which clear contextual information about the incident, its development and consequences so that crew can appreciate that this is a real accident and not just an additional training topic that the company has identified.

2. Statement No 8: “There is a system in place for crew members to share successes and failures”

Most of the answers collected from both crewmembers and shore personnel indicated that apparently there is not a system in place for crew members to share successes and failures. A higher percentage of the time the vessel is safe so it is possible to obtain more useful information when focusing on the positive events and by learning from them than when only recording and sharing negative events. Nowadays, most companies have collected their own data and developed their own databases, which include information obtained from positive events, for example, near-miss accidental data. Thus, the aforementioned information is normally accessible to all public, as multiple near-misses reports are accessible online.

Suggested solution: The company should provide a system for crew members to share experiences onboard. Thus, it should also provide crew members with adequate training regarding how to report information through this system.

3. Statement No 13: “Crew members have sufficient communication skills”

Most of the answers collected from the shore perspective acknowledged that inadequate communication skills are an important issue within the company. Effective communication is a fundamental resource to achieve outcomes of quality, especially during unexpected or emergency situations. A quick response to an unexpected situation is often dependant on information from other crew members, hence, it is essential that information and communication flow smoothly between crew members throughout the duration of the situation until control has been regained. Thus, good communication is obtained when all crew members have good communication skills and when there is a proper definition of the people responsible for communicating relevant information in the company. Moreover, the use of different languages on board can be seen as a threat within the company, as it might create a communication barrier between different crew members on board, particularly during an unexpected situation, in which a lack of communication, coordination, and understanding between crew members can quickly derive into a negative outcome.

Suggested solution: The company should provide training courses and it should conduct simulation exercises in order to enhance the ability of crew members to communicate information in an effective way, especially during critical situation (i.e. unexpected or emergency situations).

4. Combination of statements No 15 and 18: "Information and communication systems are always available and reliable during unexpected situations" and "Information systems work properly during unexpected situations"

Most of the answers collected indicated that information and communication systems are not available and reliable during unexpected situations. Adequate knowledge about how all the information and communication systems work and their interactions is important in a company, including knowledge about design assumptions and operational conditions. This knowledge provides flexibility to the company, as it facilitates insight into how systems may fail and the potential consequences.

Suggested solution: The company should provide training regarding how information and communication systems work. Thus, the company should provide redundant information and communication systems to ensure that these systems are always available, especially during unexpected situations, in which they are needed the most.

5. Statement No 34: "Crew members have sufficient redundancy (e.g. back-up, substitute, etc.) and diversity in skills when manning levels are compromised"

Most of the answers collected from both crewmembers and shore personnel indicated that crew members lack redundancy and skills when manning levels are compromised. Thus, most vessels and shore personnel feel that there are not enough crew members available to respond appropriately to unforeseen operational demands. Insufficient manning levels should be investigated carefully within the company, especially since insufficient manning levels lead other crew members to increase their workload, which often results in fatigue. Thus, fatigue is known as one of the main underlying reasons for many maritime accidents as numerous studies have indicated in the literature. It affects both crew members and shore personnel, who often lose their attention to safety when they are under stress or fatigue. Thus, by performing simultaneously multiple tasks, crew members reduce their awareness and they cannot perform their own tasks adequately.

Suggested solution: The company should guarantee that manning levels are always adequate during all ship operations, but especially during unforeseen operational demands.

6. Statement No 48: "Crew members work with an up-to-date plan for handling unforeseen operational demands"

Most of the answers collected from crewmembers showed that there is no up-to-date plan for handling unforeseen operational demands. The ability to deal with unforeseen operational demands is a resource that plays an important role when dealing with operations that cannot be fully planned in advance. Thus, the ability to respond effectively to changes in the operational demands can significantly improve the company resilience in this context. The ability to handle unforeseen operational demands is a critical aspect of any resilient company, as it must be ready to respond adequately during unexpected operations.

Suggested solution: The company should organize regular meetings or seminars, in which it provides employees with accurate and updated instructions and procedures to be used during any unexpected situation.

7. Statement No 51: "Crew members have sufficient resources to respond to unforeseen operational demands"

Most of the answers collected from vessels acknowledged that crew members do not have sufficient resources to respond to unforeseen operational demands. The ability to deal with unforeseen operational demands is a resource that plays an important role when dealing with operations that cannot be fully planned in advance.

Suggested solution: The company should have the willingness and ability to appropriately resource all operations, especially by considering unforeseen operational demands.

1. Statement No 61: "Risk information can be easily understood by all crew members"

Most of the answers collected from vessels indicated that risk information is not accessible to all crew members. The access and adherence to risk and safety operations are of paramount importance to achieve the appropriate level of safety in a shipping company. Although the shore personnel mostly think that crewmembers have access to risk information, it seems that there is a lack of communication amongst crew members, of which shore personnel is not aware.

Suggested solution: The company should facilitate employees' appreciation and knowledge about risk on an individual and organizational level, while also encouraging all crew members to share risk information since a lack of risk awareness can result in incidents or accidents in the company.

2. Combination of statements No 64, 65, 66, and 68: "Any changes in the operation (e.g. technological, organizational, external) are…well prepared/well thought out and planned/actively monitored for potential negative effects/well directed and controlled"

Most of the answers collected from vessels revealed that crew members perceive that changes in the operation are not well prepared, planned, monitored and controlled. Any changes in the operation, whether they are deliberate or not, may cause unintentional effects on safety. Hence, close attention should be paid to changes with respect to potential negative effects.

Suggested solution: The company should facilitate tools and training for all employees to encourage sharing information in the organization.

3. Statement No 72: "Crew members make well-deliberated trade-offs between safety and other goals"

Most of the answers collected from shore personnel revealed that crew members are not able to make well-deliberated trade-offs between safety and other goals. For example, the trade-off between safety and efficiency in one which every resilient company must manage effectively. Therefore, resilient companies are those that put safety first or which do not see efficiency and safety as mutually exclusive.

Suggested solution: The company should organize regular meetings or seminars to raise the level of safety awareness within the company.

11.8 Chapter Summary

This chapter applied the six phases of the proposed resilience assessment framework to a real case study on a passenger shipping company.

Chapter 12 will include discussions and recommendations for future research.

12 DISCUSSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

12.1 Overview

This chapter first provides in Section 12.2 a brief review of this research study, demonstrating the originality of the research outputs. Second, a description of the aim and objectives that have been completed through this research study is provided in Section 12.3. Thus, the limitations of this research are explained in Section 12.4. Finally, Section 12.5 provides a set of recommendations for future research.

12.2 Brief Review of the Research Study and Its Originality

The occurrence of a shipping accident usually derives into a high social impact, triggering an automatic response from the maritime authorities, which is usually translated into the development and implementation of new safety measures. As a result, adequate accident reporting practices have become indispensable within the maritime sector, and therefore, they are often enforced with laws. However, inconsistent methods followed and inaccurate training provided to report accidents adequately, and the complexity of identifying all the variables involved in a specific accident make it extremely challenging to learn lessons from past accidents. Overall, accidents are complex processes, in which usually there is not a single factor solely responsible for the accident outcome. Hence, there is not a clear answer regarding which specific set of factors are triggering an accident. This situation creates a barrier for enhancing safety, as identified risk control options cannot be effectively linked back to accident contributors. However, if the accident-contributing factor could be identified and addressed properly, efforts could be focused on developing alternative solutions to address these factors efficiently, and therefore the accidents' rate might be reduced.

Evidently, by addressing the aforementioned accident-contributing factors, safety can be enhanced to reduce the number of maritime accidents. However, it should be recognized that no system is totally safe. As systems are evolving and developing into structures that are more complex, the traditional approach to safety management, which is based on the application of risk assessment techniques, which can deal only with a single failure at a time, present some limitations to cope with these new and advanced systems. Therefore numerous authors have extensively justified the need for a resilience approach to safety, as it is challenging to adequately address complex, dynamic and unstable systems within current safety management approaches. Hence, approaching resilience-engineering concepts in order to assess the resilience level in an organization can help to identify weaknesses and areas of improvement, in which efforts can be focused on. Thus, by reinforcing an organization's resilience culture, it might be possible to prevent and/or mitigate accident consequences.

In Chapter 1 and Chapter 2 of this research study, the specific issue of Human Factors (HFs) contribution to accidents was highlighted, and a critical literature review was provided which allowed to identify the research gaps.

After an insightful literature review was conducted, the next step included data collection, aiming to identify human contributing factors from past maritime accidents. Hence, Chapter 5 examined various accident databases to identify the most suitable data set for this research. In addition, a set of descriptive statistical analyses and hypothesis tests were conducted on the selected accident database, aiming to investigate the relationship between various variables from the database. Moreover, the most influential HFs from past maritime accidents were identified. Furthermore, analysis of the aforementioned database revealed that the selected human contributing factors provided as responsible for the outcome of certain accidents were recorded inconsistently, lacking a clear description. Therefore, Chapter 6 developed a set of more generic and better-defined HFs groups by applying a card-sorting technique.

Moreover, Chapter 7 described the overall framework of the Marine Accident Learning with Fuzzy Cognitive Maps (MALFCMs) method, which was proposed with the aim to establish weightings for contributing factors involved in past maritime accidents. Thus, Chapter 8 applies the above-mentioned MALFCMs approach partially, to demonstrate how it is possible to apply the MALFCMs method by only relying on historical data. In addition, Chapter 9 conducts a MALFCMs full case study on the more generic HF groups obtained in Chapter 6.

Finally, Chapter 10 describes the overall resilience assessment framework, which is proposed with the aim to assess the resilience level in a shipping company, based on how the company performs on certain resilience abilities, which are linked to common human causes of accidents. Thus, Chapter 11 applies the above resilience assessment framework to a real case study, by assessing the resilience level in a specific passenger shipping company.

12.3 Achievement of Research Aim and Objectives

The aim of this research study is to develop a theoretical understanding and a practical framework to describe how HFs in maritime accidents can more cleverly be identified and linked to the resilience engineering abilities, which will allow assessing the resilience level in a shipping company. Thus, the overall framework that was developed within this research study is focused on fulfilling the aforementioned aim. Therefore, the final output of this research is a framework that allows assessing the resilience level within a maritime system, based on how the system performs on certain resilience abilities, which are linked to common human causes of accidents. By assessing the resilience level, it will be possible to identify weaknesses in the system and propose measures to overcome these weaknesses and increase overall safety.

In addition, the specific objectives that were defined in Chapter 3 were achieved as follows:

- To critically review the literature relevant to the current maritime safety regime and resilience engineering theory in order to identify the shortcomings of the current research and available methods.

An extensive critical review on safety management and resilience engineering (Chapter 2) was not only conducted in maritime but also in other sectors such as health, aviation or chemical industries. It was found that the current safety management approach in the maritime industry presents some limitations, as summarized in Chapter 2. Thus, as maritime systems are complex, it was identified that a resilience approach is needed to deal with the actual level of systems' complexity in order to guarantee maritime safety.

- To capture developed resilience models that could be applied to increase safety within the maritime sector.

To increase safety in any organization, the value of having an accident model has been recognized for many years. Thus, an extensive review of accident causation models was provided in Chapter 2 starting from the simple and complex linear models. Nevertheless, the limitations of the above models were summarised, highlighting the need for applying accident models that can deal with the complexity of current maritime systems (i.e. resilience models). Henceforth, a review of available accident causation models based on resilience engineering concepts (i.e. Systems-Theoretic Accident Model and Processes (STAMP) and the Functional Resonance Analysis Method (FRAM)) was also performed.

- To identify, modify or develop a suitable method that can cleverly measure the HFs contribution to maritime accidents.

It has been established in previous chapters that shipping accidents are complex processes, in which usually there is no unique accident contributing factor solely responsible for the accident outcome. Thus, a maritime accident is often the result of the combination of certain contributing factors. Nevertheless, due to the vagueness and data unavailability often associated with maritime accidents, maritime causalities occur in a fuzzy environment, hence, a method that can deal with both, complex scenarios with multiple contributing factors involved, and fuzzy data needs to be applied. The literature review that has been conducted in this research study revealed that the Fuzzy Cognitive Maps (FCMs) method is suitable to deal with the above issues. Thus, this research study is concerned with modelling the various combinations of HFs, and the extent to which these factors influence accidents within the maritime sector, and FCMs allow modelling such causal fuzzy relationships between variables as indicated by the literature. Therefore, a detailed review of the FCMs method was conducted in Chapter 2, including a specific section to justify the adoption of FCMs as a modelling approach. Nevertheless, it was also identified from the above literature review that traditional FCMs present the main limitation, which lays in the uncertainty related to each expert's response. As a result, an FCM can equally encode the experts' lack of knowledge. Therefore, the reliability of a traditional FCM is linked to the experts' knowledge, background, and familiarity with the topic that is being addressed. Thus, in order to overcome the above disadvantage of the traditional FCMs method, this research study has developed a method for Marine Accident Learning with Fuzzy Cognitive Maps (MALFCMs) (Chapter 7). Within this new approach, each FCM is developed through establishing relationships between factors from past accident experiences, combining the results with expert opinion. Therefore, the results from the MALFCMs technique might be considered more objective, as this new approach overcomes the main disadvantage of fuzzy cognitive maps (i.e. the subjective results and knowledge deficiencies between experts).

- To collect historical-accident data and to perform statistical analyses, aiming to identify the main data features (e.g. the number of accidents per ship type or vessel categories that are prone to develop an accident).

After a detailed literature review on the areas of resilience and resilience engineering, accident models, HFs and FCMs was conducted in Chapter 2, the next logical step was to obtained historical accident data to apply above mentioned MALFCMs method. Hence, first, a comparison was provided amongst various accident databases, aiming to select the most suitable historical accident database for the purposes of this research study. Thus, the MAIB database was selected as discussed in Chapter 5. Once the aforementioned MAIB database was selected for pursuing this research study, a set of descriptive statistical analyses was performed to describe and analyse the content of the MAIB database, discussing also the validity of the statistical analysis results that were obtained. In addition, the second set of statistical analyses were performed, aiming to test the various null hypothesis (Chapter 5).

- To perform additional analyses on the historical accident data in order to define a set of specific human factors that are contributing to maritime accidents.

Further analysis of the MAIB database revealed a lack of consistency when selecting and recording which human contributing factors are responsible for the outcome of certain shipping accidents. Thus, the aforementioned contributing factors often lacked a clear description. Therefore, it was identified the need to conduct a reduction and redefinition of the HFs contained within the MAIB database. Thus, within Chapter 6, a two-stage approach was presented: first, an open card-sorting case study was organized to group the HFs extracted from the MAIB accident database for the period 2011-2016, in which the results were qualitatively and quantitatively analysed. Second, a hybrid card-sorting method was utilized to fully achieve the classification of h HFs. Thus, expert analysis supported the proposed classification.

- To conduct activities to collect more information and complete gaps in HF accident data (e.g. organise workshops to capture expert judgment).

After historical accident data was obtained and further analysed to define a new set of HFs (Chapter 6), the next logical step was to collect expert opinion. Thus, by collecting expert opinion, it will be possible to apply the aforementioned MALFCMs approach to obtain the weightings for each human contributing factor. Therefore, a questionnaire was developed, which included two sets of questions. "Type A" questions were asked to establish how influential a particular contributing factor would need to be in order to have a minimum contribution to a maritime accident. The choices given were "None or very very low", "Very low", "Low", "Medium", "High", "Very high", and "Very very high". From the response to "Type A" questions, it will be possible to determine not only whether a contributing factor is considered influential in the scenario being analysed but also the degree of influence. Thus, "Type B" questions were asked to determine what would be the level of the effect on the contributing factor Cj, given a change in a particular contributing factor Ci. The choices given were "None", "Very small", "Small", "Moderate", "Big", "Very big", and "Very very big".

- To apply the above-mentioned method, which can cleverly measure the HFs contribution to maritime accidents.

To test the aforementioned MALFCMs method, two case studies were conducted. First, the first stage of the MALFCMs method was applied to a case study to demonstrate that the MALFCMs method can be applied by only relying on historical accident data (Chapter 8). Thus, a discussion was provided to examine if the findings obtained were in line with previous studies in the literature, aiming to demonstrate if the MALFCMs method can produce reliable results. In addition, a second case study was conducted to demonstrate the overall MALFCMs method (Chapter 9), in which the four major stages of the MALFCMs approach were applied to the selected case study. Thus, the validation of the MALFCMs method was achieved by performing sensitivity analysis and by comparing the results with the findings from previous studies, aiming to discuss and analyse the reliability in the results.

- To identify a specific strategy that allows linking together resilience abilities and HFs.

As discussed above, the aim of this research study was to link human contributing factors and resilience engineering abilities, in order to be able to assess the resilience level within a maritime system. Therefore, a resilience assessment framework was developed in Chapter 10 to fulfil the aforementioned aim. The so-called resilience assessment framework consists of six phases. The first phase aimed to identify and quantify the importance of those HF threats that could adversely affect the performance and safety onboard by applying the MALFCMs method. The second phase included the identification of major resilience abilities. Moreover, the third phase aimed to establish a link between HF threats and resilience abilities. Hence, a questionnaire was developed with the objective of identifying which resilience abilities could help to prevent certain HFs identified from past maritime accidents. Thus, the aforementioned questionnaire was created to overcome the lack of data availability, as there were no previous studies trying to establish a similar relation between HFs and resilience abilities. Regarding the questionnaire structure, two types of closed questions were included. The first type included general questions related to the background of each participant (i.e. years of experience, position, and level of knowledge regarding the areas of HFs, resilience, shipping safety, shipping operations, and accident investigations). The second type typically asked to select those resilience abilities that could help to prevent and/or reducing the negative effect of a specific human accident-contributing factor. In addition, the fourth phase explained the procedure that was followed to establish weightings for all resilience abilities. The fifth phase included the development and distribution of the Resilience Assessment Questionnaire (RAQ). Lastly, the sixth phase comprised the analysis of the RAQ results, the establishment of a resilience score, and recommendation for resilience improvement.

- To utilise the SEAHORSE resilience assessment framework as the initial concept to develop a more robust framework to assess resilience level of a company.

This research study extended the SEAHORSE resilience assessment framework to capture additional resilience abilities, creating an enhance resilience assessment framework.

- To conduct a case study in order to test the developed framework in a real shipping company.

To test the abovementioned resilience assessment framework, a case study was conducted to assess the resilience level within a passenger shipping company (Chapter 11).

- To identify limitations and future research opportunities.

Finally, the limitations of this research study were identified and included in Chapter 12 together with a set of recommendations for future research.

12.4 Limitations of the Research Study

Quantification of first, the HF contribution to maritime accidents and second, the resilience level in a shipping company is a complicated issue. Thus, when the estimated values are subjective to human response then it becomes even more complex. Hence, this research study includes assumptions, practical limitations or challenges experienced, which are described below as follows:

- For the purpose of the research, 2533 vessels involved in accidents reported in the Marine Accident Investigation Branch (MAIB) between 1992 and 2016 have been utilized. Nevertheless, the aforementioned database only includes information about human accident contributing factors that were involved in 129 accidents for the period 2011-2016, as before this period it was not a common practice to record the aforementioned information. Hence, for the application of the MALFCMs method, only a period of five years has been taken into account. Furthermore, MAIB database only investigates marine accidents involving UK vessels worldwide and all vessels operating in UK territorial waters. Hence, as the database utilised only includes data coming from UK, this study only identifies those HFs that may reflect UK priorities.

- In addition to the five years data limitation, inaccurate data collection procedures by accident investigators was also identify as an important limitation in this study. The taxonomy that MAIB database is utilising is known as the European Marine Casualty Information Platform (EMCIP) taxonomy, which provides a list of contributing factors from where to pick those HFs contributing to a maritime accident. However, no definition is provided for each contributing factor in the aforementioned EMCIP taxonomy. Some of these HFs are self-explanatory (e.g. inadequate training program) but some other factors might be more open to misinterpretation (e.g. Cowboy attitudes, horseplay). Hence, the lack of a proper definition for each HF may mislead accident investigators from selecting the right HFs involved in an accident, and therefore, this can also mislead the weightings obtained from the historical data analysis stage in the MALFCMs approach, as they are the result of utilising the data reported in MAIB database by accident investigators.
- Due to practical reasons, only four responses were collected to the questionnaire for sorting the initial ninety-four HFs from the MAIB database into a more concise but comprehensive set of HFs categories. The above-mentioned questionnaire included sorting numerous HFs, which could be a tedious and time-consuming task to complete. There was a possibility to distribute the above questionnaire at a larger scale, nevertheless, that possibility also includes additional risks, as participants might find the questionnaire excessively long and respond to it dishonestly. Therefore, only four responses were collected but special measures were provided to ensure the reliability of this data. The first two sets of answers were collected through a workshop, in which participants were assisted to ensure that they understood the meaning of each HF. Although this activity could be carried out individually by using a card-sorting software (e.g. OptimalSort software), it was decided to create two groups of participants and to use real cards. Hence, this session would be more beneficial as it would allow each member to interact with the group, sharing his or her ideas to classify each HF, and making the task less tedious. In addition, the last two sets of answers were collected from experts in the use and development of the MAIB database. To guarantee that they will commit to the task by providing reliable results, a skype meeting was organized with one of the experts to explain the objectives and the importance of this study. In addition, various emails were exchanged through this study with the second expert also to guarantee her commitment to providing reliable results.

- In numerous stages of this study (e.g. card-sorting application, expert opinion stage in the MALFCMs approach, etc.) an expert based approach was followed to generate data. In the aforementioned cases, the number of experts involved was limited, which could have also been improved.
- The RAQ that was developed during a workshop as part of the resilience assessment framework was applied to a shipping company, where 25 responses were collected. Due to the low number of responses, it was not possible to perform a factor analysis for dimension reductions to decrease the number of variables presented in the questionnaire.
- The resilience assessment framework was only tested on one shipping company. By testing it in additional shipping companies it would be possible to benchmark different companies and compare their resilience scores to identify the most resilient companies. Enhancing resilience levels requires an excessive amount of time, and therefore, the full potential of the resilience assessment framework will not be visible within the duration of this research study.
- Finally, when assessing resilience on board, more factual information could have been collected. For instance, the researcher could have conducted interviews and identified policies addressing safety and resilience in the company to further assess resilience culture and its implementation. Moreover, the approach presented allows to assess resilience in a company at a macro level but, it does not cover assessing it at micro level. In other words, within this study it was not possible to demonstrate this approach at functional level, focussing on a specific operation or task.

12.5 Recommendations for Future Research

Based on the limitations given in the previous section, recommendations for future research are listed below:

- An updated MAIB database can be utilized to include more accidents in which information about human accident contributing factors is recorded.
- As a result of the card-sorting technique that was applied to the MAIB accident database, high-level HF categories were developed and presented in this research study which covers a great majority of HFs concerns involved in accidents. Hence, future studies can utilize the proposed HF categories to make significant safety contributions.

- The MAIB database applies the same accident nomenclature that the European Marine Casualty Information Platform (EMCIP). Therefore, it would be possible to replicate this research study with data from another European country and compared the results.
- The RAQ was applied to a shipping company, where only 25 responses were collected. The aforementioned questionnaire should be distributed to a larger scale in order to obtain sufficient data to reduce the questionnaire size by performing factor analysis. The reduced RAQ should be used in future resilience assessment studies. Moreover, the RAQ can be tested for the redundancies in through various statistical approaches, and a more concise RAQ can be achieved.
- The resilience assessment framework was tested on a passenger shipping company. A reasonable next step would be to re-evaluate the same company after a sensitive period of time to observe if the company has implemented the provided recommendations.
- The resilience assessment framework could be also applied to other non-passenger shipping companies (e.g. tanker companies, long distance shipping companies, etc.)
- The aforementioned resilience assessment framework was only tested on one shipping company. The framework should be promoted to other shipping companies. Thus, by testing it in additional shipping companies it would be possible to benchmark different companies and compare their resilience scores to identify the most resilient companies.
- As a future research, it could be possible to investigate the Safety Management System (SMS) of a shipping company, and try to integrate the resilience assessment into the company´s SMS. Furthermore, and Human-Machine Interface (HMI) could be also developed to make companies use the proposed resilience framework seamlessly.
- Finally, the qualitative survey approach adopted in the resilience assessment framework could be complemented by collection of data about leading and lagging indicators of safety, which may increase the quality of the results obtained.

12.6 Chapter Summary

First, this chapter provided a review of the research study and its originality. Second, the main contributions of this research study were highlighted. In addition, a description of the aim and objectives that have been completed through this research study was also provided, together with the limitations of this research. Finally, a set of recommendations for future research was provided.

Chapter 13 is highlighting the final conclusions extracted from this research study.

13 CONCLUSIONS

13.1 Overview

This chapter summarises on Section 13.2 the overall conclusions of this research study.

13.2 Concluding Statements

The research conducted in this thesis provides a substantial amount of information for shipping organizations in order to enhance resilience and safety levels. Thus, this study contributed to three different areas of research:

Firstly, an analysis of the MAIB database revealed a lack of consistency when selecting and recording which human contributing factors are responsible for the outcome of certain shipping accidents. Thus, a reduction and redefinition of the HFs contained within the MAIB database was performed by applying a card-sorting technique, in which a two-stage approach was presented: first, an open card-sorting case study was organized to group the HFs extracted from the MAIB accident database for the period 2011-2016, in which the results were qualitatively and quantitatively analysed. Second, a hybrid card-sorting method was utilized to fully achieve the classification of HFs. Thus, expert analysis supported the proposed classification. As a result of the above-mentioned study, a new list of eleven HF was proposed, that can be listed as:

- Commercial pressure
- Lack of training
- Effect of environmental and external factors
- Safety culture
- Improper design, installation, and working environment
- Safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)
- Inadequate leadership and supervision
- Safety management system: Substandard monitoring
- Lack of communication and coordination
- Unprofessional behaviour
- Lack of, improper or late maintenance

Second, the contribution of HFs into accidents is difficult to quantify as there is a lack of an adequate technique that allows a systematic quantification of the importance of each contributing factor when accidents occur. Therefore, a new Fuzzy Cognitive Map (FCM)-based technique known as Marine Accident Learning with Fuzzy Cognitive Maps (MALFCMs) was developed and applied to various case studies to obtain the weighting of each contributing factor. The main advantage of the MALFCMs approach relies on its capability to integrate information obtained from real occurrences and expert judgment; hence, the results can be considered more objective, overcoming the main disadvantage of traditional FCMs by eliminating or controlling the subjectivity in results.

Finally, it is observable that the maritime sector is falling behind in terms of implementing resilience approaches. The principles of safety are addressed in a compliance driven manner, and the lessons from accidents and near misses are not effectively integrated in a proactive way to avoid future accidents. Therefore, there is a need for a detailed approach that assesses and quantifies the resilience levels in a company in order to identify shortcomings in safety, before accidents occur. Hence, in this research, the resilience framework that was created and implemented in a shipping company for the first time. The created resilience assessment framework allows first to measure the resilience level in a shipping company by providing a resilience score, which can be benchmarked with other shipping companies. Second, it allows identifying areas for improvement to increase the company resilience level. Finally, it provides a set of recommendations for resilience improvement that may serve the company for future research.

13.3 Chapter Summary

This chapter summarised the concluding comments of the author about this research study.

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APPENDICES

A EXPERT OPINION COLLECTED FOR THE OPEN CARD-SORTING CASE STUDY

Table A.1. Group1: Results from the open card-sorting case study

New HF groups created	HFs
Communication	HF42, HF43, HF55, HF60, HF83
Supervision on-board ship	HF16, HF19, HF22, HF37, HF46, HF57, HF84
Technical and installation	HF1, HF9, HF10, HF17, HF20, HF35, HF44, HF47, HF61, HF68
Company issue and economic pressure	HF8, HF39, HF49, HF63, HF66, HF72, HF77, HF78, HF81, HF92
Regulations (mainly International Safety Management (ISM))	HF7, HF14, HF18, HF21, HF38, HF40, HF41, HF62, HF67, HF70, HF73, HF79, HF88, HF90
Lack of training and competence	HF11, HF12, HF13, HF15, HF23, HF27, HF36, HF45, HF52, HF54, HF56, HF80, HF91, HF93, HF94
Behaviour	HF2, HF6, HF24, HF26, HF29, HF30, HF33, HF34, HF48, HF58, HF64, HF65, HF71, HF76, HF82, HF87
Safety culture	HF3, HF4, HF5, HF25, HF28, HF31, HF32, HF50, HF51, HF53, HF59, HF69, HF74, HF75, HF85, HF86, HF89

Table A.2. Group2: Results from the open card-sorting case study

New HF groups created	HFs
External factors (weather condition, visibility, etc.)	HF80, HF87
Restricted fairway, port congestion or heavy traffic	HF77, HF88
Not compliance	HF73, HF75
Fatigue and workload	HF19, HF57, HF86
Improper or lack of maintenance	HF24, HF30, HF47
Commercial pressure	HF8, HF39, HF72
Lack of equipment and Personal Protective Equipment (PPE)	HF28, HF44, HF78
Lack of physical and mental fitness	HF21, HF63, HF64, HF65
Lack of or improper supervision	HF25, HF46, HF83, HF84, HF85
Improper design	HF1, HF9, HF10, HF12, HF29, HF53, HF61
Substandard monitoring (negligence on monitoring)	HF2, HF3, HF17, HF41, HF49, HF68, HF93, HF94
Lack of communication and coordination	HF4, HF7, HF16, HF26, HF42, HF43, HF55, HF60, HF92
Lack of training	HF15, HF23, HF27, HF35, HF36, HF45, HF52, HF54, HF56, HF69, HF81
Unprofessional behaviour	HF6, HF20, HF33, HF48, HF50, HF51, HF58, HF59, HF71, HF76, HF79, HF82, HF89
Improper or deviation from procedures	HF5, HF11, HF13, HF14, HF18, HF22, HF31, HF32, HF34, HF37, HF38, HF40, HF62, HF66, HF67, HF70, HF74, HF90, HF91

Table A.3. Group3: Results from the open card-sorting case study

New HF groups created	**HFs**
Commercial environment	HF8, HF72
Crewing policies	HF21, HF22, HF42, HF55, HF60, HF71, HF82
Environment-external	HF77, HF80, HF87, HF88
Leadership and supervision	HF4, HF16, HF19, HF25, HF26, HF37, HF38, HF39, HF46, HF83, HF84, HF94
Maintenance	HF17, HF30, HF47, HF49, HF66
Manning levels	HF31, HF57, HF86
Regulatory	HF74, HF75
Safety culture-ship's staff	HF6, HF20, HF23, HF41, HF48, HF51, HF54, HF56, HF58, HF64, HF73, HF76, HF89
Safety culture-shore management	HF2, HF18, HF33, HF40, HF50, HF63, HF85, HF93
Safety management system	HF3, HF5, HF7, HF13, HF14, HF27, HF28, HF32, HF43, HF59, HF62, HF65, HF67, HF70, HF90, HF92
Ship design and approvals	HF1, HF9, HF10, HF11, HF35, HF44, HF53, HF61, HF68
Training	HF15, HF24, HF36, HF45, HF52, HF69, HF81
Working environment	HF12, HF29, HF34, HF78, HF79, HF91

Table A.4. Group4: Results from the open card-sorting case study

New HF groups created	**HFs**
Design and equipment	HF1, HF9, HF10, HF12, HF20, HF28, HF29, HF56
Environs	HF77, HF80, HF87, HF88
Person	HF6, HF7, HF23, HF24, HF25, HF37, HF38, HF39, HF45, HF48, HF51, HF52, HF54, HF55, HF58, HF64, HF65, HF71, HF76, HF89, HF91
Process	HF2, HF3, HF4, HF8, HF11, HF14, HF17, HF18, HF19, HF21, HF22, HF27, HF30, HF31, HF32, HF35, HF46, HF47, HF49, HF50, HF53, HF57, HF59, HF61, HF62, HF63, HF66, HF72, HF78, HF79, HF82, HF83, HF86, HF93, HF94
Process-communication	HF5, HF13, HF16, HF26, HF33, HF42, HF43, HF44, HF60, HF67, HF68, HF70, HF84, HF90
Process-training	HF15, HF36, HF69, HF81, HF92
Regs	HF34, HF40, HF41, HF73, HF74, HF75, HF85

B WORKSHOP DESCRIPTION FORM

The objectives set for this workshop are as follows:

a) Communicate the data that we have collected from the database i.e. human contributing factors into maritime accidents.
b) Classify the aforementioned human factors into smaller categories by means of the card-sorting method.
c) Identify strategies for improvement.

To achieve these objectives, the following activities are planned for today workshop:

- Invite experts with diverse maritime backgrounds to the workshop.
- Provide an initial document (i.e. this document) regarding the workshop description to participants, in order to give a better understanding of the workshop objectives and structure.
- Deliver an explanatory presentation about workshop objectives.
- Encourage participants to introduce themselves briefly, in order to identify their background.
- Split the participants into groups to sort an initial list of human factors (HFs descriptive cards will be provided for this activity).
- Find out suggestions and participants' opinions about the workshop.

C WORKSHOP FEEDBACK FORM

Statements and questions related to the participant background:

The main area of expertise (e.g. surveyor, seafarer, academic, etc.):

Years of experience:

Please, rate the following statements from 1 to 5, where 1 represents the lowest score.

Level of knowledge regarding accident investigations	1	2	3	4	5
Level of knowledge regarding human factors	1	2	3	4	5
Level of knowledge regarding ship operations	1	2	3	4	5

Statements related to the workshop structure and content:

Please, rate the following statements from 1 to 5, where 1 represents the lowest score.

The information was clearly given by the presenter	1	2	3	4	5
The presenter attracted audience attention	1	2	3	4	5
The presentation was well-structured	1	2	3	4	5
The presenter answered appropriately to the questions	1	2	3	4	5
The presenter helped to achieve the workshop objectives in time and content	1	2	3	4	5
The workshop was relevant for me	1	2	3	4	5
The workshop was interesting	1	2	3	4	5
The workshop content was significant for me	1	2	3	4	5
The workshop pushed me to reflect on my own thoughts	1	2	3	4	5
The time allocated to this workshop was adequate	1	2	3	4	5
Card sorting method was easy to understand and use	1	2	3	4	5
Card sorting method is suitable to classify human factors	1	2	3	4	5
Card sorting method generated a debate among participants	1	2	3	4	5

If you have rate any of above statements **3 or below**, please provide reasons here for improvement:

Additional comments:

If you have any additional comments or suggestions about this workshop, please provide them here:

D HUMAN-FACTORS DESCRIPTIVE CARDS

Human Factor No 1

Anthropometric factors, dimensions

Examples:

- *Lack of deck space.*
- *Deck gate not suitable for boarding.*

Human Factor No 2

Audit

Examples:

- *Owners did not ensure that its zero alcohol policy was observed on board.*

Human Factor No 3

Checks

Examples:

- *Checks and audit of previous passage plans were not effective.*
- *The information shown of the area was inaccurate.*

Human Factor No 4

Conflicting orders, cross-pressure (ex. master's standing orders)

Examples:

- *Master's standing orders were ambiguous on the use of VHF radio for collision.*

Human Factor No 5

Contingency plans not updated

Examples:

- *No means of recovery carried.*
- *Lack of practiced plan.*

Human Factor No 6

Cowboy attitudes, horseplay

Examples:

- *Officers held party on bridge.*

Human Factor No 7

Crisis handling

Examples:

- *Owner did not provide support to vessel at time of crisis.*

Human Factor No 8

Cross-pressure from schedule & economy

Examples:

- *Commercial pressure.*

Figure D.1. Human-factor descriptive cards from No 1 to No 8

Human Factor No 9 **Design (DESIGN)** Examples: - *The position and design of the seating allowed the child to climb up the backrest and lean over, and balance on the top of the ship's side guardrails.*	Human Factor No 10 **Design error** Examples: - *No alarm to indicate pitch deviation.* - *Fire alarm was in the wheelhouse and could not be heard at the winch control position aft of the wheelhouse.*
Human Factor No 11 **Deviation from standards/specifications** Examples: - *Lack of experience in fitting marine cranes.*	Human Factor No 12 **Display design, controls** Examples: - *Unsafe route plotted on ECDIS (Electronic Chart Display and Information System).* - *OOW (Officer Of the Watch) distraction.*
Human Factor No 13 **Emergency plans** Examples: - *Crew were unable to recover the crewman from the water due to as they were unable to effectively operate the recovery system carried on board.*	Human Factor No 14 **Emergency procedures** Examples: - *The vessel's owners had not carried out emergency drills.* - *Inadequate MOB (Man Overboard) procedure.*
Human Factor No 15 **Emergency training program** Examples: - *Crew unprepared for an emergency.* - *Poor response to emergency.*	Human Factor No 16 **Expectations of supervisor is unclear** Examples: - *Master did not complete night orders before going to rest.*

Figure D.2. Human-factor descriptive cards from No 9 to No 16

Human Factor No 17 **Failure not detected during IMR (Inspection, Maintenance and Repairs)** Examples: - *ECDIS (Electronic Chart Display and Information System) equipment not functioning correctly.*	Human Factor No 18 **Follow-up of non-conformities** Examples: - *Underlying management issues.*
Human Factor No 19 **Frequent change of watch schedule** Examples: - *Fatigue.*	Human Factor No 20 **Hazardous/ messy workplace** Examples: - *Urinating overboard.* - *Working in a very hazardous area.*
Human Factor No 21 **Health control of personnel** Examples: - *Designated smoking areas had not been identified.*	Human Factor No 22 **Hiring and selection policy** Examples: - *No formal hierarchy amongst deck crew.*
Human Factor No 23 **Idleness, waiting** Examples: - *Crew not trained in use of LSA (Life-saving Appliances).*	Human Factor No 24 **Improper performance of maintenance/ repair** Examples: - *Shipboard maintenance was reactive.* - *Normal to carry out autonomous repairs – on board culture/shipping industry culture.*

Figure D.3. Human-factor descriptive cards from No 17 to No 24

Human Factor No 25 **Improper supervisory example** Examples: - *Lookouts not posted.* - *Skipper left wheelhouse unmanned to prepare meal.*	Human Factor No 26 **Inadequate briefing, instruction (ex. passage briefing plan)** Examples: - *Lack of briefing from master.* - *Lack of Skipper enforcement of rules regarding wearing of lifejackets on deck.*
Human Factor No 27 **Inadequate control of life saving equipment** Examples: - *One of the liferafts drifted away from vessel before crew could enter it.*	Human Factor No 28 **Inadequate fighting equipment** Examples: - *Risk assessment for emergency situations was inadequate.*
Human Factor No 29 **Inadequate illumination** Examples: - *The unmanned tug was in darkness.*	Human Factor No 30 **Inadequate maintenance** Examples: - *Maintenance standards on board were less than adequate.*
Human Factor No 31 **Inadequate manning** Examples: - *Lack of second person on the bridge.* - *Insufficient personnel in bridge team to ensure situational awareness was maintained.*	Human Factor No 32 **Inadequate procedures and checklists (ship/port, maintenance, company, emergency, other)** Examples: - *Insufficient company oversight of navigational practices.*

Figure D.4. Human-factor descriptive cards from No 25 to No 32

Human Factor No 33 **Inadequate promotion of Safety** Examples: - *Master did not give coastguard correct information as he did not want to admit error to managers.* - *Owner's safety culture was less than adequate.*	Human Factor No 34 **Inadequate standards or specifications** Examples: - *Insufficient electronic navigation aids (no echo sounder) and plotter not used effectively.* - *Skipper assumed that it would be okay to sail without correct navigational lights.*
Human Factor No 35 **Inadequate testing** Examples: - *Inadequate knowledge of marine crane installation requirements.*	Human Factor No 36 **Inadequate training program** Examples: - *Lack of training.* - *OOW (Officer Of the Watch) unable to set up radar.*
Human Factor No 37 **Inadequate work methods** Examples: - *Crew not briefed in discharging fumigated cargo.* - *Not utilising radar.*	Human Factor No 38 **Inadequate work preparation (ex. passage plan)** Examples: - *The submarine's passage plan was not prepared or executed effectively.* - *Bridge watch alarm was not turned on for the voyage.*
Human Factor No 39 **Inappropriate peer pressure** Examples: - *Commercial pressure to press ahead with the voyage.*	Human Factor No 40 **Inappropriate regulations** Examples: - *Generic nature of small commercial vessel regulations means that they do not focus on specific operational conditions such as dive boat safety.*

Figure D.5. Human-factor descriptive cards from No 33 to No 40

Human Factor No 41

Inspection

Examples:

- *Bridge watchkeeping practices not in accordance with safety management system.*
- *Poor standard of crew familiarisation training not detected by previous PSC (Port State Control) inspections.*

Human Factor No 42

Lack of communication & coordination

Examples:

- *Coastguard began search in wrong area.*
- *Lack of communication between pilot 1 and pilot 2 aboard.*

Human Factor No 43

Lack of co-ordination of tasks

Examples:

- *Roles and responsibilities were not clearly defined.*
- *Harbour Authority not informed of high-speed test.*

Human Factor No 44

Lack of information, inadequately presented information

Examples:

- *There was no rudder indication in the wheelhouse and therefore the watchkeeper was not aware of the position of the rudder.*

Human Factor No 45

Lack of knowledge

Examples:

- *Lack of system knowledge.*
- *The skipper was unaware of the navigational dangers.*

Human Factor No 46

Lack of leadership

Examples:

- *Crew did not abandon ship in orderly manner.*
- *Leadership for planning and executing firefighting effort was missing.*

Human Factor No 47

Lack of maintenance

Examples:

- *Bilge alarms system, bilge pumping system and auxiliary generator were not maintained.*

Human Factor No 48

Lack of motivation/morale

Examples:

- *Master on final trip to sea before retirement.*
- *Reduced level of vigilance.*

Figure D.6. Human-factor descriptive cards from No 41 to No 48

Human Factor No 49 **Lack of priority to IMR (Inspection, Maintenance and Repairs)** Examples: - *Low priority given by company to ballast gauge deficiencies.*	Human Factor No 50 **Lack of resources** Examples: - *Only two crew on board - Both crew needed on deck to work catch.*
Human Factor No 51 **Lack of responsibility for own job** Examples: - *Poor professional standards.* - *Chose not to wear supplied PPE (Personal Protective Equipment).*	Human Factor No 52 **Lack of skill** Examples: - *Lack of ship handling experience on vessel.* - *Electronic aids to navigation not set up correctly to prevent accident.*
Human Factor No 53 **Lack of warning systems** Examples: - *Did not think to warn personnel to brace.*	Human Factor No 54 **Lacks initiative to deal with emergencies** Examples: - *1-hour delay in notifying the coastal state of the accident.* - *No emergency preparation.*
Human Factor No 55 **Language problem** Examples: - *Customer service agent did not understand initial emergency call due to language difficulties.*	Human Factor No 56 **Lifesaving equipment** Examples: - *Inadequate use.*

Figure D.7. Human-factor descriptive cards from No 49 to No 56

Human Factor No 57 **Long working periods, much overtime** Examples: - *OOW (Officer Of the Watch) fell asleep.* - *Fatigue of bridge team affecting decision making.*	Human Factor No 58 **Low job satisfaction, monotony** Examples: - *Skipper did not keep a proactive lookout.*
Human Factor No 59 **LTA (Less Than Adequate) assessment of needs and risks** Examples: - *Risks associated with task not identified or assessed.* - *Safety culture – "this task had been done this way previously".*	Human Factor No 60 **LTA (Less Than Adequate) communication (oral, written/read and visual)** Examples: - *Pilot not informed of manual operation.* - *Poor on board communications.*
Human Factor No 61 **LTA (Less Than Adequate) design verification** Examples: - *Arrangement / design of bowsing tackle was inadequate.*	Human Factor No 62 **LTA (Less Than Adequate) Formal safety assessment, risk analysis** Examples: - *Bridge Watch Alarm was not turned on.* - *Lack of formal risk assessment of anchoring operations.*
Human Factor No 63 **LTA (Less Than Adequate) medical services provided** Examples: - *Pilot had a history of medical conditions that may have contributed to his fall.*	Human Factor No 64 **LTA (Less Than Adequate) mental and psychological state** Examples: - *Fatigue due to alcohol consumption.* - *Crewman under influence of drugs.*

Figure D.8. Human-factor descriptive cards from No 57 to No 64

Human Factor No 65 **LTA (Less Than Adequate) physical/ physiological capability** Examples: - *Skipper was fatigued due to long working hours.* - *Under the influence of alcohol.*	Human Factor No 66 **LTA (Less Than Adequate) planning** Examples: - *No maintenance system for vessel.*
Human Factor No 67 **LTA (Less Than Adequate) safety plan and program** Examples: - *No safety management system in place.* - *Pilot was undertaking an examination on a vessel that was much larger than any he had previously experienced.*	Human Factor No 68 **LTA (Less Than Adequate) system review and evaluation** Examples: - *No emergency means of tow rope release provided.*
Human Factor No 69 **Management training** Examples: - *Use of unauthorised means of access.*	Human Factor No 70 **No review or critical tasks / operations** Examples: - *Roles and responsibilities were not clearly defined.* - *No procedure for tasks.*
Human Factor No 71 **Person-to-person conflict / animosity** Examples: - *Filipino crew previous experience of intimidation from Ghanaian deck hands.*	Human Factor No 72 **Pressure to keep schedule and costs** Examples: - *Commercial pressure to run service.* - *Cutting corners, saving time.*

Figure D.9. Human-factor descriptive cards from No 65 to No 72

Human Factor No 73 **Regulation** Examples: - *Lack of knowledge and training.* - *Deck gate not suitable for boarding.*	Human Factor No 74 **Regulatory procedures** Examples: - *Lone watchkeeper on bridge contrary to regulatory requirements for area of accident.*
Human Factor No 75 **Regulatory standards** Examples: - *History of poor practice and regulatory non-compliance.* - *Lack of shaft tachometer.*	Human Factor No 76 **Resistance to change** Examples: - *Industry guidance not followed with regard to navigation watch practices.* - *No desire to wear PFD (Personal Flotation Devices).*
Human Factor No 77 **Restricted fairway** Examples: - *The confined nature of the ferry's berth afforded little space within which to abort the approach in the event of a mechanical malfunction.*	Human Factor No 78 **Right tools and equipment unavailable** Examples: - *No designated lifelines were provided on board for use in sending crew on deck in heavy weather.*
Human Factor No 79 **Safety awareness, cutting corners** Examples: - *The watch alarm was switched off.* - *No safety management system in place.*	Human Factor No 80 **Sea motion** Examples: - *Shore worker became trapped between hull and shore fender.*

Figure D.10. Human-factor descriptive cards from No 73 to No 80

Human Factor No 81

Selection/training of officers

Examples:

- *OOW (Officer Of the Watch) received insufficient continuation training.*

Human Factor No 82

Social & cultural barriers & conflicts

Examples:

- *Lack of personal discipline.*
- *Safety culture - no allowance for cultural differences.*

Human Factor No 83

Supervision (SUPER)

Examples:

- *The parents supervising the child were distracted by the energetic behaviour of other young children within their group.*

Human Factor No 84

Supervisors not in touch

Examples:

- *Decision to continue with task.*

Human Factor No 85

Surveillance

Examples:

- *Poor safety culture.*
- *Ineffective ISM system.*

Human Factor No 86

Too high work load / low work load

Examples:

- *Master left bridge to undertake paperwork.*
- *Rushing job in anticipation of limited sleep before shooting nets.*

Human Factor No 87

Too low visibility for observation

Examples:

- *Expectation of fog to clear.*
- *The glassy calm sea denied the skipper the usual 'rock wash' around shallow hazards.*

Human Factor No 88

Traffic density hinders vessel control

Examples:

- *The vessel's movement was possibly influenced by hydrodynamic interaction.*

Figure D.11. Human-factor descriptive cards from No 81 to No 88

Human Factor No 89 **Training ignored** Examples: - *Crew did not close fire doors.* - *Crew did not use lifejackets when abandoning vessel but did take personal effects.*	Human Factor No 90 **Unclear roles and responsibility** Examples: - *Roles and responsibilities were not clearly defined.* - *Shore worker was not supervised.*
Human Factor No 91 **Use of wrong equipment** Examples: - *Name of vessel not known as AIS (automatic identification system) was not switched on.*	Human Factor No 92 **Work instruction** Examples: - *Management expectation and working instructions not clear.* - *Safety management system contained no detailed requirements with regard to sending men on deck.*
Human Factor No 93 **Work place inspections** Examples: - *Company had not picked up on diversions on board the tug. What was perceived as happening did not always happen.*	Human Factor No 94 **Wrong person assigned** Examples: - *Winch operator was unable to control winch effectively.*

Figure D.12. Human-factor descriptive cards from No 89 to No 94

E QUESTIONNAIRE APPLIED TO COLLECT EXPERT OPINION FOR THE SECOND STAGE OF THE MALFCMS METHOD

Expert Background

1) How would you evaluate your level of knowledge regarding accident investigations?

1	2	3	4	5

2) How would you evaluate your level of knowledge regarding human factors?

1	2	3	4	5

3) How would you evaluate your level of knowledge regarding ship operations?

1	2	3	4	5

4) The main area of expertise (e.g. surveyor, seafarer, academic, etc.):

5) Years of experience:

Block A Questions

1) How influential **"commercial pressure"** is in terms of contributing to maritime accidents?

Very very low	Very low	Low	Medium	High	Very high	Very very high

2) How influential **"environmental and external factors"** are in terms of contributing to maritime accidents?

Very very low	Very low	Low	Medium	High	Very high	Very very high

3) How influential **"improper design, installation or working environment"** is in terms of contributing to maritime accidents?

Very very low	Very low	Low	Medium	High	Very high	Very very high

4) How influential **“inadequate leadership and supervision”** is in terms of contributing to maritime accidents?

Very very low	Very low	Low	Medium	High	Very high	Very very high

5) How influential **“lack of communication and coordination”** is in terms of contributing to maritime accidents?

Very very low	Very low	Low	Medium	High	Very high	Very very high

6) How influential **“lack of, improper or late maintenance”** is in terms of contributing to maritime accidents?

Very very low	Very low	Low	Medium	High	Very high	Very very high

7) How influential **“lack of training”** is in terms of contributing to maritime accidents?

Very very low	Very low	Low	Medium	High	Very high	Very very high

8) How influential **“lack of safety culture”** is in terms of contributing to maritime accidents?

Very very low	Very low	Low	Medium	High	Very high	Very very high

9) How influential **“procedures or a deviation from Standard Operating Procedure (SOP)”** are in terms of contributing to maritime accidents?

Very very low	Very low	Low	Medium	High	Very high	Very very high

10) How influential **“inadequate substandard monitoring”** is in terms of contributing to maritime accidents?

Very very low	Very low	Low	Medium	High	Very high	Very very high

11) How influential **“unprofessional behaviour”** is in terms of contributing to maritime accidents?

Very very low	Very low	Low	Medium	High	Very high	Very very high

Block B Questions

1) Given a change in **commercial pressure,** what would be the effect on **environmental and external factors**?

None	Very small	Small	Moderate	Big	Very big	Very very big

2) Given a change in **commercial pressure,** what would be the effect on **design, installation or working environment**?

None	Very small	Small	Moderate	Big	Very big	Very very big

3) Given a change in **commercial pressure,** what would be the effect on **leadership and supervision**?

None	Very small	Small	Moderate	Big	Very big	Very very big

4) Given a change in commercial pressure, what would be the effect on communication and coordination?

None	Very small	Small	Moderate	Big	Very big	Very very big

5) Given a change in commercial pressure, what would be the effect on maintenance?

None	Very small	Small	Moderate	Big	Very big	Very very big

6) Given a change in commercial pressure, what would be the effect on training?

None	Very small	Small	Moderate	Big	Very big	Very very big

7) Given a change in commercial pressure, what would be the effect on safety culture?

None	Very small	Small	Moderate	Big	Very big	Very very big

8) Given a change in commercial pressure, what would be the effect on procedures or SOP?

None	Very small	Small	Moderate	Big	Very big	Very very big

9) Given a change in commercial pressure, what would be the effect on monitoring?

None	Very small	Small	Moderate	Big	Very big	Very very big

10) Given a change in commercial pressure, what would be the effect on behaviour?

None	Very small	Small	Moderate	Big	Very big	Very very big

11) Given a change in environmental and external factors, what would be the effect on commercial pressure?

None	Very small	Small	Moderate	Big	Very big	Very very big

12) Given a change in environmental and external factors, what would be the effect on design, installation or working environment?

None	Very small	Small	Moderate	Big	Very big	Very very big

13) Given a change in environmental and external factors, what would be the effect on leadership and supervision?

None	Very small	Small	Moderate	Big	Very big	Very very big

14) Given a change in environmental and external factors, what would be the effect on communication and coordination?

None	Very small	Small	Moderate	Big	Very big	Very very big

15) Given a change in environmental and external factors, what would be the effect on maintenance?

None	Very small	Small	Moderate	Big	Very big	Very very big

16) Given a change in environmental and external factors, what would be the effect on training?

None	Very small	Small	Moderate	Big	Very big	Very very big

17) Given a change in environmental and external factors, what would be the effect on safety culture?

None	Very small	Small	Moderate	Big	Very big	Very very big

18) Given a change in environmental and external factors, what would be the effect on procedures or SOP?

None	Very small	Small	Moderate	Big	Very big	Very very big

19) Given a change in environmental and external factors, what would be the effect on monitoring?

None	Very small	Small	Moderate	Big	Very big	Very very big

20) Given a change in environmental and external factors, what would be the effect on behaviour?

None	Very small	Small	Moderate	Big	Very big	Very very big

21) Given a change in design, installation or working environment, what would be the effect on commercial pressure?

None	Very small	Small	Moderate	Big	Very big	Very very big

22) Given a change in design, installation or working environment, what would be the effect on environmental and external factors?

None	Very small	Small	Moderate	Big	Very big	Very very big

23) Given a change in design, installation or working environment, what would be the effect on leadership and supervision?

None	Very small	Small	Moderate	Big	Very big	Very very big

24) Given a change in design, installation or working environment, what would be the effect on communication and coordination?

None	Very small	Small	Moderate	Big	Very big	Very very big

25) Given a change in design, installation or working environment, what would be the effect on maintenance?

None	Very small	Small	Moderate	Big	Very big	Very very big

26) Given a change in design, installation or working environment, what would be the effect on training?

None	Very small	Small	Moderate	Big	Very big	Very very big

27) Given a change in design, installation or working environment, what would be the effect on safety culture?

None	Very small	Small	Moderate	Big	Very big	Very very big

28) Given a change in design, installation or working environment, what would be the effect on procedures or SOP?

None	Very small	Small	Moderate	Big	Very big	Very very big

29) Given a change in design, installation or working environment, what would be the effect on monitoring?

None	Very small	Small	Moderate	Big	Very big	Very very big

30) Given a change in design, installation or working environment, what would be the effect on behaviour?

None	Very small	Small	Moderate	Big	Very big	Very very big

31) Given a change in leadership and supervision, what would be the effect on commercial pressure?

None	Very small	Small	Moderate	Big	Very big	Very very big

32) Given a change in leadership and supervision, what would be the effect on environmental and external factors?

None	Very small	Small	Moderate	Big	Very big	Very very big

33) Given a change in leadership and supervision, what would be the effect on design, installation or working environment?

None	Very small	Small	Moderate	Big	Very big	Very very big

34) Given a change in leadership and supervision, what would be the effect on communication and coordination?

None	Very small	Small	Moderate	Big	Very big	Very very big

35) Given a change in leadership and supervision, what would be the effect on maintenance?

None	Very small	Small	Moderate	Big	Very big	Very very big

36) Given a change in leadership and supervision, what would be the effect on training?

None	Very small	Small	Moderate	Big	Very big	Very very big

37) Given a change in leadership and supervision, what would be the effect on safety culture?

None	Very small	Small	Moderate	Big	Very big	Very very big

38) Given a change in leadership and supervision, what would be the effect on procedures or SOP?

None	Very small	Small	Moderate	Big	Very big	Very very big

39) Given a change in leadership and supervision, what would be the effect on monitoring?

None	Very small	Small	Moderate	Big	Very big	Very very big

40) Given a change in leadership and supervision, what would be the effect on behaviour?

None	Very small	Small	Moderate	Big	Very big	Very very big

41) Given a change in communication and coordination, what would be the effect on commercial pressure?

None	Very small	Small	Moderate	Big	Very big	Very very big

42) Given a change in communication and coordination, what would be the effect on environmental and external factors?

None	Very small	Small	Moderate	Big	Very big	Very very big

43) Given a change in communication and coordination, what would be the effect on improper design, installation or working environment?

None	Very small	Small	Moderate	Big	Very big	Very very big

44) Given a change in communication and coordination, what would be the effect on leadership and supervision?

None	Very small	Small	Moderate	Big	Very big	Very very big

45) Given a change in communication and coordination, what would be the effect on maintenance?

None	Very small	Small	Moderate	Big	Very big	Very very big

46) Given a change in communication and coordination, what would be the effect on training?

None	Very small	Small	Moderate	Big	Very big	Very very big

47) Given a change in communication and coordination, what would be the effect on safety culture?

None	Very small	Small	Moderate	Big	Very big	Very very big

48) Given a change in communication and coordination, what would be the effect on procedures or SOP?

None	Very small	Small	Moderate	Big	Very big	Very very big

49) Given a change in communication and coordination, what would be the effect on monitoring?

None	Very small	Small	Moderate	Big	Very big	Very very big

50) Given a change in communication and coordination, what would be the effect on behaviour?

None	Very small	Small	Moderate	Big	Very big	Very very big

51) Given a change in maintenance, what would be the effect on commercial pressure?

None	Very small	Small	Moderate	Big	Very big	Very very big

52) Given a change in maintenance, what would be the effect on environmental and external factors?

None	Very small	Small	Moderate	Big	Very big	Very very big

53) Given a change in maintenance, what would be the effect on design, installation or working environment?

None	Very small	Small	Moderate	Big	Very big	Very very big

54) Given a change in maintenance, what would be the effect on leadership and supervision?

None	Very small	Small	Moderate	Big	Very big	Very very big

55) Given a change in maintenance, what would be the effect on communication and coordination?

None	Very small	Small	Moderate	Big	Very big	Very very big

56) Given a change in maintenance, what would be the effect on training?

None	Very small	Small	Moderate	Big	Very big	Very very big

57) Given a change in maintenance, what would be the effect on safety culture?

None	Very small	Small	Moderate	Big	Very big	Very very big

58) Given a change in maintenance, what would be the effect on procedures or SOP?

None	Very small	Small	Moderate	Big	Very big	Very very big

59) Given a change in maintenance, what would be the effect on monitoring?

None	Very small	Small	Moderate	Big	Very big	Very very big

60) Given a change in maintenance, what would be the effect on behaviur?

None	Very small	Small	Moderate	Big	Very big	Very very big

61) Given a change in training, what would be the effect on commercial pressure?

None	Very small	Small	Moderate	Big	Very big	Very very big

62) Given a change in training, what would be the effect on environmental and external factors?

None	Very small	Small	Moderate	Big	Very big	Very very big

63) Given a change in training, what would be the effect on design, installation or working environment?

None	Very small	Small	Moderate	Big	Very big	Very very big

64) Given a change in training, what would be the effect on leadership and supervision?

None	Very small	Small	Moderate	Big	Very big	Very very big

65) Given a change in training, what would be the effect on communication and coordination?

None	Very small	Small	Moderate	Big	Very big	Very very big

66) Given a change in training, what would be the effect on maintenance?

None	Very small	Small	Moderate	Big	Very big	Very very big

67) Given a change in training, what would be the effect on safety culture?

None	Very small	Small	Moderate	Big	Very big	Very very big

68) Given a change in training, what would be the effect on procedures or SOP?

None	Very small	Small	Moderate	Big	Very big	Very very big

69) Given a change in training, what would be the effect on monitoring?

None	Very small	Small	Moderate	Big	Very big	Very very big

70) Given a change in training, what would be the effect on behaviour?

None	Very small	Small	Moderate	Big	Very big	Very very big

71) Given a change in safety culture, what would be the effect on commercial pressure?

None	Very small	Small	Moderate	Big	Very big	Very very big

72) Given a change in safety culture, what would be the effect on environmental and external factors?

None	Very small	Small	Moderate	Big	Very big	Very very big

73) Given a change in safety culture, what would be the effect on design, installation or working environment?

None	Very small	Small	Moderate	Big	Very big	Very very big

74) Given a change in safety culture, what would be the effect on leadership and supervision?

None	Very small	Small	Moderate	Big	Very big	Very very big

75) Given a change in safety culture, what would be the effect on communication and coordination?

None	Very small	Small	Moderate	Big	Very big	Very very big

76) Given a change in safety culture, what would be the effect on maintenance?

None	Very small	Small	Moderate	Big	Very big	Very very big

77) Given a change in safety culture, what would be the effect on training?

None	Very small	Small	Moderate	Big	Very big	Very very big

78) Given a change in safety culture, what would be the effect on procedures or SOP?

None	Very small	Small	Moderate	Big	Very big	Very very big

79) Given a change in safety culture, what would be the effect on monitoring?

None	Very small	Small	Moderate	Big	Very big	Very very big

80) Given a change in safety culture, what would be the effect on behaviour?

None	Very small	Small	Moderate	Big	Very big	Very very big

81) Given a change in procedures or SOP, what would be the effect on commercial pressure?

None	Very small	Small	Moderate	Big	Very big	Very very big

82) Given a change in procedures or SOP, what would be the effect on environmental and external factors?

None	Very small	Small	Moderate	Big	Very big	Very very big

83) Given a change in procedures or SOP, what would be the effect on design, installation or working environment?

None	Very small	Small	Moderate	Big	Very big	Very very big

84) Given a change in procedures or SOP, what would be the effect on leadership and supervision?

None	Very small	Small	Moderate	Big	Very big	Very very big

85) Given a change in procedures or SOP, what would be the effect on communication and coordination?

None	Very small	Small	Moderate	Big	Very big	Very very big

86) Given a change in procedures or SOP, what would be the effect on maintenance?

None	Very small	Small	Moderate	Big	Very big	Very very big

87) Given a change in procedures or SOP, what would be the effect on training?

None	Very small	Small	Moderate	Big	Very big	Very very big

88) Given a change in procedures or SOP, what would be the effect on safety culture?

None	Very small	Small	Moderate	Big	Very big	Very very big

89) Given a change in procedures or SOP, what would be the effect on monitoring?

None	Very small	Small	Moderate	Big	Very big	Very very big

90) Given a change in procedures or SOP, what would be the effect on behaviour?

None	Very small	Small	Moderate	Big	Very big	Very very big

91) Given a change in monitoring, what would be the effect on commercial pressure?

None	Very small	Small	Moderate	Big	Very big	Very very big

92) Given a change in monitoring, what would be the effect on environmental and external factors?

None	Very small	Small	Moderate	Big	Very big	Very very big

93) Given a change in monitoring, what would be the effect on design, installation or working environment?

None	Very small	Small	Moderate	Big	Very big	Very very big

94) Given a change in monitoring, what would be the effect on leadership and supervision?

None	Very small	Small	Moderate	Big	Very big	Very very big

95) Given a change in monitoring, what would be the effect on communication and coordination?

None	Very small	Small	Moderate	Big	Very big	Very very big

96) Given a change in monitoring, what would be the effect on maintenance?

None	Very small	Small	Moderate	Big	Very big	Very very big

97) Given a change in monitoring, what would be the effect on training?

None	Very small	Small	Moderate	Big	Very big	Very very big

98) Given a change in monitoring, what would be the effect on safety culture?

None	Very small	Small	Moderate	Big	Very big	Very very big

99) Given a change in monitoring, what would be the effect on procedures or SOP?

None	Very small	Small	Moderate	Big	Very big	Very very big

100) Given a change in monitoring, what would be the effect on behaviour?

None	Very small	Small	Moderate	Big	Very big	Very very big

101) Given a change in behaviour, what would be the effect on commercial pressure?

None	Very small	Small	Moderate	Big	Very big	Very very big

102) Given a change in behaviour, what would be the effect on environmental and external factors?

None	Very small	Small	Moderate	Big	Very big	Very very big

103) Given a change in behaviour, what would be the effect on design, installation or working environment?

None	Very small	Small	Moderate	Big	Very big	Very very big

104) Given a change in behaviour, what would be the effect on leadership and supervision?

None	Very small	Small	Moderate	Big	Very big	Very very big

105) Given a change in behaviour, what would be the effect on communication and coordination?

None	Very small	Small	Moderate	Big	Very big	Very very big

106) Given a change in behaviour, what would be the effect on maintenance?

None	Very small	Small	Moderate	Big	Very big	Very very big

107) Given a change in behaviour, what would be the effect on training?

None	Very small	Small	Moderate	Big	Very big	Very very big

108) Given a change in behaviour, what would be the effect on safety culture?

None	Very small	Small	Moderate	Big	Very big	Very very big

109) Given a change in behaviour, what would be the effect on procedures or SOP?

None	Very small	Small	Moderate	Big	Very big	Very very big

110) Given a change in behaviour, what would be the effect on monitoring?

None	Very small	Small	Moderate	Big	Very big	Very very big

F INTERACTION MATRIX FOR COLLISION ACCIDENTS IN BULK CARRIERS. PERIOD 2000-2011

Table F.1. The final representation of the interaction matrix for collision accidents in bulk carriers. Period 2000-2011

	10	12	13	14	18	21	41	45	48	49	50	59	61	65	66	68	71	76	77	84	94	95	104
10	0.000	0.000	1.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000
12	0.000	0.000	0.000	0.500	0.500	0.000	0.000	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.500	0.000	0.000	0.000
13	0.333	0.000	0.000	0.000	0.333	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.333	0.333	0.000	0.000	0.333	0.000	0.333	0.000	0.333	0.000
14	0.000	0.500	0.000	0.000	0.500	0.500	0.000	0.500	0.000	0.000	0.500	0.000	0.000	0.000	0.000	0.500	0.000	0.000	0.000	0.500	0.000	0.000	0.500
18	0.500	0.500	0.500	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.500	0.000	0.000	0.000	0.000	0.000
21	0.000	0.000	0.000	1.000	0.000	0.000	0.000	1.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	1.000	0.000	0.000	1.000
41	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
45	0.000	0.500	0.000	0.500	0.000	0.500	0.000	0.000	0.000	0.000	0.500	0.000	0.000	0.000	0.000	0.500	0.000	0.000	0.000	1.000	0.000	0.000	0.500
48	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	1.000	0.000	0.000
49	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	1.000	0.000	0.000
50	0.000	0.000	0.000	0.500	0.000	0.500	0.500	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.500	0.000	0.000	0.500	0.500	0.000	0.000	0.500
59	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	1.000	0.000	0.000
61	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
65	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
66	0.000	0.000	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.500	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.500	0.000
68	0.000	0.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	1.000
71	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
76	1.000	0.000	1.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
77	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
84	0.000	0.250	0.250	0.250	0.000	0.250	0.000	0.500	0.250	0.250	0.250	0.250	0.000	0.000	0.000	0.250	0.000	0.000	0.000	0.000	0.250	0.000	0.250
94	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	1.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
95	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
104	0.000	0.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000

G PROGRAM IN MATLAB FOR THE FCM SIMULATION PROCESS

Process

This appendix first provides and explains the Matlab program that was developed to obtain the interaction matrix, the state vector and the weightings for each accident-contributing factor, which are applied during the first and third stages of the Marine Accident Learning with Fuzzy Cognitive Maps (MALFCMs) method. In addition, the program is tested within a small example of data extracted from the MAIB database.

MATLAB code

```
function FCM= f (data, filt_i, filt_n, HF, ID, s_i, f_i, s_n, f_n, D)
%" Data " calls the database that will be analysed (i.e. Example database . xlsx ). " Filt_i " indicates the number of filters that are required to add, (i.e. if the analysis is focused on " collision accidents", "the year 2005" and " container vessels", three filters are required ). Thus, each filter 's name will be the name of the category in the accident excel spreadsheet, (i.e. Incident type ). In addition, "HF" and "ID" are the columns from the accident excel spreadsheet that contains the information regarding human factors and accident ID respectively. Finally, "s_i" and "f_i" indicates the limit values that are included within each filter, and "D" indicates how much difference between two consecutive steps is acceptable in the dynamic FCM process.
[num,txt,~] = xlsread(dataLink);
%It calls the excel database into Matlab.
for aa=1:length(txt)
   if(strcmp(txt(aa), filt_i))
      colNum_i=aa;
   end
end
%To identify which column in the excel spreadsheet is equivalent to filt_i.
for ee=1:length(txt)
   if(strcmp(txt(ee),HF))
      colNum4=ee;
   end
```

```
 end
% To identify which column in the excel spreadsheet provides information regarding human factors.
 for ff=1:length(txt)
    if(strcmp(txt(ff),ID))
        colNum5=ff;
    end
end
% To identify which column in the excel spreadsheet provides information regarding accidents ID.
a=1;
for cc=1:length(num)
    if(num(cc, colNum_i)>= s_i && num(cc,colNum_i)<=f_i &&(num(cc, colNum_n)>=
s_n&& num(cc,colNum_n)<=f_n
        Filtertablebyhumanfactors(a,:)=num(cc,:);
        a=a+1;
    end
end
%%To create a new table after applying all the previous filters.
A=unique(Filtertablebyhumanfactors(:,colNum4));
%To create a list of human factors that appear in the excel spreadsheet.
C=unique(Filtertablebyhumanfactors(:,colNum5));
%To create a list of accidents ID that appear in the excel spreadsheet.
B = zeros(size(A));
%B will be a matrix with size equal to the list of human factors.
for i = 1:length(A)
    B(i) = sum(Filtertablebyhumanfactors(:,colNum4) == A(i));
end
%B will count each time that an human factor appears.
Humanfactorsandappearance=[A,B];
% Matrix where the first column indicates the different human factors and the second the number of times that each human factor appears. Thus, if there is a missing human factor (i.e. 1,2,3,5 where 4 is missing, it does not include a space for it. Hence, the example would be [1,2,3,5]).
```

```
H=max(A);
% To identify the last human factor that appears in the matrix, which is 5 in the previous example.
sizevector=zeros([H 1]);
for pp=1:length(Humanfactorsandappearance)
sizevector(Humanfactorsandappearance(pp,1),1)=Humanfactorsandappearance(pp,2);
end
% To create a vector which counts the number of times that each human factor appears in total but it gives a zero value in the case that a factor is missing. In the previous example, for the factors [1,2,3,0,5], it gives [4.3.3.0.1] cause there is no factor 4.
State_vector=(sizevector/length(C))';
%C provides the overall number of accidents , and " State_vector " indicates the activation of each factor ( frequency of appearance).
[unqA,~,id] = unique(Filtertablebyhumanfactors(:,colNum5));
Repeatedfactorsinaccidents=unqA(histc(id,1:max(id))>1);
%To show those accidents in which there is more than one human factor.
for vv=1:length(Humanfactorsandappearance)
Listofallhumanfactors(Humanfactorsandappearance(vv,1),1)=Humanfactorsandappearance(vv,1);
end
% To create a matrix for the accidents with more than one human factor.
D = zeros(H);
b=1;
for gg=1:length(Filtertablebyhumanfactors(:,colNum5))
  for hh=1:length(Repeatedfactorsinaccidents)
      if(Filtertablebyhumanfactors(gg,colNum5)==Repeatedfactorsinaccidents(hh,1))
   E(b,:)=Filtertablebyhumanfactors(gg,:);
   b=b+1;
   end
  end
end
Accidentswithmorethanonehumanfactor=E;
%E shows the accidents with more than one human factor.
c=1;
```

```
for o=1:length(Repeatedfactorsinaccidents)
for kk=1:size(Accidentswithmorethanonehumanfactor,1)
if(Accidentswithmorethanonehumanfactor(kk,colNum5)==Repeatedfactorsinaccidents(o,1))
    F(c,1)=Accidentswithmorethanonehumanfactor(kk,colNum4);
    c=c+1;
        end
end
% To check which different factor appears in each accident separately in order to define the permutations later.
c = 1;
%reset value for c.
[ii,jj]=ndgrid(F,F);
%(min(F):max(F),min(F):max(F)).
F = 0;
%reset value for F.
Permutations=[jj(:) ii(:)];
Permutations(~(Permutations(:,1)-Permutations(:,2)),:)=[];
%Permutations will calculate the coordinates in the final transition matrix in order to compare the human factors 2x2.
for mm=1:length(Permutations)
   nn=Permutations(mm,1);
   ll=Permutations(mm,2);
D(nn,ll)=D(nn,ll)+1;
end
end
%To repeat the process for each permutation in order to create the transition matrix for the accidents with more than one human factor.
for pp=1:length(sizevector)
Transition_matrix(pp,:)=D(pp,:)/sizevector(pp,1);
end
%Transition matrix is matrix D, which was calculated before , in which each row is divided between the number of accidents that contains each human factor.
Transition_matrix(isnan(Transition_matrix))=0;
dec=1/(10.^(D));
```

```
%To indicate the decimal to show the degree of precision of the FCM process.
M=State_vector*Transition_matrix;
r=1;
s=1;
while r<=maxsteps
K(1,:)=(1./(1+exp(-1*M)));
L(s,:)=K(r,:);
K(r+1,:)=1./(1+exp(-1*(L(s,:)*Transition_matrix)));
s=s+1;
r=r+1;
end
%To apply the threshold function for several steps. K shows the results of the FCM process.
K;
d=1;
f=2;
while d<=(size(K,1)-1)
N(d,:)=abs(K(f,:)-K(d,:));
   d=d+1;
   f=f+1;
end
%To calculate a matrix with the difference between every two steps in the FCM process in order to compare it with the decimal value defined before.
N;
steps=2;
v=1;
while  v<=length(N)
   if(N(v))>dec
      steps=steps+1;
      v=v+1;
   else
      Weights=K(v+1,:);
      break
   end
end
```

```
%To calculate when the difference between two consecutive steps is smaller enough (when comparing with the decimal value defined). When the difference between two consecutive steps is acceptable, the function stops and it provides the number of steps required and the weighting of each human factor.
WeightsoffactorsFCM=Weights;
KK=Listofallhumanfactors';
for aaa=1:length(WeightsoffactorsFCM)
    if KK(1,aaa)==0
    WfactorsFCM(1,aaa)=0;
    else
    WfactorsFCM(1,aaa)=WeightsoffactorsFCM(1,aaa);
    end
end
CorrectedweightsoffactorsFCM=WfactorsFCM;
Normalised_weightsoffactorsFCM=CorrectedweightsoffactorsFCM/sum(CorrectedweightsoffactorsFCM);
%It gives the weights normalized.
HF_weights_and_Normalised_weightsoffactorsFCM=[Listofallhumanfactors';CorrectedweightsoffactorsFCM;Normalised_weightsoffactorsFCM];
%This is a matrix where the first column is the number of the human factor, the second column is the weights of each human factor and the third column is the normalised weight.
Accident_frequency_statistical=State_vector;
%It provides the statistical frequency.
Normalised_accident_frequency_statistical=Accident_frequency_statistical/sum(Accident_frequency_statistical);
%It provides the normalised statistical frequency.
HF_statistical_frequency_and_Normalised_statistical_frequency=[Listofallhumanfactors';Accident_frequency_statistical;Normalised_accident_frequency_statistical];
%This is a matrix where the first column is the number of the human factor, the second column is the statistical frequency of each human factor and the third column is the normalised statistical frequency.
Transition_matrix
HF_weights_and_Normalised_weightsoffactorsFCM
HF_statistical_frequency_and_Normalised_statistical_frequency
```

```
end
%The function returns: 1) The total steps required to obtain the equilibrium of the FCM process; 2) The transition matrix; 3) A matrix with the list of human factors, the weights and the weight normalised of these human factors; and 4) A matrix with the list of human factors, the statistical frequency of accidents and the statistical frequency of accidents normalised caused by these human factors.
```

MATLAB code verification

A small example database has been selected to validate the Matlab program as shown in Table G.1

Table G.1. Example database

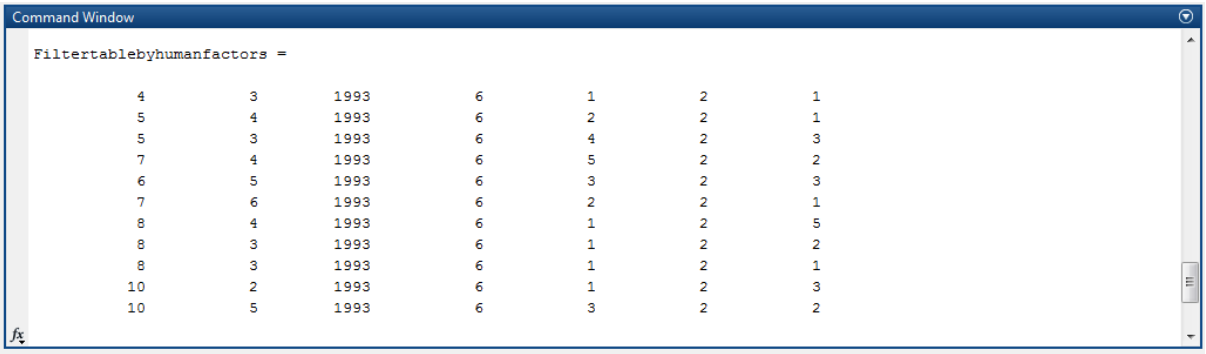
ID	Month	Year	Day of Month	Carrier	Factor	Kind of factor
1	1	1991	2	1	1	1
1	2	1992	4	2	1	2
1	2	1992	5	2	1	2
1	2	1992	5	1	2	3
1	3	1993	5	1	2	1
2	2	1992	4	2	2	1
3	2	1992	5	1	2	3
3	3	1992	5	1	2	1
3	3	1992	5	1	2	2
4	3	1993	6	1	2	1
4	2	1992	5	2	1	3
4	2	1992	5	1	2	1
5	4	1993	6	2	2	1
5	2	1992	5	2	1	3
5	2	1992	5	1	2	1
5	3	1993	6	4	2	3
6	2	1992	5	2	1	2
6	2	1992	5	1	2	4
6	3	1993	5	1	2	2
6	2	1992	5	2	1	3
6	2	1992	5	1	2	1
7	4	1993	6	5	2	2
7	2	1992	5	2	1	3
7	2	1992	5	1	2	1
6	5	1993	6	3	2	3
7	6	1993	6	2	2	1
8	4	1993	6	1	2	5
8	3	1993	6	1	2	2
8	3	1993	6	1	2	1
10	2	1993	6	1	2	3
10	5	1993	6	3	2	2
3	2	1991	5	1	2	3
4	3	1991	5	1	2	1
1	1	1991	2	1	1	1

First, the Matlab function is called, introducing the boundary conditions as in the example, obtaining the results shown in Table G.2 and Figure G.1:

- Function FCM=f('Example database.xlsx','Year','DayofMonth','Factor','Kindoffactor','ID',1993,1993,6,6,2,2,3,10)

Table G.2. Table filtered by human factors

ID	Month	Year	Day of Month	Carrier	Factor	Kind of factor
4	3	1993	6	1	2	1
5	4	1993	6	2	2	1
5	3	1993	6	4	2	3
7	4	1993	6	5	2	2
6	5	1993	6	3	2	3
7	6	1993	6	2	2	1
8	4	1993	6	1	2	5
8	3	1993	6	1	2	2
8	3	1993	6	1	2	1
10	2	1993	6	1	2	3
10	5	1993	6	3	2	2


Command Window

Filtertablebyhumanfactors =

4	3	1993	6	1	2	1
5	4	1993	6	2	2	1
5	3	1993	6	4	2	3
7	4	1993	6	5	2	2
6	5	1993	6	3	2	3
7	6	1993	6	2	2	1
8	4	1993	6	1	2	5
8	3	1993	6	1	2	2
8	3	1993	6	1	2	1
10	2	1993	6	1	2	3
10	5	1993	6	3	2	2

Figure G.1. Table filtered by human factors from Matlab screenshot

Second, the list of all human factors and frequencies are shown, as displayed in Table G.3 and Figure G.2:

Table G.3. List of all human factors and frequencies

List of all human factors	1	2	3	0	5
Size vector	4	3	3	0	1

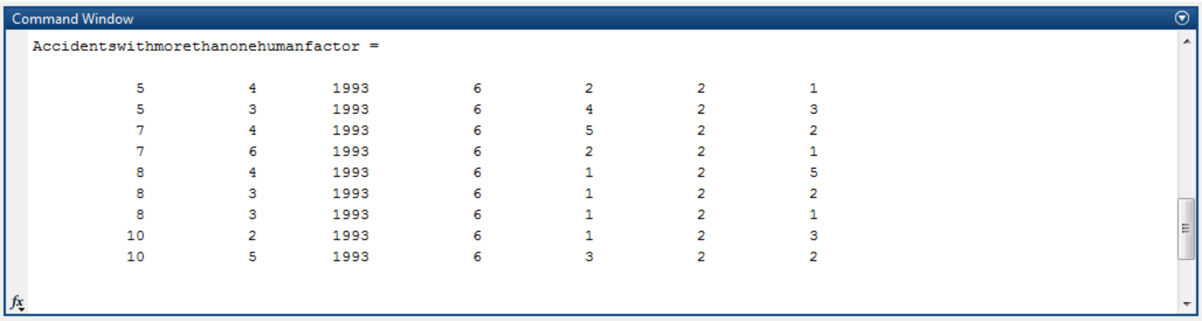
```
Command Window
Listofallhumanfactors =

     1
     2
     3
     0
     5


sizevector =

     4
     3
     3
     0
     1
```

Figure G.2. List of all human factors and frequencies from Matlab screenshot

Then, the database is filtered one more time with the accidents caused by more than one type of human factor as shown in Table G.4 and Figure G.3:

Table G.4. Accidents caused by more than one type of human factor

ID	Month	Year	Day of Month	Carrier	Factor	Kind of factor
5	4	1993	6	2	2	1
5	3	1993	6	4	2	3
7	4	1993	6	5	2	2
7	6	1993	6	2	2	1
8	4	1993	6	1	2	5
8	3	1993	6	1	2	2
8	3	1993	6	1	2	1
10	2	1993	6	1	2	3
10	5	1993	6	3	2	2



```
Command Window
Accidentswithmorethanonehumanfactor =

    5    4    1993    6    2    2    1
    5    3    1993    6    4    2    3
    7    4    1993    6    5    2    2
    7    6    1993    6    2    2    1
    8    4    1993    6    1    2    5
    8    3    1993    6    1    2    2
    8    3    1993    6    1    2    1
   10    2    1993    6    1    2    3
   10    5    1993    6    3    2    2
```

Figure G.3. Accidents caused by more than one type of human factor from Matlab screenshot

Finally, the program returns the following outputs:

1) Total steps required to obtain the equilibrium of the FCM process.
2) The transition matrix.
3) A matrix with the list of human factors, the weights and the normalised weight of these human factors.

4) A matrix with the list of human factors, the statistical frequency of accidents and the normalised statistical frequency of accidents caused by these human factors as shown in Figure G.4 and Figure G.5.

```
Command Window

Transition_matrix =

         0    0.5000    0.2500         0    0.2500
    0.6667         0    0.3333         0    0.3333
    0.3333    0.3333         0         0         0
         0         0         0         0         0
    1.0000    1.0000         0         0         0
```

Figure G.4. Transition matrix from Matlab screenshot

```
Command Window

steps =

     5


HF_weights_and_Normalized_weightsoffactorsFCM =

    1.0000    2.0000    3.0000         0    5.0000
    0.7904    0.7702    0.6115         0    0.6115
    0.2839    0.2767    0.2197         0    0.2197


HF_statistical_frequency_and_Normalized_statistical_frequency =

    1.0000    2.0000    3.0000         0    5.0000
    0.6667    0.5000    0.5000         0    0.1667
    0.3636    0.2727    0.2727         0    0.0909
```

Figure G.5. FCM results from Matlab screenshot

H EXPERT OPINION COLLECTED FOR THE SECOND STAGE OF MALFCMS METHOD

Table H.1. Interaction matrix created by Participant1 by applying linguistic terms. The second stage of the Marine Accident Learning with Fuzzy Cognitive Maps (MALFCMs) method

	HF1	HF2	HF3	HF4	HF5	HF6	HF7	HF8	HF9
HF1	-	Small	Very small	Small	Very small	Moderate	Very small	Moderate	Big
HF2	None	-	Big	Big	Big	Big	Moderate	Moderate	Very big
HF3	None	Small	-	Small	Small	Moderate	Very small	Very small	Moderate
HF4	None	Small	Small	-	Moderate	Moderate	Very small	Big	Moderate
HF5	None	Big	Moderate	Small	-	Big	Very small	Small	Big
HF6	None	Very big	Moderate	Moderate	Moderate	-	Big	Big	Very big
HF7	None	Very small	Small	Small	Small	Moderate	-	Small	Moderate
HF8	None	None	Very small	Moderate	Very small	Small	None	-	Moderate
HF9	None	Moderate	Very small	Moderate	Moderate	Big	Very small	Moderate	-

Table H.2. Initial state vector created by Participant1 by applying linguistic terms. The second stage of the MALFCMs method

	HF1	HF2	HF3	HF4	HF5	HF6	HF7	HF8	HF9
	Low	Medium	Very low	Medium	None	Low	Very low	Very low	High

Table H.3. Interaction matrix created by Participant2 by applying linguistic terms. The second stage of the MALFCMs method

	HF1	HF2	HF3	HF4	HF5	HF6	HF7	HF8	HF9
HF1	-	Very small	Moderate	Moderate	Moderate	Small	Big	Big	Moderate
HF2	None	-	Big	Very big	Very big	Very very big	Very big	Very big	Moderate
HF3	None	None	-	Small	Moderate	Big	Big	Big	Small
HF4	None	Very small	Moderate	-	Moderate	Moderate	Moderate	Big	Big
HF5	None	Small	Moderate	Very small	-	Moderate	Small	Moderate	Moderate
HF6	None	Very small	Very small	Small	Small	-	Moderate	Moderate	Moderate
HF7	None	Moderate	Big	Moderate	Big	Big	-	Big	Moderate
HF8	None	Small	None	Small	None	Moderate	Big	-	Small
HF9	None	Big	Moderate	Small	Small	Moderate	Moderate	Moderate	-

Table H.4. Initial state vector created by Participant2 by applying linguistic terms. The second stage of the MALFCMs method

	HF1	HF2	HF3	HF4	HF5	HF6	HF7	HF8	HF9
	Medium	High	Very high	Very high	High	Very very high	Very high	Medium	Very high

Table H.5. Interaction matrix created by Participant3 by applying linguistic terms. The second stage of the MALFCMs method

	HF1	HF2	HF3	HF4	HF5	HF6	HF7	HF8	HF9
HF1	-	Very small	Moderate	Moderate	Moderate	Small	Big	Big	Moderate
HF2	None	-	Big	Very big	Very big	Very very big	Very big	Very big	Moderate
HF3	None	None	-	Small	Moderate	Big	Big	Big	Small
HF4	None	Very small	Moderate	-	Moderate	Moderate	Moderate	Big	Big
HF5	None	Small	Moderate	Very small	-	Moderate	Small	Moderate	Moderate
HF6	None	Very small	Very small	Small	Small	-	Moderate	Moderate	Moderate
HF7	None	Moderate	Big	Moderate	Big	Big	-	Big	Moderate
HF8	None	Small	None	Small	None	Moderate	Big	-	Small
HF9	None	Big	Moderate	Small	Small	Moderate	Moderate	Moderate	-

Table H.6. Initial state vector created by Participant3 by applying linguistic terms. The second stage of the MALFCMs method

	HF1	HF2	HF3	HF4	HF5	HF6	HF7	HF8	HF9
	Very very low	High	Medium	Medium	Low	Very high	Very high	Medium	Very high

Table H.7. Interaction matrix created by Participant4 by applying linguistic terms. The second stage of the MALFCMs method

	HF1	HF2	HF3	HF4	HF5	HF6	HF7	HF8	HF9
HF1	-	Big	Moderate	Big	Very big	Big	Moderate	Big	Big
HF2	None	-	Big	Very big	Very big	Very very big	Very very big	Very big	Very very big
HF3	None	Moderate	-	Moderate	Moderate	Moderate	Big	Moderate	Moderate
HF4	None	Big	Big	-	Big	Big	Big	Very big	Very very big
HF5	None	Very big	Big	Very big	-	Big	Very big	Very big	Big
HF6	None	Moderate	Moderate	Big	Very big	-	Very big	Very big	Moderate
HF7	None	None	Moderate	Very small	Very big	Very very big	-	Big	None
HF8	None	Moderate	Moderate	Big	Small	Moderate	Very small	-	None
HF9	None	Moderate	Moderate	Moderate	Big	Big	Big	Big	-

Table H.8. Initial state vector created by Participant4 by applying linguistic terms. The second stage of the MALFCMs method

	HF1	HF2	HF3	HF4	HF5	HF6	HF7	HF8	HF9
	High	Very high	High	High	High	Medium	High	Medium	Medium

Table H.9. Interaction matrix created by Participant5 by applying linguistic terms. The second stage of the MALFCMs method

	HF1	HF2	HF3	HF4	HF5	HF6	HF7	HF8	HF9
HF 1	-	Very small	Big	Very big	Big	Very small	None	Big	Moderate
HF 2	None	-	Very big	Big	Big	Big	Very small	Big	Very big
HF 3	None	Small	-	Very big	Very very big	Very big	Small	Very big	Big
HF 4	None	None	None	-	Small	Small	None	Very very big	Very small
HF 5	None	Moderate	Moderate	Big	-	Very big	Very small	Big	Very big
HF 6	None	Big	Very big	Very big	Big	-	None	Big	Very very big
HF 7	None	Big	Very very big	Big	Very big	Big	-	Big	Very very big
HF 8	None	None	Small	Moderate	Very small	Small	Very small	-	Small
HF 9	None	Big	Moderate	Moderate	Big	Very big	Very small	Small	-

Table H.10. Initial state vector created by Participant5 by applying linguistic terms. The second stage of the MALFCMs method

	HF1	HF2	HF3	HF4	HF5	HF6	HF7	HF8	HF9
	Medium	Very high	Very high	Low	Very high	High	Low	Medium	High

I QUESTIONNAIRE APPLIED TO LINK HUMAN ACCIDENT-CONTRIBUTING FACTORS AND RESILIENCE ABILITIES

Expert Background

1) The main area of expertise (e.g. surveyor, seafarer, academic, etc.):

2) How many years of experience do you have in your area of expertise?

Please, answer from 1 to 5, where 1 represents the lowest score, the following questions:

3) What is your **level of knowledge regarding human factors**?

1	2	3	4	5

4) What is your **level of knowledge regarding the concept of resilience**?

1	2	3	4	5

5) What is your **level of knowledge regarding shipping safety**?

1	2	3	4	5

6) What is your **level of knowledge regarding shipping operations**?

1	2	3	4	5

7) What is your **level of knowledge regarding accident investigations**?

1	2	3	4	5

Block A Questions

Please, provide an answer to the following questions by taking into account the following resilience abilities:

- **Learning:** Ability associated with knowing what happened in the past, receiving knowledge from past events.
- **Responding:** Ability to behave and respond when an unfolding event takes place.
- **Anticipating:** Ability to predict a future outcome and take action to prevent it.
- **Monitoring:** Ability to detect and respond in consequence when an unexpected event takes place.
- **Management Commitment:** Ability that recognizes and addresses the human performance concerns by top management.
- **Reporting Culture:** Ability that involves reporting the issues up through the organization.
- **Awareness:** Gathering data and information that makes management insightful about what is going on at a company.
- **Flexibility:** Ability of a system to adapt to new challenges or complex problems.
- **Teamwork:** Work done by persons working as a team.
- **Redundancy:** Duplication of systems' critical components or resources to increase the reliability of the system.
- **Fault-tolerance:** Ability that enables a system to continue operating properly in the event of the failure of some of its components.

1) Based on previous accident reports, **commercial pressure** is identified as a common contributor factor to maritime accidents.

In your opinion, which of the following resilience abilities could help to prevent or to reduce the negative effect of a **commercial pressure**?

Resilience abilities	Please, list all applicable abilities
1) Learning **2) Responding** **3) Anticipating**. **4) Monitoring** **5) Management Commitment** **6) Reporting Culture** **7) Awareness** **8) Flexibility** **9) Teamwork** **10) Redundancy** **11) Fault-tolerance** **12) None** **13) I do not know**	

2) Based on previous accident reports, **environmental and/or external factors** are identified as a common contributor factor to maritime accidents.

In your opinion, which of the following resilience abilities could help to prevent or to reduce the negative effect of **environmental and/or external factors**?

Resilience abilities	Please, list all applicable abilities
1) Learning **2) Responding** **3) Anticipating**. **4) Monitoring** **5) Management Commitment** **6) Reporting Culture** **7) Awareness** **8) Flexibility** **9) Teamwork** **10) Redundancy** **11) Fault-tolerance** **12) None** **13) I do not know**	

3) Based on previous accident reports, an **improper design, installation and/or working environment** is identified as a common contributor factor to maritime accidents.

In your opinion, which of the following resilience abilities could help to prevent or to reduce the negative effect of **improper design, installation and/or working environment**?

Resilience abilities	Please, list all applicable abilities
1) Learning **2) Responding** **3) Anticipating**. **4) Monitoring** **5) Management Commitment** **6) Reporting Culture** **7) Awareness** **8) Flexibility** **9) Teamwork** **10) Redundancy** **11) Fault-tolerance** **12) None** **13) I do not know**	

4) Based on previous accident reports, **inadequate leadership and supervision** is identified as a common contributor factor to maritime accidents.

In your opinion, which of the following resilience abilities could help to prevent or to reduce the negative effect of **inadequate leadership and supervision**?

Resilience abilities	Please, list all applicable abilities
1) Learning **2) Responding** **3) Anticipating**. **4) Monitoring** **5) Management Commitment** **6) Reporting Culture** **7) Awareness** **8) Flexibility** **9) Teamwork** **10) Redundancy** **11) Fault-tolerance** **12) None** **13) I do not know**	

5) Based on previous accident reports, **inadequate communication and coordination** is identified as a common contributor factor to maritime accidents.

In your opinion, which of the following resilience abilities could help to prevent or to reduce the negative effect of **inadequate communication and coordination**?

Resilience abilities	Please, list all applicable abilities
1) Learning **2) Responding** **3) Anticipating**. **4) Monitoring** **5) Management Commitment** **6) Reporting Culture** **7) Awareness** **8) Flexibility** **9) Teamwork** **10) Redundancy** **11) Fault-tolerance** **12) None** **13) I do not know**	

6) Based on previous accident reports, **improper or late maintenance** is identified as a common contributor factor to maritime accidents.

In your opinion, which of the following resilience abilities could help to prevent or to reduce the negative effect of **improper or late maintenance**?

Resilience abilities	Please, list all applicable abilities
1) Learning **2) Responding** **3) Anticipating**. **4) Monitoring** **5) Management Commitment** **6) Reporting Culture** **7) Awareness** **8) Flexibility** **9) Teamwork** **10) Redundancy** **11) Fault-tolerance** **12) None** **13) I do not know**	

7) Based on previous accident reports, **inadequate training** is identified as a common contributor factor to maritime accidents.

In your opinion, which of the following resilience abilities could help to prevent or to reduce the negative effect of **inadequate training**?

Resilience abilities	Please, list all applicable abilities
1) Learning **2) Responding** **3) Anticipating**. **4) Monitoring** **5) Management Commitment** **6) Reporting Culture** **7) Awareness** **8) Flexibility** **9) Teamwork** **10) Redundancy** **11) Fault-tolerance** **12) None** **13) I do not know**	

8) Based on previous accident reports, a **lack of safety culture** is identified as a common contributor factor to maritime accidents.

In your opinion, which of the following resilience abilities could help to prevent or reduce the negative effect of a **lack of safety culture**?

Resilience abilities	Please, list all applicable abilities
1) Learning **2) Responding** **3) Anticipating**. **4) Monitoring** **5) Management Commitment** **6) Reporting Culture** **7) Awareness** **8) Flexibility** **9) Teamwork** **10) Redundancy** **11) Fault-tolerance** **12) None** **13) I do not know**	

9) Based on previous accident reports, **inadequate procedures or the deviation from SOP** are identified as a common contributor factor to maritime accidents.

In your opinion, which of the following resilience abilities could help to prevent or to reduce the negative effect of **inadequate procedures or the deviation from SOP**?

Resilience abilities	Please, list all applicable abilities
1) Learning **2) Responding** **3) Anticipating**. **4) Monitoring** **5) Management Commitment** **6) Reporting Culture** **7) Awareness** **8) Flexibility** **9) Teamwork** **10) Redundancy** **11) Fault-tolerance** **12) None** **13) I do not know**	

10) Based on previous accident reports, **substandard monitoring** is identified as a common contributor factor to maritime accidents.

In your opinion, which of the following resilience abilities could help to prevent or to reduce the negative effect of **substandard monitoring**?

Resilience abilities	**Please, list all applicable abilities**
1) Learning **2) Responding** **3) Anticipating**. **4) Monitoring** **5) Management Commitment** **6) Reporting Culture** **7) Awareness** **8) Flexibility** **9) Teamwork** **10) Redundancy** **11) Fault-tolerance** **12) None** **13) I do not know**	

11) Based on previous accident reports, **unprofessional** behaviour is identified as a common contributor factor to maritime accidents.

In your opinion, which of the following resilience abilities could help to prevent or to reduce the negative effect of **unprofessional** behaviour?

Resilience abilities	**Please, list all applicable abilities**
1) Learning **2) Responding** **3) Anticipating**. **4) Monitoring** **5) Management Commitment** **6) Reporting Culture** **7) Awareness** **8) Flexibility** **9) Teamwork** **10) Redundancy** **11) Fault-tolerance** **12) None** **13) I do not know**	

J RESILIENCE ASSESSMENT QUESTIONNAIRE (RAQ)

Statement No	Topic: Lessons learned during operation	Strongly disagree	Disagree	Agree nor disagree	Agree	Strongly agree	Do not know
1	Crew members use lessons learned in their operations						
2	Crew members document lessons learned in their operations						
3	Crew members share lessons learned in their operations						
4	Crew members evaluate lessons learned in their operations						
5	There is a system in place for crew members to register lessons learned						
	Topic: Learn from other's experiences & accidents	Strongly disagree	Disagree	Agree nor disagree	Agree	Strongly agree	Do not know
6	Crew members use incident/accident information from other companies						
7	Crew members use success stories from outside the company						
8	There is a system in place for crew members to share successes and failures						
	Topic: Learn from own experiences & accidents	Strongly disagree	Disagree	Agree nor disagree	Agree	Strongly agree	Do not know
9	Crew members use their own incident/accident information						
10	Crew members use their success stories (e.g. what went right)						
11	There is a system in place for crew members to register incident/accident information						
	Topic: Communication between team members	Strongly disagree	Disagree	Agree nor disagree	Agree	Strongly agree	Do not know
12	There is a sufficient level of communications between crew members						
13	Crew members have sufficient communication skills						
14	A well-defined communication system and its SOP exists in the organization for any unexpected situation						
15	Information and communication systems are always available and reliable during unexpected situations						
16	The information provided by other actors (e.g. company, coastguard) during unexpected situations is understandable for all crew involved						
17	Crew members use a common language (e.g. English the official language) during unexpected situations						
18	The information is communicated to all actors during unexpected situations in a timely manner						
19	Information systems work properly during unexpected situations						
	Topic: Handling of exceptions (beyond day to day operations)	Strongly disagree	Disagree	Agree nor disagree	Agree	Strongly agree	Do not know
20	Crew members respond well to exceptions during normal operations						
21	Crew members conduct regular drills for the most likely exceptional situation						
22	Crew members are well prepared for handling exceptions						
23	Crew members have sufficient resources to respond to exceptions						
2425	Crew members have established who does what during exceptions						

	Topic: Criteria for safe operation well defined and understood	Strongly disagree	Disagree	Agree nor disagree	Agree	Strongly agree	Do not know
25	Criteria for safe operations are clearly defined						
26	Crew members understand well the criteria for safe operations						
	Topic: Understanding and willingness to use external support	**Strongly disagree**	**Disagree**	**Agree nor disagree**	**Agree**	**Strongly agree**	**Do not know**
27	Crew members understand that they can ask for external support if needed						
28	Crew members are willing to use external support if needed						
	Topic: Performance of roles, tasks, and responsibilities	**Strongly disagree**	**Disagree**	**Agree nor disagree**	**Agree**	**Strongly agree**	**Do not know**
29	Crew members perform their roles, tasks and take responsibilities as described						
30	Crew members have sufficient authority for the execution of their tasks						
31	Crew members know what is important when working						
32	Crew members have experience doing the work						
33	Crew members know the important safety procedures						
34	Crew members know the risks of their work						
35	Crew members have sufficient redundancy (e.g. back-up, substitute, etc.) and diversity in skills when manning levels are compromised						
36	Roles, tasks, and responsibilities of crew members are clearly defined						
37	Crew members know who does what and when						
38	Crew members know who is formally responsible for what						
	Topic: Training (simulators, table-top, preparedness..)	**Strongly disagree**	**Disagree**	**Agree nor disagree**	**Agree**	**Strongly agree**	**Do not know**
39	Crew members follow a shared training program						
40	Crew members are trained to respond to foreseen risk scenarios						
41	Crew members are trained to respond to unforeseen risk scenarios						
42	Crew members are trained to respond to emergency scenarios						
	Topic: Ability to make (correct) decisions	**Strongly disagree**	**Disagree**	**Agree nor disagree**	**Agree**	**Strongly agree**	**Do not know**
43	Crew members receive sufficient support when making critical decisions						
44	Crew members are aware of the type of critical decisions they are responsible to make and the potential consequences of incorrect decisions						
	Topic: Ability to deal with unforeseen operational demands	**Strongly disagree**	**Disagree**	**Agree nor disagree**	**Agree**	**Strongly agree**	**Do not know**
45	There are enough crew members available to respond appropriately to unforeseen operational demands						
46	Crew members receive sufficient training to make critical decisions						
47	Crew members are able to deal with unforeseen operational demands						
48	Crew members conduct exercises to handle unforeseen operational demands at the ship						
49	Crew members work with an up-to-date plan for handling unforeseen operational demands						
50	Crew members are well prepared for unforeseen operational demands						
51	Crew members have established ' who does what ' during unforeseen operational demands						

52	Crew members have sufficient resources to respond to unforeseen operational demands						
53	Crew members are sufficiently capable of handling a variety of disturbances and perturbations						
	Topic: System knowledge	**Strongly disagree**	**Disagree**	**Agree nor disagree**	**Agree**	**Strongly agree**	**Do not know**
54	Crew members know the functioning of onboard technical systems						
55	Crew members have insight into how technical systems may fail						
56	Crew members have knowledge about design limitations of the technical systems						
57	Crewmember understand how critical systems operate in both normal and emergency situations						
58	Crewmember have knowledge about interactions and interfaces between technical systems						
	Topic: Communicating risk at all levels of the organization	**Strongly disagree**	**Disagree**	**Agree nor disagree**	**Agree**	**Strongly agree**	**Do not know**
59	Risk information is properly communicated with crew members						
60	Risk information is available through various channels e.g. meetings, safety alerts, bulletins, etc.						
61	Risk information is easily accessible to all crew members						
62	Risk information can be easily understood by all crew members						
	Topic: Monitoring of resources	**Strongly disagree**	**Disagree**	**Agree nor disagree**	**Agree**	**Strongly agree**	**Do not know**
63	The presence of crew resources (e.g. time, means, people) is monitored during the operation						
64	The quality of crew resources (e.g. means, people) is monitored during the operation						
	Topic: Changes; technical, organizational, external	**Strongly disagree**	**Disagree**	**Agree nor disagree**	**Agree**	**Strongly agree**	**Do not know**
65	Any changes in the operation (e.g. technological, organizational, external) are well prepared						
66	Any changes in the operation (e.g. technological, organizational, external) are well thought out and planned						
67	Any changes in the operation (e.g. technological, organizational, external) are implemented with care for the safety						
68	Any changes in the operation (e.g. technological, organizational, external) are actively monitored for potential negative effects						
69	Any changes in the operation (e.g. technological, organizational, external) are prepared by people with the right expertise						
70	Any changes in the operation (e.g. technological, organizational, external) are well directed and controlled						
71	Any changes in the operation (e.g. technological, organizational, external) come as a surprise in the workplace						
72	Any changes in the operation (e.g. technological, organizational, external) are carried out in a safe manner, with due care						
	Topic: Focus on safety (safety versus other issues)	**Strongly disagree**	**Disagree**	**Agree nor disagree**	**Agree**	**Strongly agree**	**Do not know**
73	Crew members are committed and take safety seriously						
74	Crew members take safety seriously						
75	Crew members are committed to a safe and healthy working						

76	Crew members make well-deliberated trade-offs between safety and other goals						
	Topic: Process disturbances; control and safety system actions	**Strongly disagree**	**Disa gree**	**Agree nor disagree**	**Agree**	**Strongly agree**	**Do not know**
77	Crew members actively share information about (potential) technical failures of equipment (e.g. control systems, power systems, sensor systems)						
78	Crew members actively share information about (potential) loss of control during operational activities						
	Topic: Bypass of control and safety functions	**Strongly disagree**	**Disa gree**	**Agree nor disagree**	**Agree**	**Strongly agree**	**Do not know**
79	Compliance to safety functions (e.g. safety procedures) is monitored during operations						
80	By-passing or disabling safety functions/barriers/defenses is actively monitored						
81	By-passing or disabling safety functions/barriers/defenses is actively controlled and corrected						
	Topic: Activity level / simultaneous operations	**Strongly disagree**	**Disa gree**	**Agree nor disagree**	**Agree**	**Strongly agree**	**Do not know**
82	In periods with high activity or a high number of simultaneous operations crew members are highly vigilant on the possibility that something might go wrong						
83	In periods with high activity or a high number of simultaneous operations crewmembers perform additional risk assessments to control for potential negative side effects						
84	In periods with high activity or a high number of simultaneous operations crew members monitor (potential) unexpected interactions between operations and/ or activities						

K EXPERT OPINION COLLECTED FOR THE SECOND STAGE OF MALFCMS METHOD ON PASSENGER SHIPS

Table K.1. Interaction matrix created by Participant1 by applying linguistic terms. The second stage of the Marine Accident Learning with Fuzzy Cognitive Maps (MALFCMs) method

	HF threat 1	HF threat 2	HF threat 3	HF threat 4	HF threat 5	HF threat 6	HF threat 7	HF threat 8
HF threat 1	-	None	None	None	None	Small	Very small	Very big
HF threat 2	None	-	None	None	None	None	Very small	Moderate
HF threat 3	None	None	-	Small	Very small	Very small	Very small	Big
HF threat 4	Small	None	None	-	Big	Moderate	Big	Very big
HF threat 5	Moderate	None	None	Big	-	Very small	Moderate	Big
HF threat 6	None	None	None	Very small	Small	-	Small	Moderate
HF threat 7	None	None	None	Small	Small	Very small	-	Moderate
HF threat 8	Moderate	None	None	Moderate	Moderate	Very small	Very small	-

Table K.2. Initial state vector created by Participant1 by applying linguistic terms. The second stage of the MALFCMs method

HF threat 1	HF threat 2	HF threat 3	HF threat 4	HF threat 5	HF threat 6	HF threat 7	HF threat 8
Medium	Medium	Low	High	Medium	High	Very high	Low

Table K.3. Interaction matrix created by Participant2 by applying linguistic terms. The second stage of the Marine Accident Learning with Fuzzy Cognitive Maps (MALFCMs) method

	HF threat 1	HF threat 2	HF threat 3	HF threat 4	HF threat 5	HF threat 6	HF threat 7	HF threat 8
HF threat 1	-	None	None	Big	Moderate	Big	Small	Moderate
HF threat 2	Very small	-	None	None	Small	Moderate	Very small	Moderate
HF threat 3	None	None	-	Very small	Moderate	Big	Moderate	Moderate
HF threat 4	Big	None	None	-	Very big	Very big	Big	Moderate
HF threat 5	Small	None	None	Small	-	Small	Moderate	Moderate
HF threat 6	Small	None	None	Moderate	Big	-	Big	Moderate
HF threat 7	None	None	None	None	Moderate	Big	-	Small
HF threat 8	Moderate	None	None	Big	Small	Moderate	Moderate	-

Table K.4. Initial state vector created by Participant2 by applying linguistic terms. The second stage of the MALFCMs method

HF threat 1	HF threat 2	HF threat 3	HF threat 4	HF threat 5	HF threat 6	HF threat 7	HF threat 8
High	High	Medium	High	High	Very high	Very high	Very high

Table K.5. Interaction matrix created by Participant3 by applying linguistic terms. The second stage of the Marine Accident Learning with Fuzzy Cognitive Maps (MALFCMs) method

	HF threat 1	HF threat 2	HF threat 3	HF threat 4	HF threat 5	HF threat 6	HF threat 7	HF threat 8
HF threat 1	-	None	None	Small	Small	Small	None	Big
HF threat 2	None	-	None	Very small	Small	Small	Very small	Big
HF threat 3	None	None	-	None	None	Moderate	None	Big
HF threat 4	Small	None	None	-	Small	Big	Moderate	Moderate
HF threat 5	Moderate	None	None	Very big	-	Very big	None	Very small
HF threat 6	None	None	None	Very big	Small	-	Moderate	Moderate
HF threat 7	None	None	None	Big	None	Very big	-	Small
HF threat 8	Small	None	None	Big	None	Big	Very small	-

Table K.6. Initial state vector created by Participant3 by applying linguistic terms. The second stage of the MALFCMs method

HF threat 1	HF threat 2	HF threat 3	HF threat 4	HF threat 5	HF threat 6	HF threat 7	HF threat 8
Medium	Low	Very very low	High	Low	Very high	Medium	Very high

Table K.7. Interaction matrix created by Participant4 by applying linguistic terms. The second stage of the Marine Accident Learning with Fuzzy Cognitive Maps (MALFCMs) method

	HF threat 1	HF threat 2	HF threat 3	HF threat 4	HF threat 5	HF threat 6	HF threat 7	HF threat 8
HF threat 1	-	None	None	Moderate	Big	Big	Moderate	Moderate
HF threat 2	Big	-	None	Moderate	Moderate	Big	Moderate	Small
HF threat 3	Moderate	None	-	Big	Very big	Moderate	Moderate	Big
HF threat 4	Moderate	None	None	-	Very big	Very very big	Big	Very very big
HF threat 5	Small	None	None	Very big	-	Very big	Big	Big
HF threat 6	None	None	None	None	Very big	-	Moderate	None
HF threat 7	None	None	None	Moderate	Moderate	Big	-	Moderate
HF threat 8	Very small	None	None	Moderate	Big	Big	Moderate	-

Table K.8. Initial state vector created by Participant4 by applying linguistic terms. The second stage of the MALFCMs method

HF threat 1	HF threat 2	HF threat 3	HF threat 4	HF threat 5	HF threat 6	HF threat 7	HF threat 8
Medium	Medium	High	Very high	High	High	High	Medium

Table K.9. Interaction matrix created by Participant5 by applying linguistic terms. The second stage of the Marine Accident Learning with Fuzzy Cognitive Maps (MALFCMs) method

	HF threat 1	HF threat 2	HF threat 3	HF threat 4	HF threat 5	HF threat 6	HF threat 7	HF threat 8
HF threat 1	-	None	None	Very small	Very small	None	Very big	Moderate
HF threat 2	None	-	None	Very small	Big	None	Moderate	Very small
HF threat 3	Very small	None	-	Very small	Big	None	Big	Moderate
HF threat 4	None	None	None	-	Big	Very small	Very big	Very big
HF threat 5	Very small	None	None	Moderate	-	Very small	Moderate	Very big
HF threat 6	Big	None	None	Big	Very big	-	Very very big	Very very big
HF threat 7	Moderate	None	None	Small	Very very big	Small	-	Big
HF threat 8	Very small	None	None	Big	Big	Very small	Moderate	-

Table K.10. Initial state vector created by Participant5 by applying linguistic terms. The second stage of the MALFCMs method

HF threat 1	HF threat 2	HF threat 3	HF threat 4	HF threat 5	HF threat 6	HF threat 7	HF threat 8
Very high	High	Medium	Very high	Very high	Low	Very high	High

L EXPERT OPINION COLLECTED TO ESTABLISH A LINK AMONGST HUMAN FACTORS AND RESILIENCE ABILITIES

Table L.1. Participant1: Link amongst human factors and resilience abilities.

Human Factors	Resilience Abilities
Commercial pressure	Anticipating
Effect of environmental and external factors	Monitoring
Improper design, installation, and working environment	Fault-tolerance, Learning
Inadequate leadership and supervision	Reporting culture
Lack of communication and coordination	Teamwork, Management commitment
Lack of, improper or late maintenance	Redundancy, Monitoring
Lack of training	Awareness, Management commitment
Safety culture	Reporting culture, Learning
Safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)	Reporting culture
Safety management system: Substandard monitoring	Fault-tolerance
Unprofessional behaviour	Learning

Table L.2. Participant2: Link amongst human factors and resilience abilities.

Human Factors	Resilience Abilities
Commercial pressure	Management commitment, Teamwork, Learning, Monitoring, Anticipating, Reporting culture, Redundancy
Effect of environmental and external factors	Awareness, Learning, Monitoring, Flexibility, Redundancy
Improper design, installation, and working environment	Management commitment, Awareness, Reporting culture, Learning
Inadequate leadership and supervision	Teamwork, Management commitment, Awareness, Reporting culture
Lack of communication and coordination	Teamwork, Reporting culture, Awareness, Monitoring, Learning
Lack of, improper or late maintenance	Monitoring, Awareness
Lack of training	Management commitment, Learning
Safety culture	Management commitment, Learning, Teamwork, Reporting culture
Safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)	Management commitment, Learning, Awareness
Safety management system: Substandard monitoring	Learning, Monitoring, Awareness
Unprofessional behaviour	Teamwork

Table L.3. Participant3: Link amongst human factors and resilience abilities.

Human Factors	Resilience Abilities
Commercial pressure	Awareness, Redundancy, Anticipating
Effect of environmental and external factors	Monitoring, Reporting culture, Awareness
Improper design, installation, and working environment	Learning, Redundancy, Flexibility, Teamwork, Management commitment, Reporting culture
Inadequate leadership and supervision	Management commitment, Responding, Fault-tolerance
Lack of communication and coordination	Responding, Monitoring, Reporting culture, Management commitment, Teamwork, Awareness
Lack of, improper or late maintenance	Responding, Reporting culture
Lack of training	Learning, Awareness
Safety culture	Reporting culture, Management commitment
Safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)	Awareness, Monitoring
Safety management system: Substandard monitoring	Management commitment, Teamwork
Unprofessional behaviour	Learning, Management commitment, Teamwork

Table L.4. Participant4: Link amongst human factors and resilience abilities.

Human Factors	Resilience Abilities
Commercial pressure	Management commitment, Awareness, Anticipating, Reporting culture
Effect of environmental and external factors	Redundancy, Anticipating, Responding, Monitoring
Improper design, installation, and working environment	Redundancy, Management commitment, Teamwork, Anticipating, Monitoring, Responding, Reporting culture
Inadequate leadership and supervision	Management commitment, Monitoring, Teamwork
Lack of communication and coordination	Teamwork, Reporting culture, Management commitment, Monitoring, Learning
Lack of, improper or late maintenance	Fault-tolerance, Flexibility, Redundancy, Reporting culture
Lack of training	Management commitment, Reporting culture
Safety culture	Anticipating, Responding, Monitoring, Reporting culture, Learning
Safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)	Reporting culture, Management commitment
Safety management system: Substandard monitoring	Anticipating, Responding, Reporting culture
Unprofessional behaviour	Monitoring, Reporting culture

Table L.5. Participant5: Link amongst human factors and resilience abilities.

Human Factors	Resilience Abilities
Commercial pressure	Anticipating, Monitoring, Management commitment
Effect of environmental and external factors	Monitoring, Learning, Awareness
Improper design, installation, and working environment	Redundancy, Monitoring, Learning, Teamwork, Reporting culture, Management commitment
Inadequate leadership and supervision	Reporting culture, Management commitment, Monitoring
Lack of communication and coordination	Responding, Reporting culture, Monitoring, Learning, Teamwork
Lack of, improper or late maintenance	Monitoring, Reporting culture, Responding
Lack of training	Learning, Responding, Awareness
Safety culture	Reporting culture, Management commitment, Monitoring
Safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)	Monitoring, Awareness, Management commitment
Safety management system: Substandard monitoring	Monitoring, Management commitment, Anticipating
Unprofessional behaviour	Learning, Reporting culture, Management commitment

Table L.6. Participant6: Link amongst human factors and resilience abilities.

Human Factors	Resilience Abilities
Commercial pressure	Teamwork
Effect of environmental and external factors	Monitoring
Improper design, installation, and working environment	Learning, Awareness
Inadequate leadership and supervision	Teamwork
Lack of communication and coordination	Reporting culture, Teamwork
Lack of, improper or late maintenance	Monitoring
Lack of training	Teamwork
Safety culture	Management commitment
Safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)	Management commitment
Safety management system: Substandard monitoring	Anticipating
Unprofessional behaviour	Management commitment

Table L.7. Participant7: Link amongst human factors and resilience abilities.

Human Factors	Resilience Abilities
Commercial pressure	Management commitment, Learning, Teamwork, Awareness, Anticipating
Effect of environmental and external factors	Reporting culture, Flexibility
Improper design, installation, and working environment	Learning, Monitoring, Awareness, Teamwork
Inadequate leadership and supervision	Teamwork, Learning, Management commitment
Lack of communication and coordination	Management commitment, Learning, Teamwork
Lack of, improper or late maintenance	Learning, Teamwork
Lack of training	Learning, Awareness
Safety culture	Learning, Reporting culture
Safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)	Management commitment, Awareness
Safety management system: Substandard monitoring	Monitoring
Unprofessional behaviour	Learning

Table L.8. Participant8: Link amongst human factors and resilience abilities.

Human Factors	Resilience Abilities
Commercial pressure	Awareness, Anticipating, Teamwork, Reporting culture
Effect of environmental and external factors	Awareness, Monitoring, Anticipating
Improper design, installation, and working environment	Awareness, Learning, Monitoring, Responding, Teamwork, Anticipating, Fault-tolerance
Inadequate leadership and supervision	Teamwork, Reporting culture, Flexibility, Fault-tolerance
Lack of communication and coordination	Teamwork, Reporting culture, Awareness, Responding, Management commitment
Lack of, improper or late maintenance	Awareness, Monitoring, Reporting culture
Lack of training	Learning, Monitoring, Teamwork
Safety culture	Learning, Awareness
Safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)	Learning, Monitoring, Teamwork
Safety management system: Substandard monitoring	Monitoring, Teamwork
Unprofessional behaviour	Monitoring, Learning, Awareness

Table L.9. Participant9: Link amongst human factors and resilience abilities.

Human Factors	Resilience Abilities
Commercial pressure	Learning
Effect of environmental and external factors	Anticipating
Improper design, installation, and working environment	Learning, Awareness, Monitoring, Reporting culture
Inadequate leadership and supervision	Management commitment, Reporting culture
Lack of communication and coordination	Reporting culture, Monitoring, Awareness
Lack of, improper or late maintenance	Monitoring, Awareness, Reporting culture
Lack of training	Monitoring, Responding
Safety culture	Monitoring, Management commitment
Safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)	Monitoring, Learning, Anticipating
Safety management system: Substandard monitoring	Reporting culture, Awareness
Unprofessional behaviour	Monitoring, Anticipating

Table L.10. Participant10: Link amongst human factors and resilience abilities.

Human Factors	Resilience Abilities
Commercial pressure	Awareness, Monitoring, Learning, Responding, Flexibility
Effect of environmental and external factors	Awareness, Monitoring, Learning, Flexibility
Improper design, installation, and working environment	Learning, Awareness, Flexibility, Reporting culture, Responding, Management commitment
Inadequate leadership and supervision	Learning, Awareness, Monitoring, Reporting culture
Lack of communication and coordination	Redundancy, Teamwork, Reporting culture, Flexibility, Fault-tolerance
Lack of, improper or late maintenance	Monitoring, Teamwork, Reporting culture
Lack of training	Learning, Management commitment
Safety culture	Learning, Management commitment
Safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)	Learning, Monitoring, Reporting culture, Flexibility
Safety management system: Substandard monitoring	Monitoring, Reporting culture, Teamwork
Unprofessional behaviour	Reporting culture, Responding

Table L.11. Participant11: Link amongst human factors and resilience abilities.

Human Factors	Resilience Abilities
Commercial pressure	Anticipating, Awareness, Learning, Monitoring, Teamwork, Reporting culture
Effect of environmental and external factors	Awareness, Responding, Monitoring
Improper design, installation, and working environment	Teamwork, Reporting culture, Learning, Awareness, Management commitment
Inadequate leadership and supervision	Reporting culture, Monitoring
Lack of communication and coordination	Reporting culture, Monitoring, Flexibility, Anticipating, Management commitment
Lack of, improper or late maintenance	Learning, Awareness, Redundancy, Responding
Lack of training	Awareness
Safety culture	Learning, Awareness, Reporting culture
Safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)	Responding, Awareness, Management commitment
Safety management system: Substandard monitoring	Learning, Anticipating
Unprofessional behaviour	Anticipating, Reporting culture, Management commitment

Table L.12. Participant12: Link amongst human factors and resilience abilities.

Human Factors	Resilience Abilities
Commercial pressure	Management commitment, Awareness
Effect of environmental and external factors	Flexibility, Monitoring
Improper design, installation, and working environment	Reporting culture, Learning, Fault-tolerance, Management commitment, Anticipating
Inadequate leadership and supervision	Management commitment, Teamwork, Awareness
Lack of communication and coordination	Management commitment, Awareness, Learning, Teamwork
Lack of, improper or late maintenance	Reporting culture, Anticipating, Redundancy, Fault-tolerance
Lack of training	Reporting culture, Learning, Management commitment
Safety culture	Management commitment, Reporting culture, Learning
Safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)	Reporting culture, Learning, Awareness
Safety management system: Substandard monitoring	Management commitment, Teamwork
Unprofessional behaviour	Management commitment, Reporting culture, Learning

Table L.13. Participant13: Link amongst human factors and resilience abilities.

Human Factors	Resilience Abilities
Commercial pressure	Redundancy, Flexibility, Monitoring
Effect of environmental and external factors	Anticipating, Awareness
Improper design, installation, and working environment	Learning, Responding, Management commitment, Awareness
Inadequate leadership and supervision	Management commitment, Teamwork
Lack of communication and coordination	Monitoring, Redundancy, Learning, Management commitment
Lack of, improper or late maintenance	Management commitment. Fault-tolerance
Lack of training	Management commitment, Learning
Safety culture	Management commitment, Learning
Safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)	Flexibility, Anticipating
Safety management system: Substandard monitoring	Monitoring, Anticipating
Unprofessional behaviour	Management commitment, Responding

Table L.14. Participant14: Link amongst human factors and resilience abilities.

Human Factors	Resilience Abilities
Commercial pressure	Management commitment, Learning, Awareness, Responding, Teamwork, Reporting culture
Effect of environmental and external factors	Responding, Anticipating, Fault-tolerance, Redundancy, Learning, Monitoring
Improper design, installation, and working environment	Monitoring, Anticipating, Teamwork, Reporting culture, Responding, Management commitment
Inadequate leadership and supervision	Management commitment, Teamwork, Reporting culture, Responding
Lack of communication and coordination	Teamwork, Management commitment, Reporting culture
Lack of, improper or late maintenance	Monitoring, Anticipating, Fault-tolerance, Reporting culture, Redundancy
Lack of training	Learning, Awareness, Management commitment
Safety culture	Learning, Anticipating, Monitoring, Management commitment, Awareness
Safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)	Management commitment, Learning, Reporting culture, Teamwork
Safety management system: Substandard monitoring	Monitoring, Reporting culture, Responding, Management commitment, Awareness
Unprofessional behaviour	Management commitment, Reporting culture, Teamwork, Learning, Responding

Table L.15. Participant15: Link amongst human factors and resilience abilities.

Human Factors	**Resilience Abilities**
Commercial pressure	Management commitment, Awareness, Monitoring, Anticipating, Responding, Learning, Flexibility
Effect of environmental and external factors	Learning, Responding, Monitoring, Flexibility, Teamwork, Redundancy, Fault-tolerance
Improper design, installation, and working environment	Redundancy, Fault-tolerance, Learning, Monitoring, Awareness, Management commitment, Reporting culture
Inadequate leadership and supervision	Management commitment, Reporting culture, Teamwork, Fault-tolerance
Lack of communication and coordination	Teamwork, Monitoring, Responding, Anticipating, Learning
Lack of, improper or late maintenance	Fault-tolerance, Redundancy, Monitoring, Awareness, Learning, Flexibility
Lack of training	Management commitment, Learning, Awareness, Reporting culture, Teamwork, Fault-tolerance, Redundancy
Safety culture	Management commitment, Reporting culture, Learning, Responding, Flexibility, Fault-tolerance, Redundancy
Safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)	Management commitment, Awareness, Reporting culture, Learning, Anticipating, Responding
Safety management system: Substandard monitoring	Management commitment, Reporting culture, Awareness, Learning, Responding, Teamwork, Flexibility
Unprofessional behaviour	Learning, Management commitment, Reporting culture, Monitoring, Awareness, Responding, Fault-tolerance

Table L.16. Participant16: Link amongst human factors and resilience abilities.

Human Factors	**Resilience Abilities**
Commercial pressure	Management commitment, Teamwork
Effect of environmental and external factors	Anticipating, Monitoring, Learning, Responding, Awareness
Improper design, installation, and working environment	Management commitment, Awareness, Fault-tolerance, Redundancy, Reporting culture
Inadequate leadership and supervision	Management commitment, Awareness, Flexibility
Lack of communication and coordination	Teamwork, Awareness, Management commitment, Reporting culture
Lack of, improper or late maintenance	Redundancy, Fault-tolerance, Flexibility, Responding, Monitoring, Anticipating, Learning
Lack of training	Management commitment, Awareness
Safety culture	Management commitment, Learning, Reporting culture, Responding, Anticipating, Monitoring, Awareness, Teamwork
Safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)	Reporting culture, Responding, Monitoring, Learning, Anticipating
Safety management system: Substandard monitoring	Monitoring, Responding, Learning, Anticipating, Management commitment
Unprofessional behaviour	Reporting culture, Learning, Awareness

Table L.17. Participant17: Link amongst human factors and resilience abilities.

Human Factors	Resilience Abilities
Commercial pressure	Redundancy, Flexibility, Management commitment, Anticipating, Responding, Learning
Effect of environmental and external factors	Anticipating, Monitoring, Responding, Learning, Redundancy, Flexibility, Teamwork
Improper design, installation, and working environment	Management commitment, Teamwork, Reporting culture, Awareness, Learning
Inadequate leadership and supervision	Management commitment, Teamwork, Reporting culture
Lack of communication and coordination	Responding, Monitoring, Reporting culture, Teamwork, Learning, Management commitment, Awareness
Lack of, improper or late maintenance	Monitoring, Anticipating, Awareness
Lack of training	Learning, Management commitment, Awareness
Safety culture	Management commitment, Reporting culture
Safety management system: Inadequate procedures or deviation from Standard Operating Procedure (SOP)	Management commitment, Reporting culture, Learning, Anticipating
Safety management system: Substandard monitoring	Monitoring, Reporting culture
Unprofessional behaviour	Learning, Awareness, Teamwork, Reporting culture, Monitoring

M RESILIENCE ASSESSMENT QUESTIONNAIRE (RAQ) PRESENTATION LETTER

Resilience Assessment Questionnaire (RAQ) Background

Shipping accidents are frequently reported to involve human error as the main cause of the accidents. This situation raises from the fact that traditional safety approach focusses on errors and unsafe behaviour rather than focussing on the abilities and skills that are available in human that help us to achieve safer operations.

As a result, statistical analysis report that human error contributes into more than 80% of shipping accidents but the same approach fails to identify the behaviour and skills that crewmembers developed to prevent accidental events.

Traditional safety management regime in the maritime sector focusses on accidents and develops reactive regulations to prevent re-occurrence, which results in two types of solutions: training and increased automation. However, which this approach envisaged safety improvements are not fully achieved.

Recently, a new safety approach has emerged, which is called the "Safety-II" approach. This approach considers positive behaviour and skills that allow shipping operation to succeed and maintain safety levels under varying conditions. This new safety approach is based on resilience engineering concepts and precepts. There are numerous definitions for the resilience engineering; nevertheless, a common interpretation is that resilience is the ability of a system to react to unforeseen or unexpected changes or disturbances to maintain safety of the operation by preventing failures and accidents. Hence, in a ship system, the main component that has the ability to be flexible and deal with unexpected situations is the crewmembers themselves. Therefore, it becomes essential to focus on the strengths of the crew and their resilient behaviour that contribute towards achieving safe operations.

Hence, this survey study aims to capture aforementioned resilience abilities that exist in a successful shipping company with a proven record of safety. Your feedback is very valuable to help this project, which aims to change the way safety viewed in shipping from a "reactive blame practice" to a "proactive collaborated approach".

Figure M.1. RAQ presentation letter