University of Piraeus

School of Industry and Shipping

Department of Maritime Studies

MSc Sustainability and Quality in the Marine Industry

SAFETY II CONCEPT – RESILIENCE ENGINEERING IN MARITIME TRANSPORT

Master Thesis

submitted to the Department of Maritime Studies of the University of Piraeus as part of the requirements for the award of the Postgraduate Diploma in ‘Sustainability and Quality in the Marine Industry’.

Submitted by:

Persefoni Vlachokyriakou

Supervised by:

Ass. Prof. Stefanos Chatzinikolaou

Piraeus, Greece

November 2024

Declaration Of Authenticity

“The person, who submits the Masters’ dissertation is fully responsible for the definition of the fair use of the material, which is based upon the following factors: the purpose and nature of the use (commercial, non-profitable or educational), the nature of the material which is used (part of the text, boards, shapes, pictures or maps), the percentage and the significance of the part, which is used in comparison to the whole, under copyright text, and of the possible consequences of this use in the purchase or the overall value of the copyright text.”

Three-member Examination Committee

The present Master Thesis was unanimously approved by the three-member Examination Committee appointed by the Department of Maritime Studies of the MSc program in "Sustainability and Quality in Marine Industry" in accordance with the Operating Regulation of the MSc program.

The members of the Committee were as follows:

- Assistant Prof. Stefanos Chatzinikolaou (supervisor)
- Associate Prof. Andreas Andrikopoulos (member)
- Prof. Fani Sakellariadou (member)

The approval of the Master Thesis by the Department of Maritime Studies of the University of Piraeus does not imply acceptance of the author's views.

Acknowledgments

I would like to express my deepest gratitude to Ass. Professor Stefanos Chatzinikolaou for giving me the opportunity to study this intriguing topic and for providing his valuable support and guidance during my research.

I then wish to thank Professor Fani Sakellariadou for the knowledge and experience shared throughout both my undergraduate and postgraduate studies.

I would also like to thank Associate Professor Andreas Andrikopoulos for dedicating time to review my thesis.

Last but certainly not least, I am grateful to my family, friends and colleagues who are always there to support and motivate me.

Table Of Contents

1. Introduction ... 1
2. Research Methodology ... 5
   2.1 Objectives ... 5
   2.2 Methodology ... 5
3. Literature Review ... 8
   3.1 Safety I ... 8
   3.2 Safety II ... 13
      3.2.1 Work-as-Imagined and Work-as-Done ... 15
   3.3 Resilience ... 16
   3.4 Resilience Engineering ... 18
      3.4.1 Complex Socio-Technical Systems ... 22
      3.4.2 Functional Resonance Analysis Method (FRAM) ... 24
   3.5 Safety III ... 28
   3.6 Comparison of safety concepts ... 30
   3.7 Application of Resilience Engineering in various industries ... 32
4. Case Study ... 38
   4.1 Applications of Resilience Engineering in the Maritime Industry ... 39
   4.2 Integration of the four abilities of Resilience Engineering in maritime operations ... 46
      4.2.1 Respond - Knowing what to do ... 46
      4.2.2 Monitor - Knowing what to look for ... 47
      4.2.3 Learn - Knowing what has happened ... 48
      4.2.4 Anticipate - Knowing what to expect ... 49
   4.3 Application of Resilience Engineering principles on an SMS form ... 52
   4.4 Discussion ... 65
5. Conclusions ... 67
Appendix I ... 69
Bibliography ... 71

Table Of Figures

Figure 1: Ship losses over the past decade (AGCS, 2023). 2
Figure 2: Accident Analysis & Risk Assessment Methods' distribution (Leonhardt, et al., 2009). 4
Figure 3 Methodology flowchart 7
Figure 4: The imbalance between things that go right and things that go wrong (Hollnagel, et al., 2015) 9
Figure 5: Things that go right and things that go wrong happen in different ways (Hollnagel, et al., 2015). 10
Figure 6: Safety by elimination and prevention (Hollnagel, et al., 2015) 10
Figure 7: Spread of disorder across a system using Safety I (Bastan, et al., 2019) 11
Figure 8 The set of potential outcomes (Leonhardt, et al., 2009) 13
Figure 9 Resilient system and less resilient system (RINA, n.d.) 17
Figure 10: Things that go wrong and things that go right happen in the same way (Hollnagel, et al., 2015) 18
Figure 11: Understanding everyday performance variability is the basis for safety (Hollnagel, et al., 2015) 19
Figure 12: The cornerstones of Resilience Engineering (Costa, et al., 2021) 20
Figure 13 Change in the system safety focus point (Furuta, 2015) 22
Figure 14: Relationships between the characteristics of complex STS (Saurin & Gonzalez, 2013) 23
Figure 15: Function or Activity aspects (Hollnagel, et al., 2014) 25
Figure 16 FRAM Method used to develop a FRAM model (Patriarca, et al., 2020). 26
Figure 17 Departure process modeled using FRAM (Adhita, et al., 2023) 27
Figure 18 BBS principle to incident prevention (Chen & Tian, 2012) 42
Figure 19 Left: Bridge Simulator, Right: Virtual Reality hardware. (Mallam, et al., 2019) 43
Figure 20 Applications of RE in Maritime Industry 45
Figure 21 Possible applications of the Resilience Engineering abilities in Maritime Operations 51

List Of Tables

Table 1. Adopted table of main characteristics of Safety I & Safety II (Hollnagel, et al., 2015). 14
Table 2. Adopted table of Resilience definitions (Righi, et al., 2015) 17
Table 3 Adopted table of Established Safety Approaches versus Resilience Engineering, Reproduced from (Kim, 2013) 21
Table 4 Adopted table of main characteristics of Safety I & Safety II, reproduced from (Hollnagel, et al., 2015) with the addition of current Safety approach and Safety III in the last two columns, reproduced from (Leveson, 2020) 30
Table 5 SEAHORSE Multi Level Resilience Matrix (Turan, et al., 2016) 40
Table 6 Adopted approach vs Resilience Engineering in Near Miss reporting. 64

Glossary

AHP: Analytic Hierarchy Process

AIS: Automatic Identification System

ASRS: Aviation Safety Reporting System

BBS: Behavior Based Safety

BN: Bayesian Network

BRM: Bridge Resource Management

BT: Bow Tie Method

CHIRP: Confidential Hazardous Incident Reporting Programme

CSTS: Complex Socio-Technical Systems

CREAM: Cognitive Reliability and Error Analysis Method

CRM: Crew Resource Management

DCS: Distributed Control Systems

DGPS: Differential Global Positioning System

DNV-GL: Det Norske Veritas Germanischer Lloyd

DWT: Deadweight Tonnage

HER: Electronic Health Records

ETA: Event Tree Analysis

FMEA: Failure Mode and Effect Analysis

FSA: Formal Safety Assessment

FTA: Fault Tree Analysis

FRAM: Functional Resonance Analysis Method

HAZOP: Hazard and Operability

HFI: Human Factors Integration

HROs: High Reliability Organizations

IACS: International Association of Ship Classification Societies

IALA: International Association of Marine Aids to Navigation and Lighthouse Authorities

ILO: International Labour Organization

IMO: International Maritime Organization

ISM: International Safety Management (Code)

MRM: Maritime Resource Management

M-SCAT: Marine Systematic Cause Analysis Technique

OCIMF: Oil Companies International Marine Forum

ORS: Open Reporting System

PIF: Performance Influencing Factor

PSM: Process Safety Management

RA: Risk Assessment

RAG: Resilience Assessment Grid

RE: Resilience Engineering

RCA: Root Cause Analysis

SIRE: Ship Inspection Report programme

SIS: Safety Instrumented Systems

SMS: Safety Management Systems

STAMP: System theory-based AcciMap, AcciNet, Systems-Theoretic Accident Model and Processes

STCW: International Convention on Standards of Training, Certification and Watchkeeping for Seafarers

STS: Socio-Technical Systems

UNCTAD: United Nations Conference on Trade and Development

WAD: Work-as-Done

WAI: Work-as-Imagined

WHO: World Health Organization

Abstract

In safety and risk management, the maritime industry tends to adopt reactive strategies. When accidents happen, the most common question that is asked is “why does something go wrong?”. A relevant investigation into the causes is conducted, however, an assessment of the safety level attained by the system that resulted to its general safe performance is not included in the investigation. This means that the current ideas of safety in the maritime sector need to be reviewed because it is likely that they have reached their limit. The Resilience Engineering concept, which prioritizes system performance over system failure, seems promising for the shipping industry.

This thesis delves into the practical implementation of Safety II principles and Resilience Engineering within the maritime transport industry, with the primary aim of enhancing operational resilience and safety outcomes. Safety II places a significant emphasis on dissecting routine tasks and identifying factors contributing to successful outcomes, while Resilience Engineering supplements this perspective with its four key abilities - learn, respond, monitor, and anticipate - providing a holistic framework to evaluate system performance under diverse conditions.

This research employs a case study approach to investigate the applicability of Safety II and Resilience Engineering principles in enhancing safety management systems within shipping companies. By examining a real-world scenario, the study aims to explore how these principles can be effectively implemented. The core objectives include the identification of areas for improvement, particularly from an adaptive and proactive safety standpoint. This involves a critical evaluation of the efficiency of traditional safety approaches within the rapidly evolving and intricate sector of maritime transport.

It is successfully highlighted in this study that there are aspects of the existing shipping operations that can adopt a resilience engineering perspective and integrate the theory’s abilities to learn, monitor, respond and anticipate. Moreover, it is concluded that there are grounds for the introduction and practical application of the resilience engineering principles in shipping, which can be achieved by integration into the Safety Management Systems.

Keywords: maritime transport, resilience engineering, safety II

1. Introduction

The maritime transport sector plays a significant role in international merchandise trade taking into consideration that almost 90% of global trade is transported by ships (ICS, 2020). UNCTAD projects maritime trade to grow on annual average of 2.1 % in the period 2023-2027. In fact, the total number of vessels and deadweight tonnage (DWT) have increased internationally in the previous decade (UNCTD, 2022). As the total number of vessels rises, it is commonly acknowledged that safety issues related to maritime trade will become more crucial (Adhita, et al., 2023).

For this purpose, the International Maritime Organization (IMO) regularly produces guidelines, codes and conventions in order to secure a safety level of shipping operations (Qiao, et al., 2021). For instance, the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) was adopted by IMO in 1978 to establish basic requirements on training, certification and watchkeeping for seafarers on an international level (IMO, 1978). In addition, considering the "human error" as the root cause of 80% of maritime accidents, a new type of training, the Maritime Resource Management (MRM) was launched in 1993, as a set of human factors, soft skills and non-technical training (Hernqvist, 2011).

Additionally, the International Safety Management (ISM) Code was established in 1993 to "ensure safety at sea and prevent damage to property, personnel and environment", following the capsizing of M/V Herald of Free Enterprise, which caused the highest death count of any peacetime maritime disaster, and other serious ship disasters of the late 1980s (IMO, 2018) (Adhita, et al., 2023). Besides the IMO, the safety of maritime operations is a concern of other international organizations, such as the International Association of Ship Classification Societies (IACS), the International Labour Organization (ILO) and the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA).

Although maritime accidents showed a declining trend in the recent years, the present situation is far from satisfactory (Qiao, et al., 2021). According to the "Safety & Shipping Review 2023", 3,032 shipping incidents occurred in 2022 and, despite the decrease in total losses, as depicted in Figure 1, the number of recorded shipping casualties or incidents rose during the year. Moreover, 526 serious shipping incidents took place between 2017 and 2020 that involved loss of life, major pollution or the total loss of a vessel. Globally, most of the 27,477 incidents reported over the past decade have been caused by machinery damage/failure (10,753), followed by collision (3,098) and wrecked/stranded (2,936). Over the past ten years in particular, there has been a tremendous improvement in maritime safety. It is also noted that 75% of the total shipping incidents involve human error. The worldwide fleet was losing more than 200 ships a year in the 1990s. By the end of 2022, this number had fallen to less than 40. Six years have passed since the last year with a triple-digit loss, as seen in the below figure (AGCS, 2023).

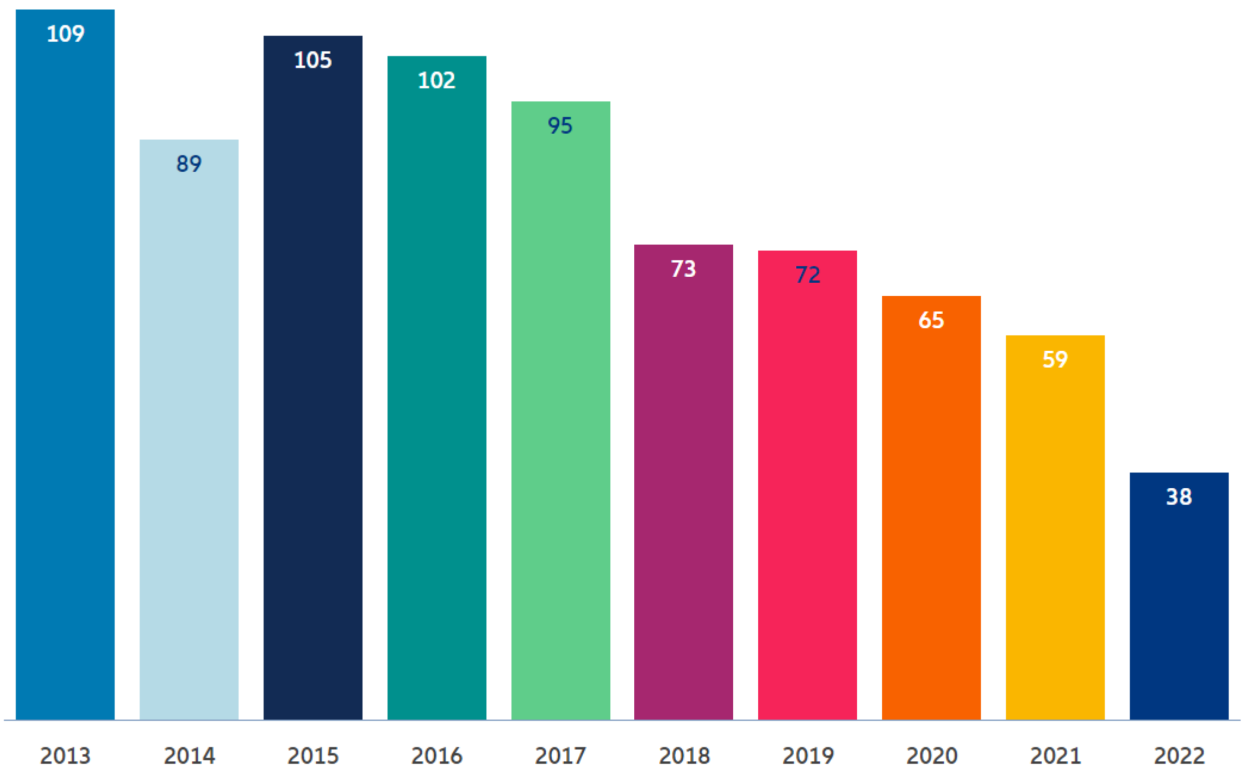

Figure 1: Ship losses over the past decade (AGCS, 2023).

The study of maritime transport accidents has evolved from being the sole domain of naval architects to a significant area including expertise from other disciplines. Social characteristics or technical aspects can be used to categorize the primary causes of accidents or incidents. As a result, it is essential to examine the issues associated with safety of maritime transportation from the perspective of complex sociotechnical systems and consider all the factors related to technology and society. Furthermore, the available data from marine incidents are not sufficient for cutting-edge technologies, like big data analysis and artificial neural network, which inspire pioneers and researchers to look into methodologies and address safety challenges of shipping operations (Qiao, et al., 2021).

Despite the implementation of numerous rules and regulations by organizations such as the IMO, catastrophic accidents continue to occur within the marine industry (Uyanık, et al., 2021). Therefore, it is crucial to understand why these accidents keep happening. Accident analysis is crucial in this situation because it helps identify the root causes of accidents and enables all parties involved to take preventive measures in the future. To pinpoint defects and the underlying causes of accidents, accident causation models may also be used. Future accidents can be avoided by recognizing this fact.

As a result, various accident analysis techniques have been put out and employed over time. The approaches that are most frequently employed in the literature are Event Tree Analysis (ETA), Fault Tree Analysis (FTA), Formal Safety Assessment (FSA), Bow-Tie Model (BT), Hazard and Operability (HAZOP), Risk Matrix and Cognitive Reliability and Error Analysis Method (CREAM), Failure Mode and Effect Analysis (FMEA), Analytic Hierarchy Process (AHP), Bayesian Network (BN) etc. (Ceylan, et al., 2022) (Peng, et al., 2022). The two analysis methods that have been found to be most often researched are System theory-based AcciMap, AcciNet, Systems-Theoretic Accident Model and Processes (STAMP) and Functional Resonance Accident Model (FRAM) (Ceylan, et al., 2022). Figure 2 illustrates the distribution of the commonly used methods of risk assessment and accidents analysis (Leonhardt, et al., 2009).

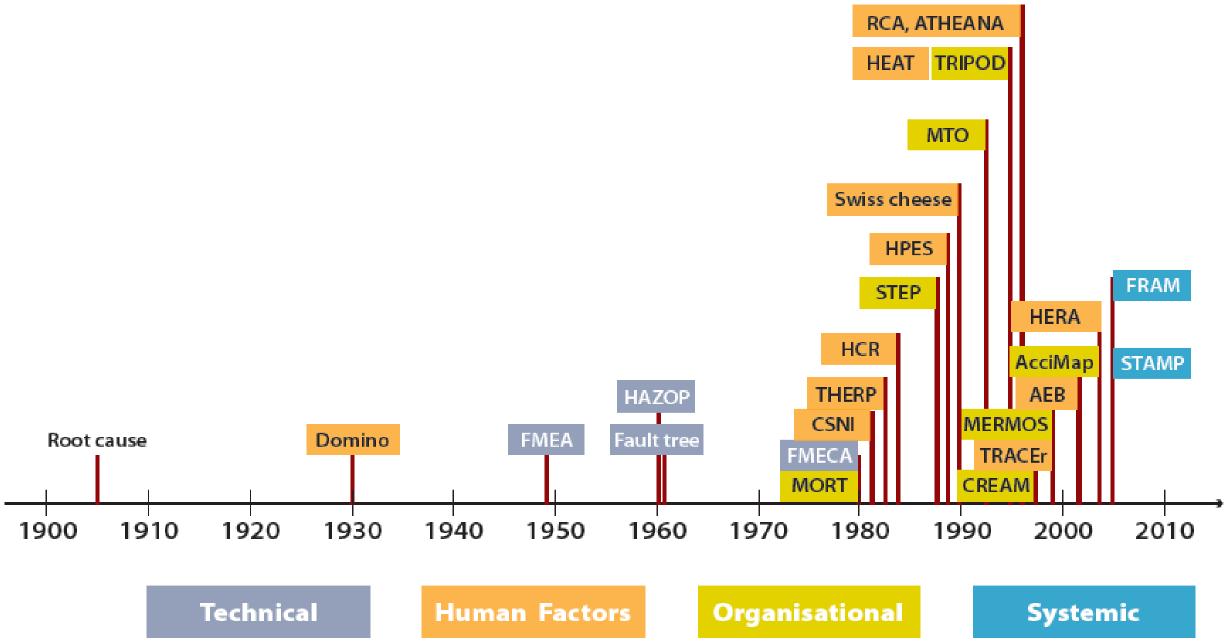

Figure 2: Accident Analysis & Risk Assessment Methods' distribution (Leonhardt, et al., 2009).

Resilience Engineering seems to offer a viable solution to this issue. RE provides a systemic framework by defining safety as a natural occurrence that results from complex sociotechnical systems. RE is necessary in safety analysis that focuses on the operation of the system and work-as-done and defines four pillars of system's resilience (monitor, learn, respond and anticipate). This concept has further led to the creation of a new safety terminology, the so called "Safety II" (Adhita, et al., 2023).

2. Research Methodology

2.1 Objectives

The main research questions of this study are the following:

1. Which are the available approaches for safety? How Safety I, Safety II, and Safety III, are defined?
2. What is Resilience Engineering and how it is applied in various industries? Are there implementation examples in the shipping industry?
3. Which of the existing tasks in the operation of a ship managing company could adopt a resilience engineering perspective?
4. How can the four abilities of resilient systems (i.e. learn, monitor, respond and anticipate) be applied in existing safety tasks and operations in the operation of a shipping company?
5. How can the principles of resilience engineering be integrated in the safety management system of a shipping company?

Potential answers to the research questions could be found in literature and academic works related to the subject safety approaches. Reports related to Resilience Engineering in various industries, including practical examples of the theory's application, may reveal specific tasks embracing this safety approach. Moreover, operational protocols and safety management systems of shipping companies may provide deeper understanding and actionable insights for the integration of the resilience principles.

2.2 Methodology

The analysis is based on literature, qualitative data, and documentation from the safety management systems of shipping companies. For the compilation of the first part, an overview of literature was carried out. The collection of qualitative data from secondary sources was preferred, as the most suitable tool to identify and present the main principles of Safety II and Resilience Engineering concepts and provide examples of their application in various industries and in maritime.

Using pertinent keywords, as resilience engineering, Safety II and maritime industry, a systematic investigation was carried out across databases holding scientific literature to determine the sources used in the study. Following that, certain studies were selected in accordance with their reliability and relevance to the research inquires. After completion of the previously described study, a thorough examination was carried out with the aim of deciding which serve best the purposes the thesis . To ensure the accuracy and reliability of the selected data, publications with solid scientific foundations were chosen. The framework for the study was based on the ideas of esteemed scientists, such as Erik Hollnagel, David Woods and Sidney Dekker and a few recent academic works which included application of the concepts in shipping.

In the first part of the thesis, the concepts of Safety I and Safety II are presented, Then, the concept of Safety III is discussed, and a comparison follows among these three safety perceptions. Moreover, the concept of Resilience Engineering is presented and a focus is made on the four abilities of resilient systems and the concept's practical applications in various industries.

In the second part of the study, the main objective is to explore possible applications of the Safety II and Resilience Engineering principles in the maritime transport sector. For this purpose, a case study approach is adopted on the basis of being the best way to address the specific research questions. Due to the contemporary nature of the research and the existence of recent data in scientific sources, the case study is expected to allow for a comprehensive examination of specific instances within the shipping industry and shed light on the implementation of resilience engineering principles in real-world contexts and daily operations.

Firstly, we elaborate on paradigm of resilience applications in maritime operations. Then, a shipping company is considered as an example, to investigate the application of resilience engineering's four abilities (i.e. learn, respond, monitor & anticipate) in real maritime transport scenarios.

This thesis is structured into 5 sections.

Section 1 lists introductory information and Section 2 presents the key objectives and the methodology followed.

Section 3 includes the literature review on the main concepts discussed (i.e. Safety I, Safety II and Safety II) as well as Resilience Engineering with its four abilities and its application in various industries, like aviation, healthcare and oil and gas.

Section 4 focusses on the application of Resilience Engineering in shipping, including the integration of the four abilities and the possibility of the concept's practical integration in a Shipping Company's SMS through a case study which uses and change real safety documentation and forms in use.

Section 5 summarizes the research findings, presents suggestions for industry stakeholders, and proposes ideas for future research.

The methodology flowchart of this research is illustrated below:

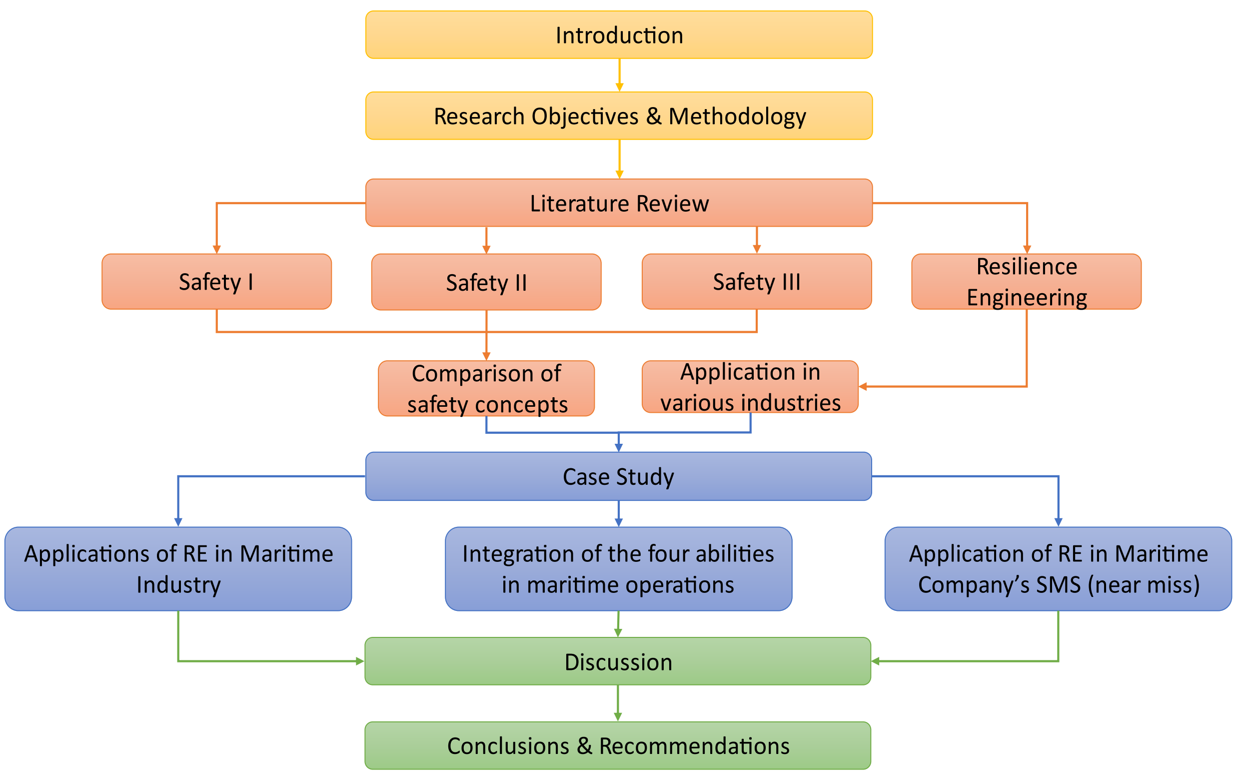

Figure 3 Methodology flowchart

3. Literature Review

3.1 Safety I

Since practically everyone uses and recognizes the word "safety", we often neglect to define it more precisely, because we assume that everyone else understands it in the same manner that we do (Hollnagel, et al., 2015). Defining and measuring Safety is a challenging task (Lofquist, 2010). The most common way to measure safety performance is by the occurrence of unforeseen outcomes or failures, which almost always have some sort of negative impact. These are referred to as accidents, incidents, near misses etc. We often look into these undesirable events in various ways depending on their severity in an effort to identify the so-called "root causes", a responsible party, and someone to hold accountable or punish (Dekker, 2012).

Safety is known as the system quality that needs to be met and is adequate to ensure that the number of occurrences that can be potentially dangerous to employees, the public or the environment is tolerably low. Patient safety, for example, is defined by the World Health Organization (WHO) as "the prevention of errors and adverse effects to patients associated with health care" (Hollnagel, et al., 2015). Safety is generally considered as the absence of incidents and accidents. In this approach, which is referred to as "Safety I", safety is defined as a condition where "as few things as possible go wrong". (Hollnagel, et al., 2015).

Safety concerns have historically been sparked by the occurrence of accidents (which have actual negative effects) or identified hazards (which may have potential negative outcomes). Things that go wrong have often been explained by looking into the probable causes. The solution has been either to eliminate them or to keep them in control. New types of causes have been introduced, such as those pertaining to technology, human element or the organization to account for new types of accidents. Throughout the decades we have become accustomed to explaining incidents in terms of cause-and-effect relations. However, this has been successful in offering quick remedies, and as a result, we no longer notice it. Despite the fact that it is getting more and more difficult to reconcile with reality, we strongly hold onto this tradition. Unfortunately, looking back and identifying weaknesses does not help to explain how they were created or why they persisted. (Hollnagel, et al., 2015).

Considering the potential consequences for property, the environment, and human life, safety is always a crucial and widely studied topic in a variety of industries (Yu, et al., 2021). In 1960s and 1980s, Safety I is how the traditional safety is referred to. This perspective was widespread in safety critical industries, such as nuclear and aviation. However, performance requirements were much lower back then than they are now, and systems were less complex and interdependent. (Hollnagel, et al., 2015). Safety I concept is still widely adopted though in numerous industries, including oil and gas. (Aven, 2021).

From a safety standpoint, efforts should be made to pinpoint the reasons and contributing variables that lead to a negative outcome, and people are frequently seen as liabilities or hazards, whether individually or collectively. Health care companies perform similar studies, frequently employing methods like Root Cause Analysis (RCA) to identify the various contributing elements that have come together in a way that has harmed patients. Although it's critical to comprehend "what went wrong," remedies should be properly thought out. A common response to a negative event is to try to standardize procedures, remove causative elements, and strengthen barriers. (Patterson & Deutsch, 2015).

Figure 4: The imbalance between things that go right and things that go wrong (Hollnagel, et al., 2015)

Figure 4 illustrates the consequences of considering safety as "what goes wrong". The probability of a failure is 1 out of 10,000 represented by the red line, while things are expected to go 9,999 times right out of 10,000 which corresponds to the green area (Hollnagel, et al., 2015).

From a Safety I perspective, works and activities are considered in a bimodal way, meaning that positive and negative events occur due to different modes of functioning. Acceptable outcomes occur when people and systems operate as they are intended to; while unacceptable outcomes occur because something failed to function as it should. Since the two modes are considered to be distinctly different, the safety management's goal, as per Safety I, is to make sure that the system always stays in the first mode and never enters the second, as per figure 5 below (Hollnagel, et al., 2013):

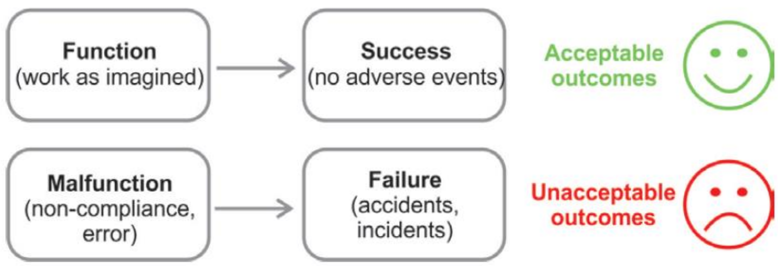

Figure 5: Things that go right and things that go wrong happen in different ways (Hollnagel, et al., 2015).

From this point of view, either a risk has been identified or something has gone wrong. A "find and fix" approach is applied for both situations; by identifying the hazards in order to take actions to control them, or by identifying the causes and formulating a suitable reaction (Hollnagel, et al., 2013). Another option is to prevent the state from shifting to "abnormal" from "normal", despite if this is the result of a sudden or a gradual change. To achieve this, as shown in figure 6, performance in the "normal" condition is constrained, compliance is strengthened, and variability is eliminated. Efforts are considered successful when the number of adverse outcomes becomes smaller (Hollnagel, et al., 2015).

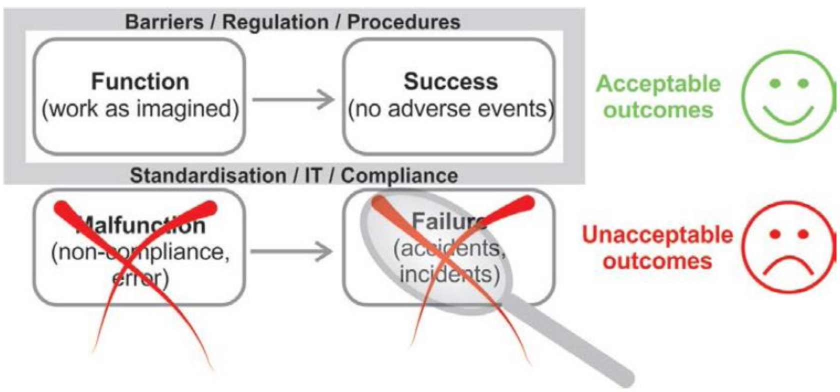

Figure 6: Safety by elimination and prevention (Hollnagel, et al., 2015)

Safety I is used to illustrate the fault propagation inside a system in figure 7. Four (4) fundamental elements, prevention, detection, tolerance, and strength are noticed on the different levels of the system:

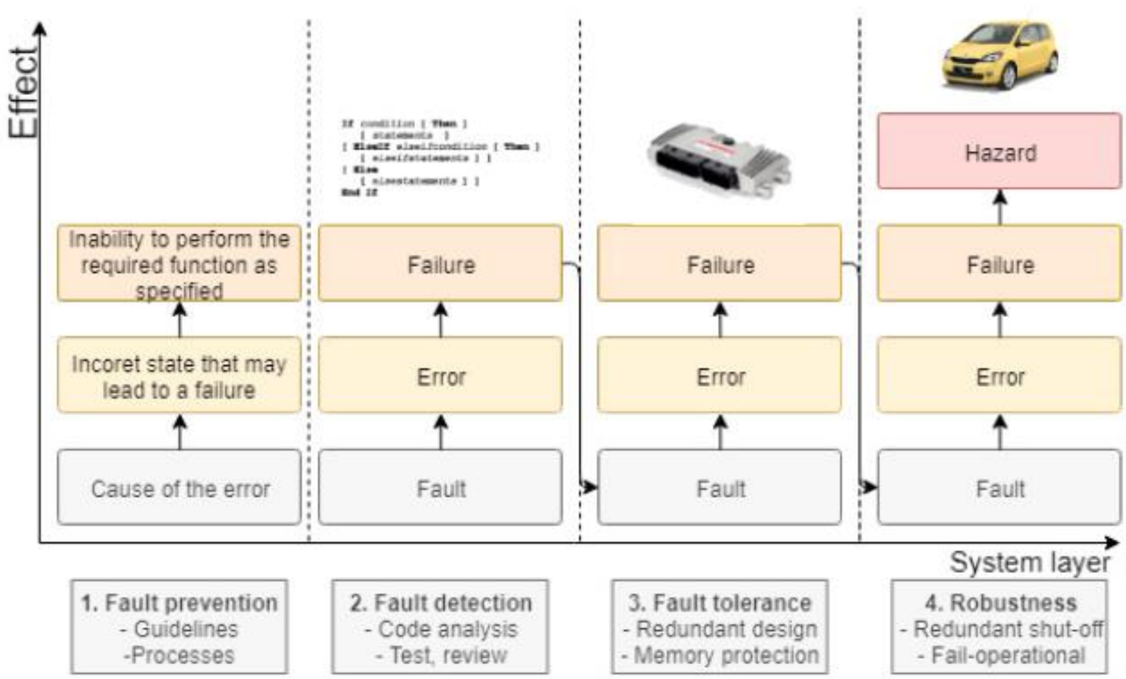

Figure 7: Spread of disorder across a system using Safety I (Bastan, et al., 2019)

Thus, the present method of developing a safe system that adheres to the Safety I concept spreads through the entire design process. First, best practices are followed in the system's design. Then, faults are corrected to increase tolerance after being identified through risk analyses.

Therefore, Safety I primarily attempts to learn from its own failures and safety is, as already discussed, ensured by the "absence" of harmful circumstances. As a result, this philosophy has a reactive approach and focuses firstly on identifying what goes wrong. This concept aims to pinpoint the root causes of accidents, prevent errors and thereby minimize losses. It is obvious that this approach is not flexible, and safety can only be attained by making components stiffer or reducing risks. To overstate this point, a safe airplane is, in line with Safety I philosophy, one that never takes off in reality (Bastan, et al., 2019).

In most cases, the linear approach in dealing with complex control issues only repositions us for the next unfavorable event and leads to unforeseen outcomes. This requires a new, proactive perspective that focuses more on the reasons why things succeed than why they fail (Hollnagel, 2014). For simpler systems, Safety I seems to be adequate, while for more and extremely complex systems its processes are insufficient and frequently unrealistic, because they take considerable time and are frequently expensive (Bastan, et al., 2019).

There is no literature available regarding the term “Safety I” in Maritime publications. However, the main focus of the safety management approach applied in the sector is to identify root causes of accidents and incidents. An example of this reactive method is the International Convention for the Safety of Life at Sea (SOLAS), which was first adopted in 1914 “in response to the Titanic disaster” (IMO, 1974). The International Safety Management (ISM) Code has been implemented in the sector, as part of SOLAS, to improve safety awareness and reduce incidents. The main components according to the Code for safety management systems include the risk assessment and the incident reporting. Risk assessments help identify the potential hazards and the risks associated with them. Then risk management actions are taken to reduce the likelihood of incidents. When incidents occur, they are reported and investigated to identify “what went wrong” to avoid recurrence. Moreover, to eliminate causes of incidents and improve safety barriers, regular inspections are required by the Code, including, for example, planned maintenance systems (IMO, 2018).

3.2 Safety II

Safety II is a concept within the safety management field which highlights the necessity of resilience and adaptability in risk management and safety assurance. Contrary to the Safety I way of thinking, Safety II is a relatively new and more proactive approach, which considers safety as "the ability to succeed under varying conditions" (Hollnagel, 2014). As a result, safety management should switch from making sure that "as few things as possible go wrong" to making sure that "as many things as possible go right" (Hollnagel, et al., 2015). This is fairly straightforward; in order to understand how things go right, we need to look at the 9,999 cases that this happens, instead of only focusing on the 1 cases where things go wrong (figure 4) (Hollnagel, et al., 2013). The set of potential outcomes can be also graphically represented in figure 8, in which y axis shows the outcome's value with range from negative to positive and the x axis shows the predictability with range from very low to very high (Leonhardt, et al., 2009).

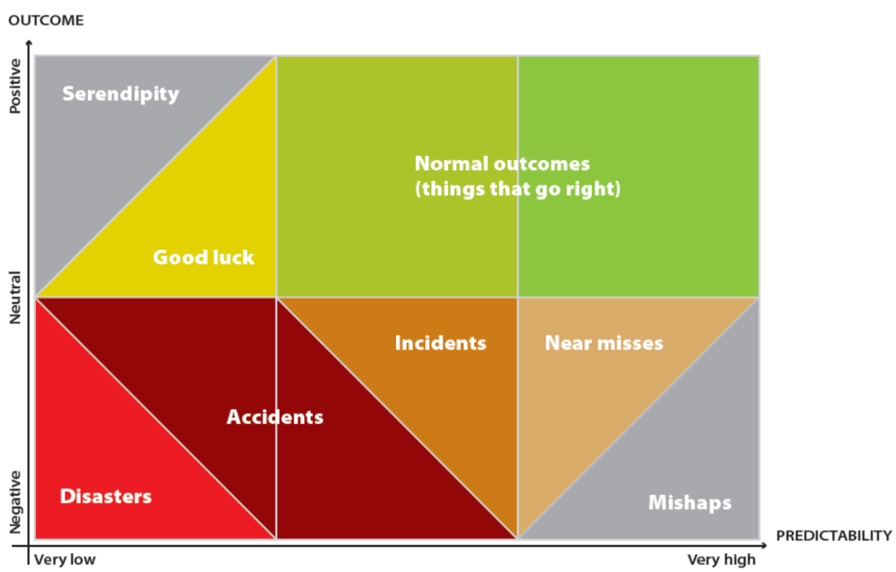

Figure 8 The set of potential outcomes (Leonhardt, et al., 2009)

From a Safety II perspective, people are the main asset to achieve safety (Hollnagel, et al., 2015). Rather than assuming that people work as expected, we should recognize that things go right as people are able to adapt to the current conditions and adjust their work to different circumstances (Hollnagel, et al., 2013). According to this philosophy, the cause of things going well derives from everyday performance variability and the adaptations required to respond to the varying conditions (Hollnagel, et al., 2015). As systems tend to become more complex and grow both horizontally and vertically, these adaptations are increasingly essential for safety performance and pose an obstacle and at the same time an opportunity for the safety management (Hollnagel, et al., 2013).

People usually employ a combination of Safety I and Safety II in their day-to-day work. Numerous factors, like the type of work, employee experience, organizational culture, management and client pressures, etc., affect the particular balance. Although it is common knowledge that prevention is preferable to therapy, there are situations in which prevention cannot always serve its intended purpose. The main objective of comparing Safety I and Safety II is to highlight the implications of relying solely on one for safety management. The following table provides a summary of the main characteristics and differences of the two theories (Hollnagel, et al., 2013):

Table 1. Adopted table of main characteristics of Safety I & Safety II (Hollnagel, et al., 2015)

Aspect	**Safety-I**	**Safety-II**
Definition of safety	That as few things as possible go wrong.	That as many things as possible go right.
Safety management principle	Reactive, respond when something happens or is categorized as an unacceptable risk.	Proactive, continuously trying to anticipate developments and events.
View of the human factor in safety management	Humans are predominantly seen as a liability or hazard. They are a problem to be fixed.	Humans are seen as a resource necessary for system flexibility and resilience. They provide flexible solutions to many potential problems.
Accident investigation	Accidents are caused by failures and malfunctions. The purpose of an investigation is to identify the causes.	Things basically happen in the same way, regardless of the outcome. The purpose of an investigation is to understand how things usually go right as a basis for explaining how things occasionally go wrong.
Risk assessment	Accidents are caused by failures and malfunctions. The purpose of an investigation is to identify causes and contributory factors.	To understand the conditions where performance variability can become difficult or impossible to monitor and control.

3.2.1 Work-as-Imagined and Work-as-Done

Work-as-Imagined (WAI) describes what should occur under typical working circumstances. On the other hand, Work-as-Done (WAD) is how work actually happens over time in complex circumstances. (Hollnagel, et al., 2015). Safety I considers that safety can be attained by making sure that WAD is carried out in accordance with WAI (Martins, et al., 2022). However, WAI presents an ideal view of the task environment and ignores the continuously changing conditions and relevant performance adaptations that need to be made (Hollnagel, et al., 2015). In complex adaptive systems, work unfolds differently than planned by those in charge of the procedures and regulations. Understanding the difference between WAD and WAI is a key component of Safety II (Martins, et al., 2022). This difference results from the inability to anticipate every circumstance that might occur during normal operations when the system in designed (Hollnagel, 2012).

Nowadays, systems are considered larger and more complex than those of the past in task analysis. Accordingly, we must have a deeper understanding of WAD than we currently have. Of course, this is not a brand-new subject; in the past, many researchers have focused on it (Hollnagel, 2012). At the operational level, the difference between WAD and WAI is another indicator of resilience.

It is inevitable that our thinking of WAI is not sufficient, unless completely incorrect, because WAD reflects the reality that people need to handle as a matter of fact. This represents a constructive challenge to the conventional ideas and procedures regarding ergonomics, human factors, and safety engineering. If we continue to try to tackle the issues of the present using the models, theories, and methods of the past, we may unintentionally create the complexity of the future (Hollnagel, 2012).

3.3 Resilience

Resilience comes from the Latin verb “resilire”, which means to “bounce back” or “recoil” (Fletcher & Sarkar, 2013). It has been used in a variety of contexts and has been defined in slightly different ways by many researchers (Furuta, 2015). The term was initially used in relation to ecology and psychology. CS Holling, a Canadian ecologist first introduced this term in 1973 in ecological systems to highlight the equilibrium between stability and change and predictability and unpredictability (Bastan, et al., 2018). In terms of preventing disasters, seismic resilience has been defined as the capacity of both physical and social systems to cope with the forces and demands brought on by earthquakes as well as to deal with their effects through situational assessment, quick action, and effective recovery techniques (Furuta, 2015).

Later, the term was used to characterize actions taken by organizations, such as enterprises, communities, and governments, to enhance their ability to withstand threats and to respond and recover rapidly from catastrophic occurrences, such as terrorist attacks or natural disasters, which endanger their existence. (Bastan, et al., 2018). In socio-technical systems (human operators, technological and organizational settings), resilience is considered the capacity to maintain required operations and achieve system goals under varying conditions, which include expected and unexpected events (Schröder-Hinrichs, et al., 2015).

In the context of a transportation system, resilience refers to the capacity to recover from a disturbance and return to an operational state comparable to the pre-disturbance condition within an appropriate timeframe. The extent and duration of the disruption's impact on operations directly correlate with the level of resilience of the transport system – a system is considered less resilient if the disruption has prolonged and profound effects. The functionality of the system diminishes in the aftermath of the crisis, but over time, it gradually restores itself to its pre-crisis level. The speed of recovery is swift for a highly resilient system but sluggish for one with lower resilience, as depicted in figure 9 (Clark-Ginsberg, 2016).

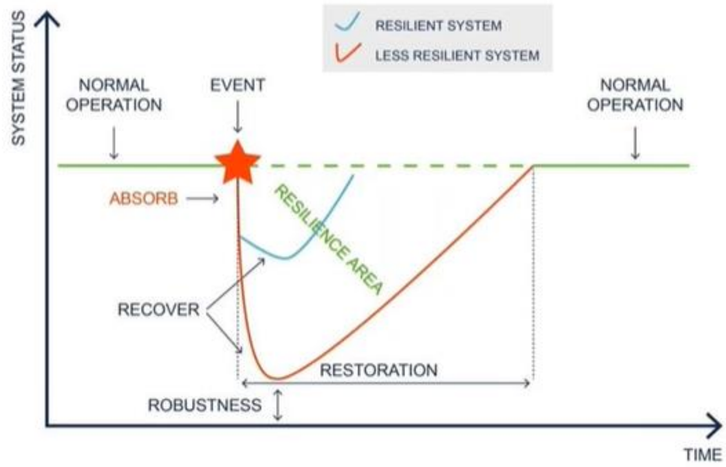

Figure 9 Resilient system and less resilient system (RINA, n.d.)

Currently, various definitions are available for "resilience". Some of them are summarized in the below table:

Table 2. Adopted table of Resilience definitions (Righi, et al., 2015)

"Resilience is a universal capacity which allows a person, group or community to prevent, minimize or overcome the damaging effects of adversity" (Grotberg, 1997)
"Resilience is an organization's ability to adjust to harmful influences rather than to shun or resist them" (Hollnagel, et al., 2006)
"Resilience is the capacity to cope with unanticipated dangers after they have become manifest, learning to bounce back" (Wildavsky, 1989)
"Resilience, as a form of adaptive capacity, is a system's potential for adaptive action in the future when information varies, conditions change, or new kinds of events occur, any of which challenge the viability of previous adaptations, models, or assumptions" (Wood, 2009)
"Resilience is the intrinsic ability of a system to adjust its functioning prior to, during, or following changes and disturbances, so that it can sustain required operations even after a major mishap or in the presence of continuous stress" (Hollnagel, et al., 2006)
Resilience is defined in four concepts: "(1) resilience as rebound from trauma and return to equilibrium; (2) resilience as a synonym for robustness; (3) resilience as the opposite of brittleness, i.e., as graceful extensibility when surprise challenges boundaries; (4) resilience as network architectures that can sustain the ability to adapt to future surprises as conditions evolve" (Woods, 2015)

3.4 Resilience Engineering

Resilience Engineering (RE) was first introduced in the early 1980s and has further gained a lot of attention since 2004, after the first RE Symposium in Sweden. Several studies have been conducted on resilience in different fields, like ecology, psychology, sociology, engineering, and management science. Similarly, the concept of RE has been developed to represent a new way of thinking of safety (Ranasinghe, et al., 2020). It is widely used in incident investigation and risk assessment in all major industries (Kim, 2013). RE is creating valuable tools and techniques, not only for the system developers, but also for those in charge of managing and maintaining system safety in the various industries. The benefit of the RE approach is that it offers means of addressing unforeseen accidents and their disproportionate impacts, which result from evolving technologies and increasingly interconnected organizations (Leonhardt, et al., 2009).

As illustrated in figure 10, RE recognizes that daily performance adjustments are the common basis for acceptable and unacceptable outcomes (Hollnagel, et al., 2013).

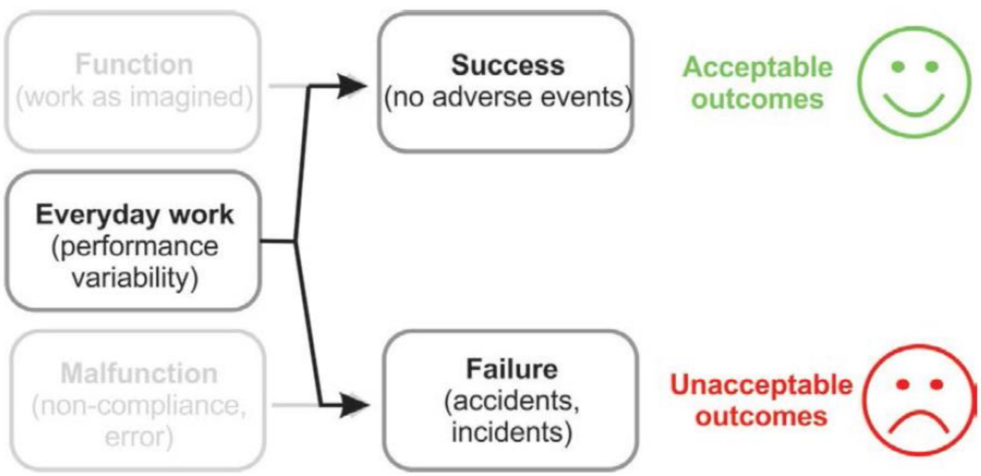

Figure 10: Things that go wrong and things that go right happen in the same way (Hollnagel, et al., 2015)

From this view, failures should not be treated as individual events, but as an aspect of performance variability. It is therefore a good guess that, with the exception of extraordinary occurrences, something that fails will have succeeded many times in the past and will succeed many times again in the future. Knowing how something goes well is a prerequisite to knowing how it goes wrong. To put it another way, when adverse outcomes happen, instead of searching for the causes to explain the failure, we need to start with understanding how acceptable outcomes usually occur instead (figure 11). Failures are frequently caused by the combinations of performance variability, which is commonly viewed as unimportant for safety (Hollnagel, et al., 2015).

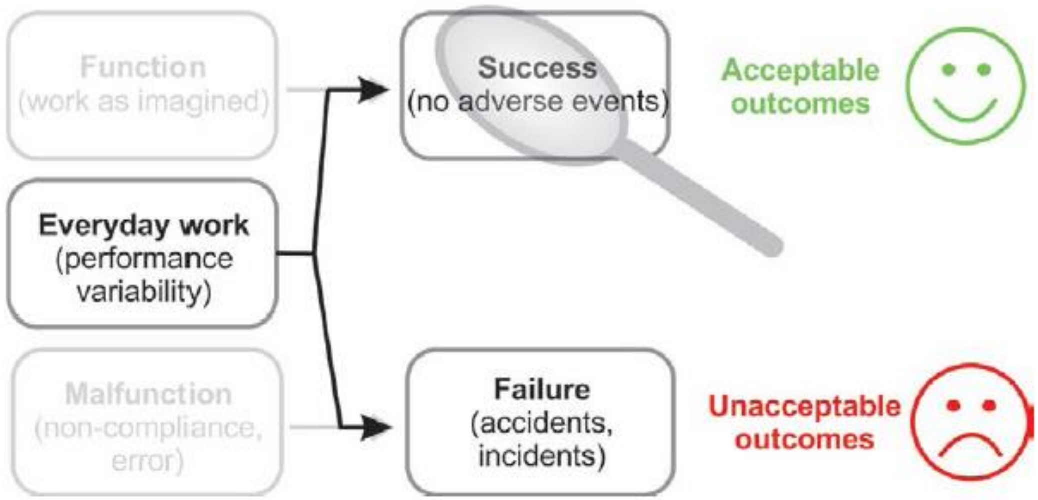

Figure 11: Understanding everyday performance variability is the basis for safety (Hollnagel, et al., 2015)

The four pillars or abilities of RE (figure 12) - monitor, respond, anticipate, and learn – are used to describe and evaluate system performance, in the context of both normal operations and disruptions (Schröder-Hinrichs, et al., 2015). RE suggests that a system, despite if it is an individual or a complex STS, needs to have the following abilities in order to be resilient, or in other words “adjust its functioning prior to, during, or following changes and disturbances, so that it can sustain required operations under both expected and unexpected conditions” (Hollnagel, et al., 2011):

1. Ability to respond to current challenges - A resilient work system needs to be able to react to both predictable and unpredictable events that may occur during an activity.
2. Ability to monitor incoming critical situations - It must also be able to keep track of events and identify any changes that would make it difficult to retain control.
3. Ability to anticipate the occurrence of future events - It must be able to foresee occurrences of the distant future, potentially even over a long period of time.
4. Ability to learn from the past - It must be capable of learning from the past, both from what went well and what did not (Hollnagel, 2012).

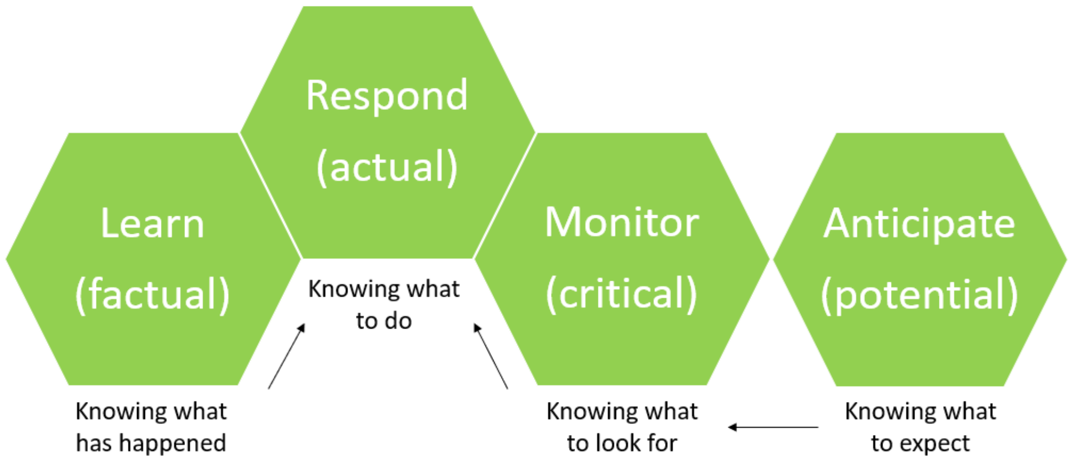

Figure 12: The cornerstones of Resilience Engineering (Costa, et al., 2021)

Resilient STS have different features, which include reaction, recovery, resourcefulness, strengthness and redundancy (Muecklich, et al., 2023). RE is a safety framework which "uses the insights from research on failures in complex systems, including organisational contributors to risk, and the factors that affect human performance to provide systems engineering tools to manage risks proactively" (Woods, 2003). It is focused on the overall system functionality and risk/hazard assessment, than on technical aspects (Muecklich, et al., 2023).

A comparison of the established safety approaches and the resilience engineering principles is demonstrated in table 3. In the established safety procedures, safety is considered the absence of adverse outcomes and systems are considered basically safe, while the negative outcomes are caused by failures, malfunctions and human errors. The focus is on "what goes wrong" and in order to achieve safety, failures and errors need to be eliminated. Safety is measured by the number of adverse events. On the other hand, from a Resilience Engineering perspective safety is the ability to succeed under varying conditions and systems are considered inherently imperfect and conflicted, while they are always under the pressure of limited resources. The focus is on "what goes right" and to achieve safety the ability to succeed under both expected and unexpected conditions needs to be ensured. In this case, safety is measured by the ability to succeed.

Table 3 Adopted table of Established Safety Approaches versus Resilience Engineering, Reproduced from *(Kim, 2013)*

Established Safety Approaches	Resilience Engineering
• **Systems are already basically safe.** → Negative outcomes are caused by failures, malfunctions and human errors	• **Systems are inherently imperfect and conflicted.** → Systems are always under the pressure of limited resources
• **Achieve Safety by** "Eliminate failures and errors"	• **Achieve Safety by** "Ensure ability to succeed in both expected and unexpected conditions"
• **Focus is on** "What goes wrong?"	• **Focus is on** "What goes right?"
• **Safety is:** "The absence of adverse outcomes"	• **Safety is:** "The ability to succeed under varying conditions"
• **Measure Safety by** "Number of adverse events"	• **Measure Safety by** "Ability to succeed"

The concept of resonance (unforeseen combinations) is used in RE to illustrate how normal performance variations can combine in dynamic ways that lead to non-linear effects. Resonance is a theory that describes how seemingly minor performance and condition alterations can have disproportionately significant impacts. Historically, methods of assessing safety have progressed from technical to organisational, through human factor methods. Although many existing approaches combine these methods, resonance needs to be treated at the system level (Leonhardt, et al., 2009).

3.4.1 Complex Socio-Technical Systems

A Socio-Technical System is described as a set of components that are interconnected and include humans, machines, and their work environment. A complex STS, on the other hand, is one that possesses specific qualities, such as a significant number of dynamically interacting parts that lead to unpredictable behaviors (Saurin & Gonzalez, 2013).

Socio-technical systems typically grow more closely connected, as integration increases both vertically and horizontally. Hence, STS become less tractable and less manageable, which affects system safety, including risk assessment and accident investigation (Hollnagel, 2016). Although it is likely that all STS contain at least some complexity-related traits, specific systems, such as power plants, aviation, healthcare, and computer security, are frequently viewed as strongly complex (Saurin & Gonzalez, 2013).

Figure 13 illustrates how the emphasis on system safety has evolved throughout the years. When STSs were less complicated, experts believed that issues occurred due to technical factors, such as hardware failures, and that future technological advancements could prevent accidents and tragedies. The majority of technical issues were successfully fixed as a result of the efforts made to make safety design and quality assurance based on failure mechanisms' understanding (Furuta, 2015).

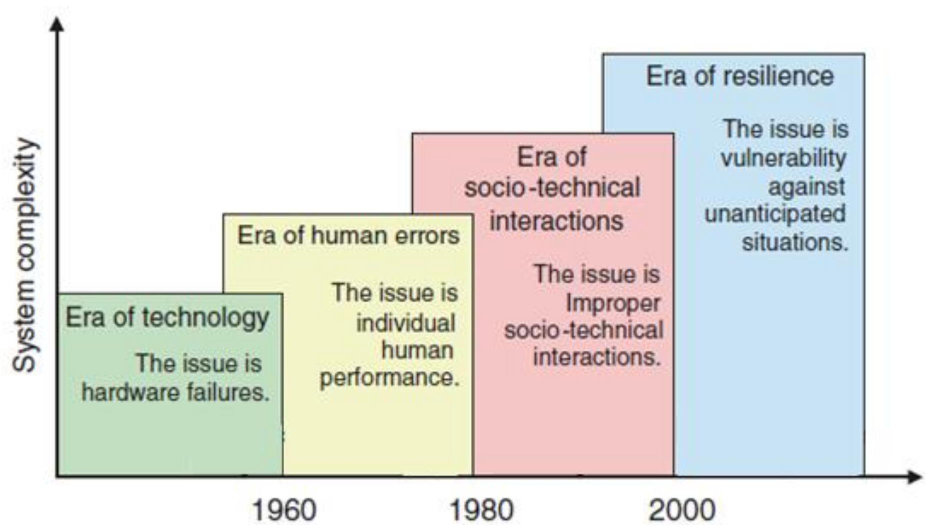

Figure 13 Change in the system safety focus point (Furuta, 2015)

Figure 14 demonstrates how the characteristics of complex STS affect the system's resilience, highlighting connections between the four categories of these characteristics. It is claimed that a complex STS's functional property of resilience benefits from its other two functional characteristics (Saurin, et al., 2013). An advantage for resilience is a large number of dynamically interacting elements because it tends to give more options for performance adjustment. A wide variety of components is beneficial for resilience because performance adjustment is likely to be more accurate if decisions and actions are based on a deeper grasp of the context. This is especially true if there is a diversity of complimentary abilities (Saurin & Gonzalez, 2013).

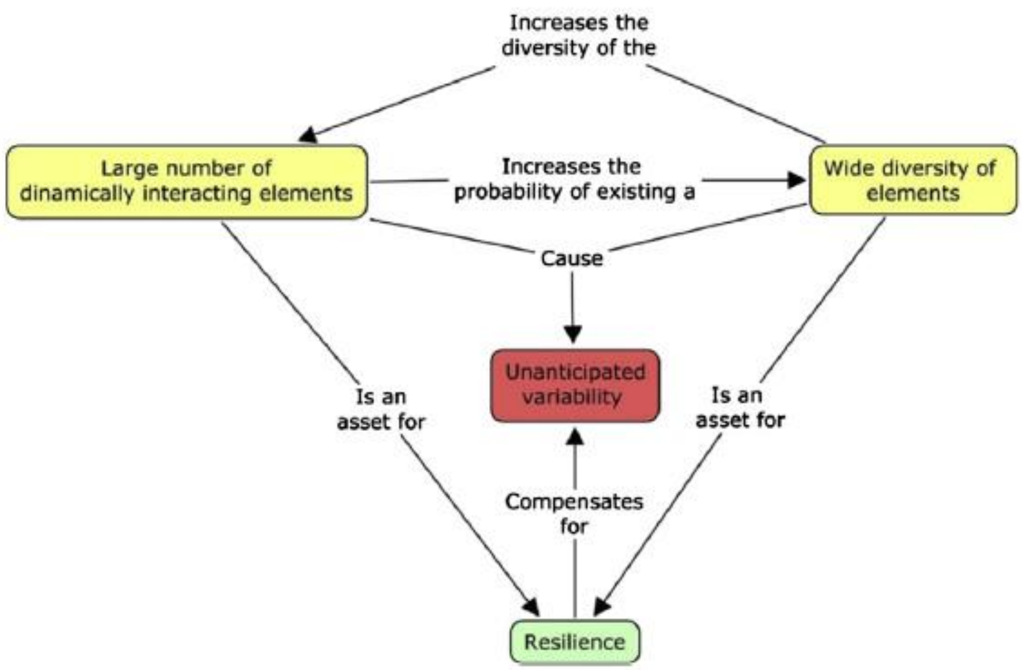

Figure 14: Relationships between the characteristics of complex STS (Saurin & Gonzalez, 2013)

This figure shows resilience's capacity to maintain operations when procedures are insufficient by making up for unexpected variability. Even though this potential is not explicitly depicted in the figure, resilience can help to lower the incidence of unexpected variability. Indeed, the occurrence of unexpected variability is likely to decline as long as performance adjustment also addresses reducing wasteful interactions, elements, and diversity (Saurin, et al., 2013).

3.4.2 Functional Resonance Analysis Method (FRAM)

The Functional Resonance Analysis Method (FRAM) is a modeling approach used to understand complex systems and identify potential sources of error. It is a non-linear, systems-based approach that emphasizes the interconnectedness of different elements within a system (Patriarca, et al., 2020).

FRAM was initially introduced by (Hollnagel, 2004) as a method for risk assessment and accident analysis. The model is based on the concept of functions, which are the purposes or goals that a system is designed to achieve. These functions are interconnected and can be influenced by various factors, including external events, system components, and human behaviors. By analyzing how these functions resonate and interact with one another, the FRAM model can identify potential sources of error and help to develop effective solutions (Hollnagel, 2012).

The FRAM method is made up of four principles (Hollnagel, 2004):

1. *Equivalence of successes and failures.* Meaning that both successes and failures emerge from the same sources, thus they occur for the same reason. Therefore, things succeed for the same reason they fail.
2. *The principle of approximate adjustments*. It means that working conditions in complex STS, are frequently vague and consequently partially unanticipated. It can be stated that, when humans are involved both individually and collectively, the everyday performance of STS is altered to match the system conditions.
3. *The principle of emergence.* The usual performance variability is not significant enough to result in a malfunction or even to be the direct cause of an accident. However, the variability of several functions could combine in unexpected ways, leading to outcomes that are excessively big; as a result, a non-linear effect is created.
4. *Functional resonance.* It expresses the potential of a set of functions' variability to resonance, meaning that an extraordinarily high level of variability may be conveyed in a function's output that the system's capacity is unable to handle under the circumstances. As a result, the accident could occur (Hollnagel, 2012).

The six characteristics that make up a function's specifications are depicted in the below figure with a hexagonal shape (Salihoglu & Besikci, 2020). These are: Input (I), Output (O), Preconditions (P), Control (C), Time (T) and Resources (R).

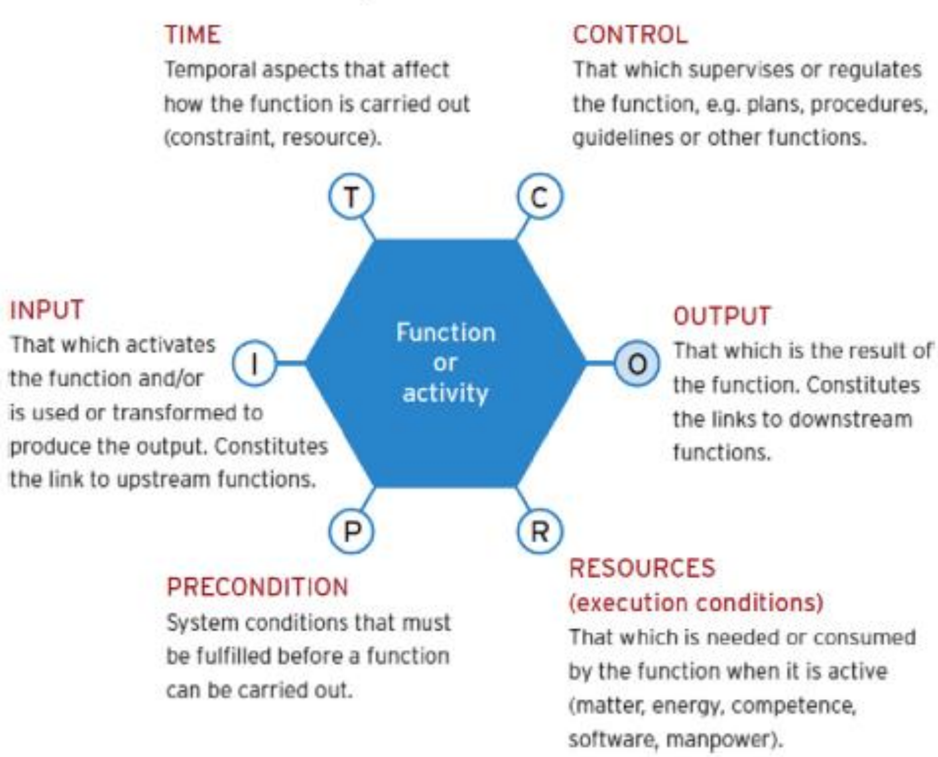

Figure 15: Function or Activity aspects (Hollnagel, et al., 2014)

In addition to learning from safety events and unpleasant situations, FRAM can be used to identify how things are done successfully in a system, by pointing out the gap between WAI and WAD. FRAM is being utilized more frequently across a wide range of fields, and it can improve our comprehension of complicated systems and suggest tactics to improve task design (Tian & Caponecchia, 2020).

There is no practical "one-size-fits-all" approach to manage complex STS. The FRAM approach is not an exception, as it is incredibly flexible and can be used for a variety of modeling applications, including the modeling of abstract concepts, ideas and other methods. In order to provide a conceptual description, it has been purposefully used here to model itself, meaning FRAM method has been used to develop a FRAM model, as per below figure. The functions in blue are the FRAM analysis, the green function refers to the development of the FRAM philosophy and the red functions are organizational ones that belong to the company engaged in the analysis (Patriarca, et al., 2020).

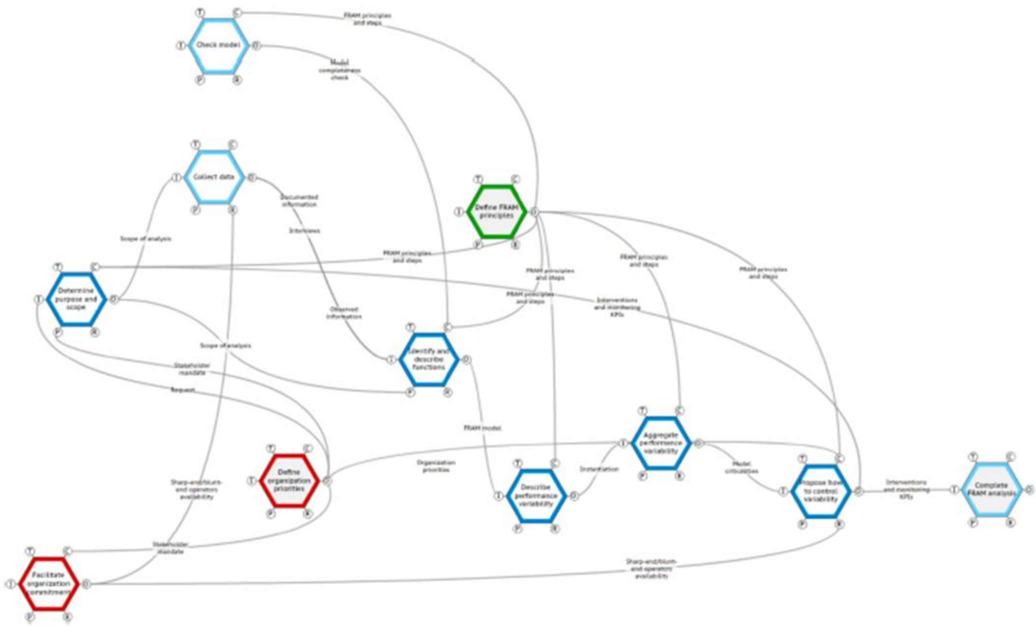

Figure 16 FRAM Method used to develop a FRAM model (Patriarca, et al., 2020).

FRAM was also used to analyze marine accidents. In a recent study (Salihoglu & Besikci, 2020), FRAM was applied in the analysis of the Prestige Oil Spill, a major catastrophe that harmed irreparably the environment. The analysis' findings attempted to identify the various factors that led to the accident and provided recommendations for further investigation. Relevant study showed the need of having a consistent opinion about the system's operation and that FRAM is an essential tool for improving the risk analysis of ship accidents. The comparison of the accident report with the FRAM revealed that the method is more trustworthy in fully identifying the causes than the traditional accident analysis techniques. Moreover, FRAM has been proven more capable in the identification of possible interactions' causes than those listed in the accident report (Salihoglu & Besikci, 2020).

The tragic accident of MV Herald of Free Enterprise was also re-analysed using the FRAM method. This fatal accident of the 6th of March 1987, when 188 people lost their lives at sea, led to the introduction of the International Safety Management (ISM) Code, one of the most important safety standards in the shipping industry. According to the findings of this systemic study, there was a functional resonance that spread across the range of performance in different functions. Therefore, it is not possible to attribute the accident to a single cause, but rather to the fact that a number of functions performed inconsistently at the time, which resulted in the undesirable result. Therefore, one of the main causes of the outcome not being what was anticipated cannot be attributed to human error or failure. Even though the analysis did not reach any new conclusion on the accident reasons and causes, it did deepen our understanding of how the functions resonate in shipping domain and how the method could be used to highlight a system's flaws and provide suitable remedies (Praetorius, et al., 2011).

FRAM method was also used to provide insights into the Officers contribution to the establishment of safety in vessel navigation. The method's application revealed great understanding of how resilience is integrated into ship's everyday operations. The functional resonance analysis approach and a qualitative observation were used to examine officers' day-to-day performance and highlight the performance of the bridge team in navigating the ship successfully. Important functions of the bridge officers' activities have been generated through observation and interviews on a training ship. Flows were modeled in relation to the system's actual operations. The outcome showed that the officers' flexibility and adaptability resulted in the improvement of system's ability to monitor, respond, learn and anticipate. This study also recognized that human functions are a source for handling increasing complexity of technological development for future maritime transportation. A part of the relevant FRAM model is presented in the following figure that includes information about the vessel's departure (Adhita, et al., 2023).

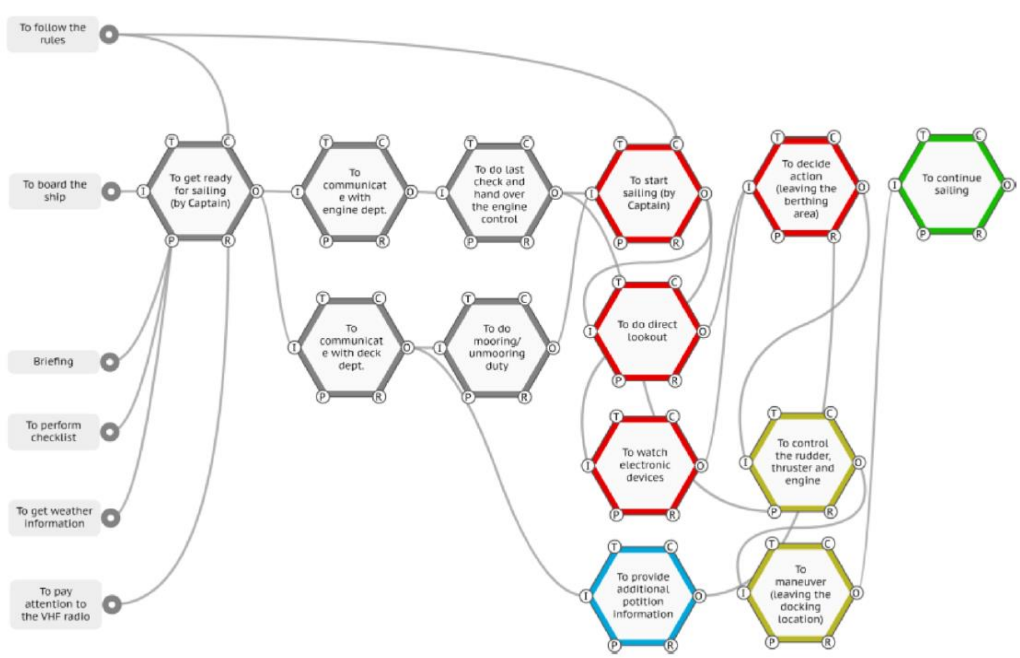

Figure 17: Departure process modeled using FRAM (Adhita, et al., 2023)

.

3.5 Safety III

Safety III is another approach to safety, which has been around since the 1950s. It is described as “System Safety”, in other words as a system’s approach to safety, which is very different from what happens today and can address emergent aspects such as safety across the sociotechnical system as a whole. From a Safety-III perspective, safety is defined by the system stakeholders as “freedom from unacceptable losses” and according to recent studies this is the best way forward. The aim of the management is to handle and mitigate the hazards, which are conditions that can result in these types of losses (Leveson, 2020) Safety III goes beyond resilience and Safety-II (Aven, 2021).

Safety III approach is holistic and considers that all the organizational, human and technical components should be viewed as parts of a single system that needs to be designed in harmony to accomplish its objectives, including the requirement to design for flexibility and adaptations. Resilience in systems must be incorporated into the overall design of the system. In highly automated systems, human operators are rarely able to provide resilience unless the engineers have built it in for them to be capable of doing so. In Safety III, it is assumed that the design of the system within which people operate in may have an impact on their potential for resilience and adaptability. Thus, the objective should be to develop resilient systems rather than resilient people. The ability to create resilient systems for people is the most important skill to have. It goes without saying that the system as a whole, not just the human operators, must be resilient. (Leveson, 2020).

Poor management of hazards is the root cause of accidents; more precisely, insufficient management or enforcement of safety-related limitations is the cause of accidents. In addition to learning from events, accidents, incidents, and audits of the system's performance, the focus is on preventing hazards and losses (Aven, 2021).

The Safety III approach covers the full lifecycle, with particular attention paid to incorporating safety in from the initial stages of the system formulation. Instead of just concentrating on human operators, resilient systems are precisely designed to minimize, if not completely eliminate, risks, with the operator playing a crucial role in this process. Furthermore, the system is designed in order for human operators to successfully handle emergencies not designed to handle, and it comes with tools that enable humans to be resilient in an emergency (Leveson, 2020).

Resilience in Safety III is viewed as the system's ability to remain within the safety limits regardless of unexpected or insufficiently controlled risks or behaviors. In a resilient system, losses are avoided or reduced in the event of unforeseen circumstances. In particular, we should not simply assume that human operators would be able to contribute to resilience in any system design; rather, we should design the sociotechnical system as a whole, not just a part of it, in order to achieve this goal (Leveson, 2020).

3.6 Comparison of safety concepts

The main characteristics and key elements of the three safety approaches are presented in Table 4, emphasizing eight core themes that encompass fundamental concepts and principles within the realm of safety management. The insights regarding Safety I and II predominantly originate from Hollnagel, while Leveson contributes to the understanding of Safety III.

Moving forward, Safety III may serve as a model for advancements in all industries, including work/system safety. Inevitably, as our culture and technology evolve, it will require modifications and improvements to remain applicable to engineering in the future (Leveson, 2020).

Table 4 Adopted table of main characteristics of Safety I & Safety II, reproduced from (Hollnagel, et al., 2015) with the addition of current Safety approach and Safety III in the last two columns, reproduced from (Leveson, 2020)

Aspect	Safety-I	Safety-II	Safety Engineering Today	Safety-III
Definition of Safety	As few things as possible go wrong	As many things as possible go right	Safety is usually defined as freedom from unacceptable losses as identified by the stakeholders, but may be defined in terms of acceptable risk or ALARP in some fields. The goal is to eliminate, mitigate, or control hazards, which are the states that can lead to these losses.	Safety is defined as freedom from unacceptable losses as identified by the system stakeholders. The goal is to eliminate, mitigate, or control hazards, which are the states that can lead to these losses.
Safety Management Principle	Reactive, respond when something happens, or is categorised as an unacceptable risk	Proactive, continuously trying to anticipate developments and events	Concentrates on preventing hazards and accidents but does learn from accidents, incidents, and audits of how system is performing.	Concentrates on preventing hazards and losses, but does learn from accidents, incidents, and audits of how system is performing.

Explanations of accidents	Accidents are caused by failures and malfunctions. The purpose of an investigation is to identify causes and contributory factors.	Things basically happen in the same way, regardless of the outcome. The purpose of an investigation is to understand how things usually go right as a basis for explaining how things go wrong.	Accidents are caused by linear chains of failure events. The purpose of investigation is to identify the chain of events and the root cause.	Accidents are caused by inadequate control over hazards. Linear causality is not assumed. There is no such thing as a root cause. The entire socio-technical system must be designed to prevent hazards; the goal of investigation is to identify why the safety control structure did not prevent the loss.
Attitude to the human factor	Humans are predominantly seen as a liability or a hazard.	Humans are seen as a resource necessary for system flexibility and resilience.	Humans are expected to prevent or respond to hazards and to be flexible and resourceful when they occur.	The system must be designed to allow humans to be flexible and resilient and to handle unexpected events.
Role of performance variability	Harmful, should be prevented as far as possible.	Inevitable but also useful. Should be monitored and managed.	The primary reason for performance variability is to enhance productivity and system requirements. Procedures are provided when response time and information is limited. Effort is put into providing appropriate controls and interfaces to allow operators to prevent or respond to hazards. Design so that when performance (of operators, hardware, software, managers, etc.) varies outside safe boundaries, safety is still maintained.	Design the system so that performance variability is safe and conflicts between productivity, achieving system goals, and safety are eliminated or minimized. Design so that when performance (of operators, hardware, software, managers, etc.) varies outside safe boundaries, safety is still maintained.

3.7 Application of Resilience Engineering in various industries

The concept of resilience engineering has been applied to a wide range of industries to improve safety and reliability. Here are some examples of its application in different fields:

Aviation

Resilience engineering has been applied to the aviation industry to improve safety in the face of unexpected events. The safety approach has changed from merely preventing failures to understanding how complex systems function successfully. This paradigm acknowledges that the aviation industry is a complex socio-technical system where adaptability, resilience, and variability play crucial roles in ensuring safety. This comprehensive exploration will delve into the principles of Safety II and illustrate its application in various facets of aviation, from crew resource management to incident reporting systems, maintenance practices, and beyond.

1. Crew Resource Management (CRM):

Crew Resource Management (CRM) is a fundamental application of Resilience Engineering in aviation. Airlines have implemented CRM programs to improve communication, teamwork and decision-making among flight crews (Wiegmann & Shappell, 2003). CRM incorporates Safety II concepts to improve resilience and adaptation. For instance, the Threat and Error Management (TEM) framework within CRM encourages crews to identify and manage potential threats, fostering a proactive safety approach (Helmreich & Merritt, 2001).

2. Simulation and Training:

Aviation simulation and training programs are designed based on Safety II principles, providing crews with a controlled environment to practice handling challenging situations. By simulating a range of situations, such as emergencies and system failures, flight simulators allow pilots to become more adaptive and capable of making effective decisions under pressure. This application ensures that crews are well-prepared to respond to unexpected challenges in real-world situations, contributing to overall operational resilience (Salas, et al., 2010).

3. Safety Culture and Learning from Success:

Resilience Engineering promotes a safety culture that actively learns from both successes and failures. Rather than focusing solely on incidents and accidents, organizations examine their successful operations to find beneficial performance patterns. For instance, analyzing flights with smooth and efficient turnarounds at airports can uncover practices that enhance operational efficiency and safety (Hollnagel, et al., 2006).

4. Human Factors Integration:

The significance of human factors in aviation safety is acknowledged by Safety II. Human Factors Integration (HFI) involves designing aviation systems that consider the capabilities and limitations of human operators. For example, HFI is used in the design of cockpit interfaces and controls to reduce the risk of human errors during flight operations (Wickens, 2017).

5. Incident Reporting Systems:

The aviation industry has developed strong incident reporting systems with evident use of the Safety II principles. These systems allow frontline personnel, including pilots and air traffic controllers, to report incidents, near misses, and hazards without fear of punitive measures. One such system is the Aviation Safety Reporting System (ASRS) in the US. By allowing aviation professionals to voluntarily report incidents for analysis and subsequent safety improvements, it promotes an environment of open dialogue and continuous learning (Wiegmann & Shappell, 2003).

6. Dynamic Risk Assessment:

Resilience Engineering encourages a dynamic approach to risk assessment that takes into account both expected and unexpected risks. This entails continuously monitoring and adapting to changes in the operational environment. Safety Management Systems (SMS) in aviation exemplify this approach, where organizations systematically identify, assess, and mitigate risks in an ongoing and adaptive manner (Hudson, 2007).

7. Maintenance Practices:

In recognition of the fact that maintenance is an essential part of aviation safety, Safety II is applied to aircraft maintenance procedures. Learning from successful maintenance operations and understanding how maintenance teams adapt to challenges are key components of the Safety II concept. For instance, analyzing instances where maintenance teams effectively identified and rectified potential issues during routine checks contributes to a proactive safety approach (Dekker, 2011).

8. Redundancy and Diverse Defenses:

In aviation systems, resilience engineering highlights the value of redundancy and diverse defenses. This includes designing aircraft with backup systems and ensuring that critical functions have multiple layers of protection. To reduce the possibility of a single point of failure, the Airbus A380, for example, has redundant systems for crucial components including multiple hydraulic systems and redundant flight control computers (Wickens, 2017).

Healthcare

In the healthcare sector, resilience engineering has emerged as a key paradigm that focuses on the healthcare systems' ability to adapt and recover in the face of unforeseen circumstances. The complexity of healthcare delivery demands a proactive approach that goes beyond traditional risk management. RE has been applied to healthcare to improve patient safety and reduce medical errors.

1. Understanding Everyday Work:

An in-depth understanding of the routine procedures and activities carried out in healthcare settings is encouraged by Safety II. This entails researching how healthcare professionals manage the difficulties of their jobs to guarantee patient safety. For example, examining how nurses handle interruptions when giving medication might reveal information about how resilient their procedures are and point out areas where system enhancements can be implemented (Braithwaite, et al., 2017).

2. Learning from Variability:

Safety II recognizes that healthcare is inherently variable and that variations in performance can provide valuable information about system functioning. Deviations are considered as opportunities for learning rather than as failures. An example is the study of surgical teams and how they adapt their communication and coordination strategies during unexpected events in the operating room, highlighting the importance of flexibility in response to variations (Battles, et al., 2019).

3. High-Reliability Organizations (HROs):

High-Reliability Organizations (HROs) in the healthcare industry are a concept that clearly demonstrates resilience engineering principles. Healthcare organizations have implemented HROs to reduce the risk of errors and improve communication among healthcare providers. These organizations focus on creating a culture of safety, improving teamwork, and enhancing situational awareness to ensure that healthcare providers can respond effectively to unexpected events. HROs prioritize safety and reliability by emphasizing preoccupation with failure, sensitivity to operations, reluctance to simplify interpretations, commitment to resilience, and deference to expertise. For example, safety reporting systems that encourage frontline staff to report near misses and possible hazards can be implemented by healthcare companies to promote a continuous improvement culture (Weick & Sutcliffe, 2007).

4. Emergency Response:

When crises such as pandemics, natural disasters, or other catastrophes strike, the healthcare sector needs to be able to bounce back quickly. Resilience engineering promotes the development of adaptive capacity in emergency response planning. Resilience concepts are integrated into healthcare systems, including hospitals and public health organizations, to guarantee that they can quickly adjust to changing conditions. For instance, in order to offer the best possible patient care during the COVID-19 epidemic, healthcare systems across the world had to quickly adapt protocols, allocate resources effectively, and collaborate across disciplines to provide optimal patient care (Kruk, et al., 2021). As another example in the Emergency Departments, a study examining the resilience of triage processes identified adaptive strategies employed by triage nurses to manage surges in patient volume. This knowledge can inform system improvements that enhance the resilience of emergency care delivery (Wears, et al., 2015).

5. Investigating Success:

Safety II promotes examining successful outcomes to find beneficial performance patterns. Examining instances in which medical teams had positive results can provide important insights into the elements that led to success. For example, examining instances in which patients with complex medical conditions underwent smooth transitions between different places of care can reveal procedures that improve continuity and patient safety (Dekker, 2014).

6. Human Factors and Crew Resource Management (CRM):

The role of human factors in healthcare delivery is recognized by resilience engineering. Crew Resource Management (CRM), adapted from aviation, is one such example applied in healthcare settings. In order to prevent errors and improve patient safety, CRM focuses on teamwork, communication, and situational awareness among healthcare professionals. Preoperative briefings and checklists, for example, are used by surgical teams to enhance communication and lower the risk of mistakes during surgeries (Gawande, 2010).

7. Information Systems and Decision Support:

The integration of advanced information systems and decision support tools in the healthcare industry is encouraged by resilience engineering. Electronic Health Records (EHRs) and clinical decision support systems help healthcare providers access critical patient information, support diagnosis, and make informed decisions. By ensuring that healthcare providers have access to the information they need, this resilience-building technology reduces the risk of medical errors and enhances patient care overall (Bates, et al., 2014).

8. Patient and Family Engagement:

The value of involving patients and their families in the healthcare process is acknowledged by resilience engineering. Patients and their families are essential components of the healthcare system, contributing to the identification of risks, providing valuable information, and participating in decision-making. To improve the resilience of the healthcare system as a whole, patient safety initiatives should, for instance, encourage patients to voice their concerns, have transparent communication, and involve them in the planning of their care (Leape, et al., 2013).

Oil and Gas

Resilience engineering has emerged as a crucial framework in the oil and gas industry, aiming to enhance safety and reliability amid the dynamic and hazardous nature of operations. This paradigm emphasizes an organization's ability to adapt and learn, going beyond standard risk management. For example, companies have implemented Safety Management Systems (SMS) to identify and manage risks associated with offshore drilling. These systems focus on enhancing communication, improving situational awareness, and implementing effective emergency response plans to ensure that workers can respond effectively to unexpected events.

1. Process Safety Management (PSM):

Resilience engineering principles are deeply integrated into Process Safety Management (PSM) programs within the oil and gas industry. As part of PSM, process hazards are identified, assessed, and controlled systematically. By highlighting the significance of preparing for and handling the unexpected, RE adds an extra safety layer. For instance, organizations to visualize potential hazard scenarios with the use of bow-tie analysis in risk assessments to identify preventive barriers and plan strategies for recovery (Mannan, 2012).

2. Human Factors Integration:

Resilience engineering recognizes the role of human factors in ensuring operational resilience. This includes training programs and procedures designed to enhance the ability of personnel to adapt and respond effectively to unexpected challenges. Human factors integration in oil and gas emphasizes the importance of designing work systems that align with the capabilities and limitations of the human operators, thereby enhancing resilience and adaptability in dynamic operational environment. For instance, the design of oil rig control rooms incorporates HFI to ensure that interfaces are intuitive, reducing the risk of errors during critical operations (Braithwaite, et al., 2017).

3. Real-Time Monitoring and Control Systems:

Resilience engineering is evident in the implementation of advanced real-time monitoring and control systems. These systems allow for immediate corrective actions by continuously assessing and responding to changes in the operational environment. As an example, in oil refineries, Distributed Control Systems (DCS) and Safety Instrumented Systems (SIS) can automatically shut down processes in the event of abnormal conditions preventing potential incidents and providing a resilient layer of protection (Leveson, 2011).

4. Emergency Response Planning:

Comprehensive emergency response plans are clearly developed using Safety II principles. These plans go beyond traditional procedural approaches by incorporating adaptive strategies that consider the dynamic nature of emergencies. Incident Command Systems (ICS), for instance, enables organizations to coordinate responses, allocate resources, and adapt strategies in real-time during unexpected events such as oil spills or well blowouts (API RP 1009, 2015).

5. Supply Chain Resilience:

The oil and gas industry relies on complex supply chains that span the globe. Resilience engineering is applied in ensuring the robustness of these supply chains, minimizing the impact of disruptions. This involves diversifying suppliers, developing contingency plans, and utilizing real-time tracking systems. For example, organizations may maintain strategic reserves of critical equipment or establish alternative supply routes to ensure continuity of operations in the face of unforeseen challenges (Ponomarov & Holcomb, 2009).

4. Case Study

This part of the paper explores the possible application of the concept of Resilience Engineering in the Maritime Industry and proposes the practical integration of the concept's four abilities in various Maritime operations. Then, it suggests how the Safety II principles and the concept of Resilience Engineering with its four abilities can be effectively applied in the context of a shipping company.

The shipping company from which safety practices and documentation were collected for the case study, is a global leader in maritime transport and operates a diverse and large fleet of vessels engaged in international shipping, logistics and offshore services. Various examples of the practical implementation of the four abilities are presented, which contribute to a better understanding of their applicability.

The company has an established safety management system (SMS) to ensure continuous and sustainable improvement in Health, Safety, Quality and Environmental (HSQE) management processes. The documentation from the shipping company's safety management system is utilised, specifically the Near Miss Report to identify grounds for improvement from a Safety II and resilience engineering perspective. This form is amended, and new sections are developed which contribute to the practical implementation of the new safety concepts discussed in this thesis

A near miss is defined as a sequence of conditions and events that could lead to loss. However, this loss is prevented by an unexpected break in the chain of conditions and events. Potential losses could include harm to the people or the environment, or detrimental impact to the company (IMO, 2018)

4.1 Applications of Resilience Engineering in the Maritime Industry

Resilience engineering represents a paradigm shift in the maritime industry, offering a holistic approach that focuses not only on preventing errors but also on understanding how systems function successfully. The maritime sector's unique challenges, including adverse weather conditions, navigational hazards, and complex operations, necessitate a proactive and adaptive approach to ensure the resilience of the entire system. In this context, Safety II acknowledges that maritime operations are intricate socio-technical systems influenced by human factors, technology, and organizational structures (Kujala, et al., 2016). This comprehensive exploration will delve into the principles of RE and illustrate its application in various facets of maritime operations, from bridge resource management to incident reporting systems, emergency response planning, maintenance practices, and beyond.

1. Maritime Resource Management (MRM)

In maritime operations, Maritime Resource Management (MRM) is a prime example of applying resilience engineering principles. MRM focuses on enhancing communication, decision-making, and teamwork among personnel to improve situational awareness and prevent accidents. Bridge Resource Management (BRM) also incorporates Safety II by focusing on understanding how crews successfully navigate through complexities and emphasizing the adaptability and learning capabilities of bridge crews (International Maritime Organization (IMO), 2019). Considering that 80% of maritime accidents involve human error, the resource management training is a crucial countermeasure (The Swedish Club Academy, 2011).

2. SEAHORSE Resilience Model

The SEAHORSE project run in 2013-2016 to enhance safety and address human factors in maritime transport by transferring established practices and methodologies from air transport. The approach is characterized by effectiveness, collaboration, and innovation, involving the adaptation and customization of aviation practices to suit the distinct requirements of marine transport. The main strategy involves incorporating resilience engineering principles and smart procedures methodology into an integrated framework. This integration aims to establish multi-level resilience, connecting individuals, teams, multi-party teams, and organizations in ship operations, ultimately improving safety within the maritime sector.

Due to the inadequacies of current accident analysis methods in measuring the resilience of a maritime socio-technical system (STS), the Seahorse project developed the Resilience Assessment Method (RAM) as depicted in table 5. The evaluation tool comprises a resilience survey, a multi-level resilience matrix, and a set of resilience recommendations that organizations can adopt to enhance their resilience. To enhance resilience to unforeseen disruptions or challenges, any maritime organization should initiate the resilience assessment process by identifying safety-critical operations/functions (in various operational phases) for analysis. Examples of safety-critical functions include mooring, navigation, lifting, and unloading. Once the functional breakdown is completed, the organization utilizes the resilience survey to outline the function's operational requirements, outcomes, resources, and coping strategies. The survey evaluates the adequacy of available resources and strategies to meet the specified outcomes under operational demands. The results are presented in a multi-level resilience matrix, with rows representing different organizational levels (individual, team, organizational), and columns indicating scores for the four crucial resilience abilities: anticipation, monitoring, responding, and learning. If, for instance, an organization scores low in team learning, it might be recommended to implement a human factor training program to strengthen this aspect.

Table 5 SEAHORSE Multi Level Resilience Matrix *(Turan, et al., 2016)*

Ability ***Level***	**Anticipate**	**Monitor**	**React**	**Learn**
Individual *Operational Demand / Resilience Resource*	New crew members needs time to familiarize --- Let new crew members express lack of experience with specific situations	Tiredness induced concentration loss --- Enhance recognition of significant change	Foreign crew members face reading challenge --- use of pictograms instead of written procedures	Lack of ship type specific knowledge --- Delta Learning
Team *Operational Demand / Resilience Resource*	Lack of team competences --- Team Dimensional Training	Reduced crew atmosphere --- Discuss information flow, initiative/ leadership, communication, supportive behaviour	Suboptimal team performance --- Support Team awareness	Blame culture on board --- Structural Debrief of good practices
Multi-party *Operational Demand / Resilience Resources*	Crews and stevedores have different safety culture --- Structured Briefings at start loading/unloading	Insufficient trust between ship and shore organisation --- Virtual social sessions	Inter-party confusions --- Introduce time outs	mutual experiences do not last --- Celebrate successful partnerships
Organisation *Operational Demand / Resilience Resource*	Economic pressure on board --- Increase awareness of negative consequences	Insufficient insight in strength of safety regime --- Registration of successful deviations from plans	Insufficient safety resources --- Resilience Model based safety investments	Underexplained accidents --- FRAM-based accident analysis

The SEAHORSE project conclusively illustrated that diverse modes of transportation have the capacity and should collaborate to exchange best practices, yielding tangible improvements in safety.

3. Human Factors Integration

Safety II recognizes the role of human factors in maritime safety and emphasizes the integration of human factors principles into system design. Human Factors Integration (HFI) is the process of designing tools, processes, and work systems with human operators' abilities and limits in consideration. In the maritime industry, this could entail creating user-friendly navigational interfaces or communication systems on ships to lower the possibility of human error (Wickens, 2017).

4. Inspection and Audit

The application of RE is also evident in the new vetting inspection regime (i.e. SIRE 2.0), which has been introduced by OCIMF and will roll out in the tanker vessels industry in 2024. Under the new inspection type, inspectors will be called to raise also positive observations on human performance and identify performance influencing factors (PIFs) when noting both negative and positive observations.

The PIFs are listed below:

- Recognition of Safety criticality of the task or associated steps.
- Custom and practice surrounding use of procedures.
- Procedures accessible, helpful, understood and accurate for task.
- Stress, workload, fatigue, time constraints.
- Morale, motivation, nervousness.
- Workplace ergonomics including signage, tools, layout, space, noise, lights, heat etc.
- Human-Machine Interface.
- Opportunity to learn and practice. (OCIMF, 2022).

5. Behavioral Based Safety

The concept of Safety II is evident in the application of the Behavioral Based Safety (BBS) in the maritime sector. BBS aspires to enhance safety performance and minimize occurrence of incidents in the workplace by replacing unsafe behavior practices with sound behaviors. Advocates of BBS share the belief that accidents are mostly caused by unsafe behavior and that accidents may be prevented by adopting adequate behavior. The objective of BBS is to create a work environment in which employees encourage each other to use safe behaviors and eliminate at-risk behaviors (Ismail, et al., 2012). Figure 17, illustrates the BBS principle to incident prevention, stating that safety awareness and safety habits can be enhanced by training (Chen & Tian, 2012).

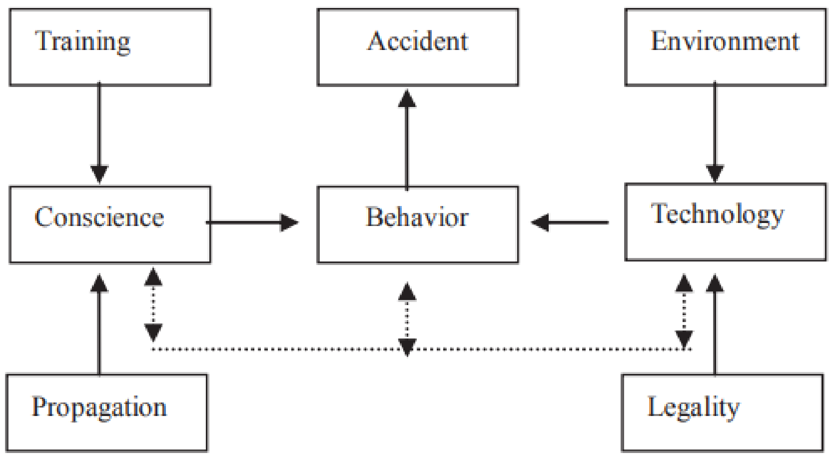

Figure 18 BBS principle to incident prevention (Chen & Tian, 2012)

6. Training and Simulation

One important way resilience engineering is implemented in maritime operations is through simulation training. Seafarers can practice handling difficult events, such as emergencies and severe weather in a controlled environment by using simulators. This improves their capacity for adaptation and judgment. Realistic simulations of challenging scenarios, such engine failures or collision avoidance, are frequently incorporated into training programs to make sure crews are well-prepared to respond effectively in actual situations (International Maritime Organization (IMO), 2010). As vessels are becoming increasingly varied and complex, Virtual Reality solutions also help seafarer's to be prepared for the upcoming challenges.

Figure 19 Left: Bridge Simulator, Right: Virtual Reality hardware. (Mallam, et al., 2019)

7. Voyage Planning & Navigation

Resilience engineering can be applied in risk assessment and voyage planning procedures. Risks associated with navigation, such as rocks, reefs, and unfavorable weather, can be systematically recognized and mitigated. A key component of resilient voyage planning involves a continuous risk assessment that takes expected as well as unexpected complications into account. For instance, using electronic charting systems offers seafarers access to real-time weather and navigational data, allowing them to modify their plans in response to unforeseen difficulties and changing conditions (International Maritime Organization (IMO), 1999). Moreover, through the examination of cases in which ships successfully and securely navigated difficult routes, maritime organizations can pinpoint optimal performance patterns. To comprehend the elements that contribute to safe navigation, this may involve researching successful pilotage operations in constrained channels or challenging weather conditions (Adhita, et al., 2023).

8. Supply Chain

The maritime sector depends on complex supply chains for transporting goods. By applying Safety II principles, these supply chains are made more resilient and the effects of disruptions are reduced. This involves diversifying suppliers, developing contingency plans, and utilizing real-time tracking systems. To guarantee operations continue in the event of unexpected challenges companies could, for instance, create backup supply lines or maintain strategic stocks of critical equipment (Ponomarov & Holcomb, 2009).

9. Maintenance and Reliability

Resilience engineering is also incorporated into reliability and maintenance procedures. Vessel resilience is enhanced via routine maintenance, condition-based monitoring, and inspections of critical systems. Predictive maintenance methods, for instance, employ real-time data to foresee equipment failures, enabling proactive interventions and lowering the possibility of unexpected malfunctions during operations (Ditlevsen, et al., 2019).

10. Incident Reporting Systems:

In the maritime sector, resilience engineering promotes the development of robust incident reporting systems, which allow seafarers and maritime professionals to report near misses, accidents, incidents and identified hazards. Using these data, organizations are capable of detecting systemic vulnerabilities and take preventive action to mitigate potential hazards. The Confidential Hazardous Incident Reporting Programme (CHIRP) is an example of incident reporting system that promote a culture of continuous improvement and resilience (CHIRP, n.d.). Moreover, the Lloyd's List Intelligence provides analysis, data, risks and trends based on information from exclusive data sources and maritime authorities, which provide comprehensive understanding of the global fleet, enabling smarter and more informed strategic decisions (Intelligence, n.d.).

11. Benchmarking:

Resilience Engineering is also evident in the benchmarking of maritime organizations with other industry sources. Benchmarking is a practical tool for improving performance by learning from best practices and the processes by which they are achieved. It involves looking both inward and outside the organization or even the shipping sector, to examine how others achieve their performance levels and to understand processes they use. When the lessons learnt from a benchmarking exercise are applied appropriately, they facilitate improved performance in critical functions of the organization's procedures. Benchmarking is not a one-off exercise, and it must be an ongoing, integral part of the improvement process to become effective.

In figure 19 the possible applications of resilience engineering in maritime operations are summarized:

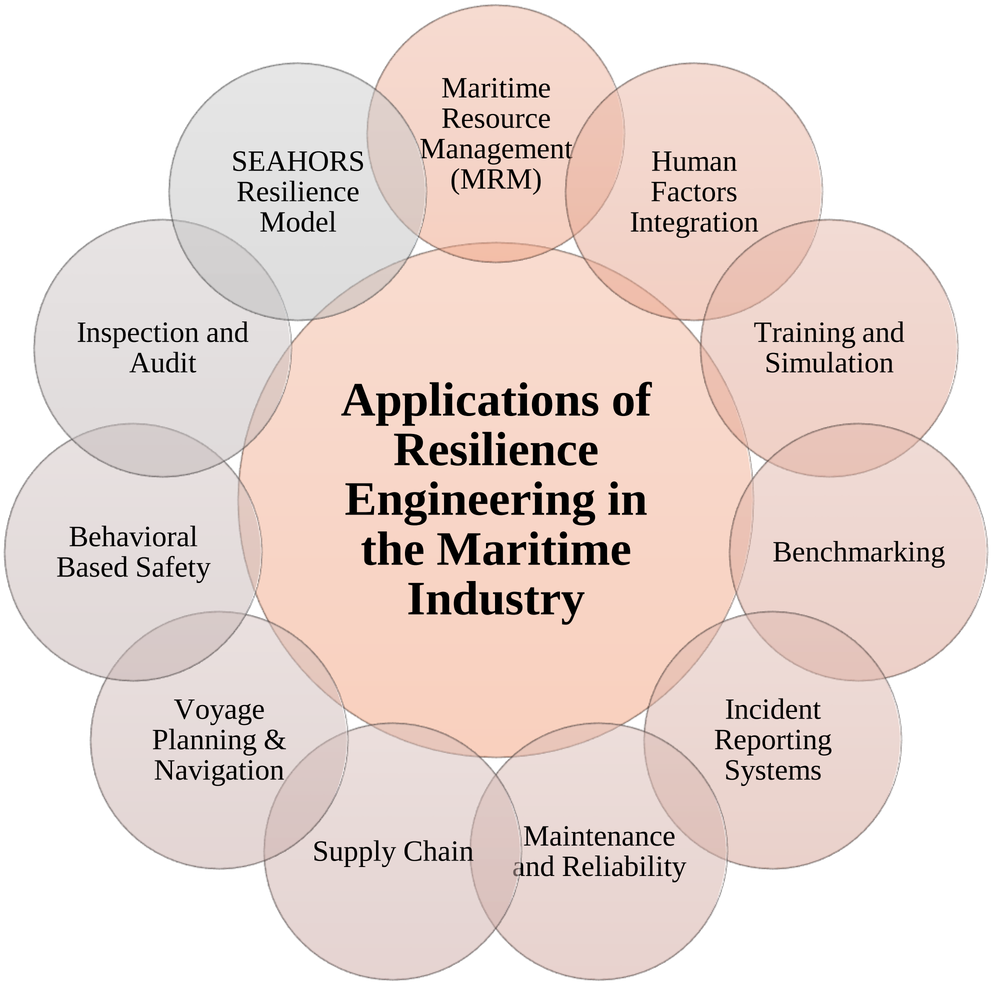

Figure 20 Applications of RE in Maritime Industry

4.2 Integration of the four abilities of Resilience Engineering in maritime operations

4.2.1 Respond - Knowing what to do

In resilience engineering, the ability to respond involves the capability to address and mitigate unexpected occurrences in operations, such as breakdowns in equipment or changes in the weather conditions, by activating prepared actions or by adjusting current mode of functioning (Owen, et al., 2017). The establishment of procedures for emergency response is already mandated by the ISM code. Nevertheless, a company's decision to integrate the respond ability involves, in addition to having such procedures, ensuring that they are dynamic and adaptive.

The Company has included the enhancement of its respond ability in its top priorities and, rather than just providing a list of actions to take in case of an emergency in the emergency response plan, the company has put in place a robust and comprehensive framework for response that involves:

1. Precise, succinct and adaptive emergency response procedures. Response plans are updated frequently in accordance with the knowledge gained from drills and actual events. For instance, the Company has developed procedures for navigating a vessel in narrow channels, which consider vessel-specific characteristics, including turning radius and stopping distance, and provide clear guidance for responding to sudden changes in the conditions or obstacles occurring within the channel.
2. Frequent drills and simulations based on real scenarios to make sure that the crew is well-prepared for various emergency situations, ranging from equipment failures to collision. These exercises are not routine, but they are intended to assess and challenge the crew's decision-making under stress and adaptability. For example, through dynamic drills, the seafarers employed by the Company are trained to respond immediately in emergency situations, such as unexpected engine failures during routine voyages. Utilizing satellite technology, the captains are able to establish real-time contact with onshore support for swift coordination. Potential risks are mitigated and minimal downtime is ensured because of the crew's ability to respond promptly and adapt to the evolving situation. Consequently, integrating resilience principles into the training program of company's crew ensures that they possess the necessary skills to respond dynamically to unforeseen circumstances.

3. Advanced communication systems, such as satellite communication and real-time tracking to enable swift and effective communication during an emergency. These systems improve cooperation in emergency situations by enabling smooth communication between ships, ashore installations and relevant authorities. For example, in the case of a potential collision of one of the Company's vessels, the master is able to make use of the dynamic emergency response procedures and immediately respond by informing the relevant authorities and making real-time communication with other involved vessels. This allows for swift coordination and exchange of critical information.

4.2.2 Monitor - Knowing what to look for

The ability to monitor in the context of resilience engineering involves the continuous surveillance of a system's own operations as well as its environment to identify any deviations from standard operating procedures, which is (i.e. in the present) or can (i.e. in the future) seriously affect the system's performance in the near term - positively or negatively (Owen, et al., 2017). Effective monitoring is essential for detecting possible hazards and deviations in shipping. The monitor ability can be integrated into the existing SMS procedures of a company to go beyond compliance and emphasize dynamic surveillance for early risk detection. Monitoring is a continuous process that improves the company's ability to adapt, instead of just a compliance exercise. The Company has made significant investments in order to enhance its monitoring ability by:

1. Implementing sophisticated monitoring systems, like sensors and data analytics for detecting abnormalities in the equipment's operation. These systems use real-time data analytics to monitor environmental factors, navigational parameters and vessel performance. For instance, the Company measures water depths, tidal currents and weather conditions using onboard the company's vessels. The crew is able to make informed decisions during navigation based on this data, which is integrated into the vessel's monitoring systems. When transiting an area of concern, for example, VDR recordings are monitored as an approach to extract lessons that may be communicated, both positive and negative.

2. Establishing a reporting culture, encouraging crew members to report any near misses, including even minor deviations from standard procedures. The Company. incorporates, for

example, the results of near misses, like avoided collisions, that necessitate prompt investigation into the monitoring system. These data demonstrate how the company uses monitoring for continuous development by working to improve collision avoidance methods and modify navigation operations. Moreover, crew onboard company's ships are urged to report occasions where successful operations take place in order to incorporate these best practices into the monitoring system as well.

3. Employing cutting-edge surveillance and navigational systems to track vessel's movements and surrounding environmental conditions. For example, the Company employs advanced vessel positioning technologies, such as Automatic Identification System (AIS) and Differential Global Positioning System (DGPS). By delivering real-time information on a vessel's position, speed, and proximity to other vessels, these technologies enhance situational awareness.

4.2.3 Learn - Knowing what has happened

Resilience engineering requires a systematic review and integration of lessons learned from both failures and successes, but particularly the right lessons from the right experiences (i.e. doubleloop learning) (Owen, et al., 2017). In order to continually enhance safety protocols, the Company needs to prioritize continuous learning. The learn ability of resilience engineering aligns seamlessly with the ISM Code's requirement for continuous improvement. Encouraging a reporting culture that identifies and examines situations in which procedures had favorable results is necessary to be incorporated into the company's safety management system. The Company places a strong emphasis on cultivating a continuous learning culture by:

1. Establishing a robust incident investigation system, that encourages reporting not just for compliance but as a vital source of learning to capture and analyze data from accidents, near misses, and successes. For example, a vigilant crew member onboard one of the Company's vessels reports a minor fuel leak incident. The incident triggers a thorough investigation into what went wrong but also what went well and how the system adapted. and subsequent adjustments to fuel storage procedures. This data-driven approach allows for the identification of trends and patterns, facilitating continuous improvement in safety protocols. The findings

are disseminated across the fleet through a digitalized learning platform, ensuring that the entire organization benefits from the lessons learned.

2. Conducting regular safety audits to identify areas for improvement in safety procedures. For example, the Company has an established plan for carrying out regular safety audits and reviews as a proactive measure to identify areas for improvement in safety procedures. These audits may encompass equipment inspections, crew training assessments, and compliance checks, contributing to a culture of continuous learning and enhancement. The established SMS form compiled by the office personnel during vessel inspections, for instance, includes a dedicated section for reporting best practices observed, which on a later stage are collected and communicated with the company's employees, both onboard and ashore.

3. Implementing a feedback loop that allows for the continuous improvement of safety protocols based on real-world experiences. For example, the Company makes real-time adjustments to its safety procedures based on insights from the frontline by facilitating ongoing communication between crew members and safety managers. The vessels' masters share with the office minutes of the post-drill debriefing sessions, which are held to analyze the crew's performance, identify areas of improvement, and share lessons learned. Moreover, similarly to near miss reporting, the company's crews are encouraged to report good practices observed during their daily routines. A relevant section is included in the safety committee meeting minutes form of the Company's SMS to record and suggest potential improvements to the already applied good practices. These insights contribute to ongoing training and continuous improvement efforts.

4.2.4 Anticipate - Knowing what to expect

A key component of the resilience engineering's ability to anticipate, is to foresee potential future events, in order to prepare for them in advance, for example potential disruptions, novel demands or constraints, new opportunities or changing operating conditions (Owen, et al., 2017). This contributes to a proactive approach towards safety, which is essential considering that in maritime transport adverse conditions may arise swiftly. While the ISM Code acknowledges the need for risk assessments, resilience engineering's anticipate ability enriches this process by promoting a proactive and forward-looking approach.

The Company recognizes the anticipate ability as fundamental for proactive risk management. The company adopts key strategies, which include:

1. Conducting thorough and comprehensive risk assessments before each voyage to identify potential challenges, considering historical data, emerging trends, and potential systemic issues. For example, anticipating potential piracy threats is crucial for proactive risk management. During the preparation of one of the Company vessel's transit through a high-risk area, for example the Gulf of Aden, a relevant risk assessment is employed, considering risk mitigation measures against piracy. Amongst others, the enhancement of security protocols and employment of armed guards are considered. The identification of high-risk areas and implementation of proactive measures highlight the ability to anticipate and mitigate piracy threats.

2. Implementing predictive maintenance strategies to address potential equipment failures before they occur. For instance, the Company implements predictive maintenance strategies, to identify impending failures in critical engine components during routine checks. This anticipatory approach allows for the timely replacement of any component, preventing a potential breakdown during a voyage. This underscores how anticipation contributes to preventing potential breakdowns at sea and minimizing the risk of unplanned downtime and enhancing safety.

3. Providing continuous training to crew members to enhance their situational awareness and ability to anticipate potential risks. Recognizing the importance of crew preparedness, for example, the Company conducts scenario-based training for its crews. These sessions simulate various collision scenarios, allowing the crew to anticipate potential challenges and practice adaptive responses. Considering that most seafarers may not go through these situations during their entire career, the Company recognizes the importance of simulators. This proactive approach aimed to enhance the crew's ability to anticipate risks.

In the following chart we summarize the indicative tasks that were analysed in this section for the possible application of the four abilities of resilience engineering in maritime operations.

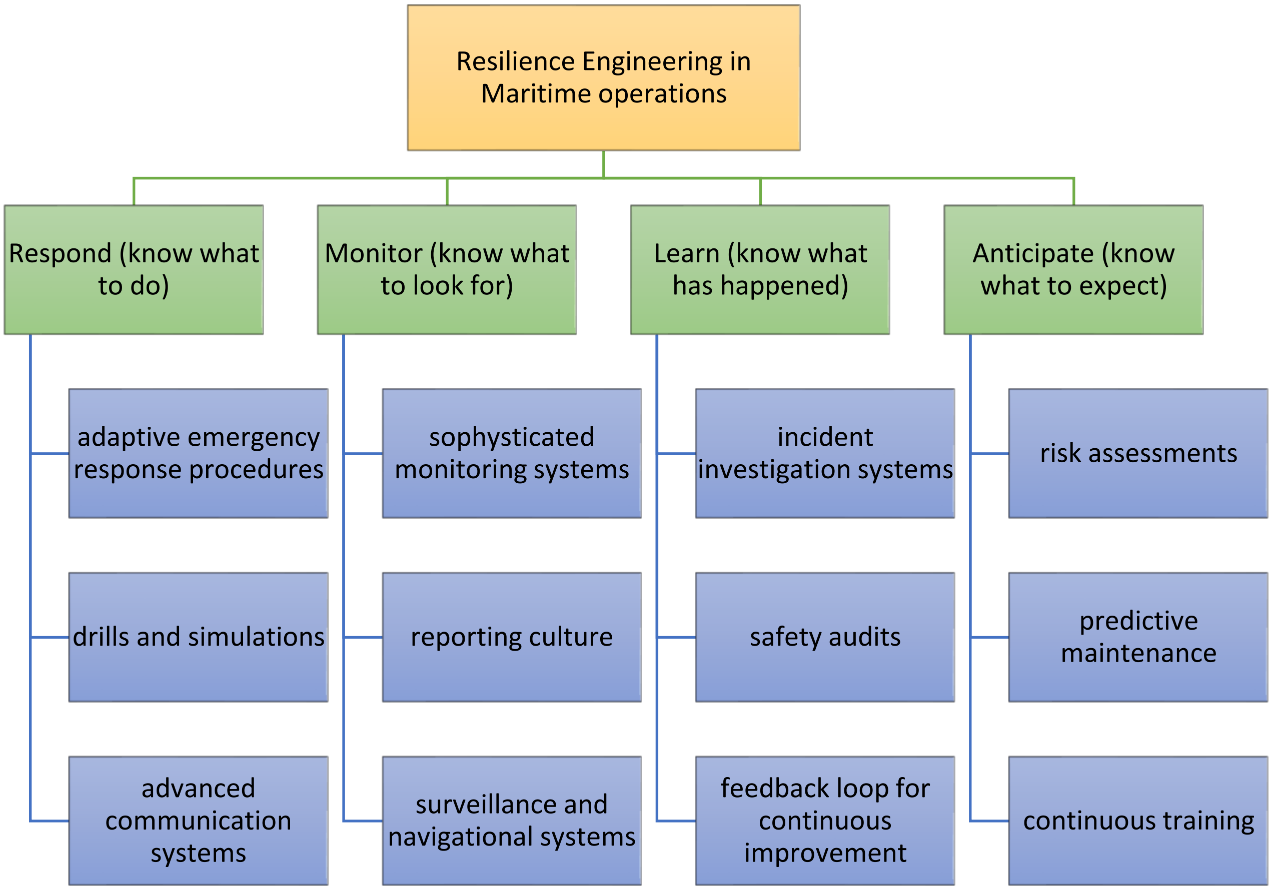

Figure 21 Possible applications of the Resilience Engineering abilities in Maritime Operations

4.3 Application of Resilience Engineering principles on an SMS form

This part of the paper suggests how the concept of Resilience Engineering can be applied in a shipping company's safety management system (SMS). The company has established an SMS in order to generate continuous and sustainable improvement in Health, Safety, Quality and Environmental (HSQE) management processes. This system complies with the requirements of:

- International Management Code for the Safe Operation of Ships and for Pollution Prevention (ISM Code)
- Standard of Quality Management Systems - Requirements (ISO 9001)
- Environmental Management Systems - Specification with guidelines for use ISO 14001
- Energy Management Systems - Requirements with guidance for use ISO 50001
- Occupational Health and Safety (ISO 45001)
- Maritime Labour Convention (MLC 2006)
- Tanker Management and Self-Assessment (TMSA) programme
- Other industry standards

Among other policies, the Company's SMS contains detailed procedures for reporting near misses.

According to the ISM Code, the following are required for the "Reports and analysis of non-conformities, accidents and hazardous occurrences":

- Paragraph 9.1 Procedures ensuring that non-conformities, accidents, and hazardous situations are reported to the company, investigated and analyzed with the aim of enhancing safety and pollution prevention should be included in the safety management system.
- Paragraph 9.2 Procedures for taking necessary corrective actions, including preventive actions to avoid recurrence should be established by the company (IMO, 2018).

Moreover, the TMSA Element 8, Incident Reporting, Investigation and Analysis stage 1 requires the following:

- 8.1.1 Clear procedures include the timely reporting and investigation of incidents and significant near misses, the responsible personnel and department for the investigation and details of the investigation procedure.
- 8.1.3 When a near miss happens, the company rapidly notifies the fleet with relevant information and identified immediate causes and preventive actions that should be addressed onboard each fleet vessel (OCIMF, 2017).

For ensuring that all undesired events are identified, analysed and, when necessary, investigated, in order to avoid reoccurrence, the Company has established and maintains relevant procedures in the safety management system. These procedures have been developed in line with the ISM Code and other existing industry requirements, regulations and standards. By promoting a "just culture", the Company encourages detailed reporting and promotes the systematic identification of hazards and the taking of measures to eliminate or reduce risks to the lowest practicable level (IMO, 2018). The Company considers the reporting of near misses vital. According to the Australian Maritime Safety Authority (AMSA), reporting near misses is helping in:

1. Identifying the risks affecting the industry and being able to react to risks that are not well identified.
2. Constructing an accurate and trustworthy database to guide future compliance and education initiatives.
3. Providing data and trends to develop effective safety policies and campaigns.
4. Giving the assurance that the safety culture in the sector is improving (AMSA, n.d.).

The Company maintains an Open Reporting System (ORS) for all ashore and onboard personnel involved in the operation of the vessels. Any identified Near Miss onboard a vessel is immediately reported to the relevant Officer or the Master. Initial reporting may be verbal, but a written report should follow, as presented in the below Form 1 “Near Miss Report”. Near misses are reviewed by the DPA, who has the ultimate authority to decide on the adequacy of corrective/ preventive actions or to initiate additional measures.

The results of the near misses are reviewed and analysed and relevant KPIs are monitored, which include the reporting of at least 4 near misses per vessel per month and the reporting of at least 20 near misses annually by office personnel during their onboard visits. Moreover, the company utilizes information and data received from external sources and the industry to identify trends and compare results from near misses.

Form 1 “Near Miss Report” includes details of the vessel and her location, the date and location of the near miss, the existing weather conditions, a full description of the near miss and results into the shipboard investigation in the causes. Once the sequence of events is established and understood, the “immediate causes” and the “basic/root causes” that if eliminated would have prevented the incident from occurring or mitigates its consequences are identified. For this purpose, the DNV-GL Marine Systematic Cause Analysis Technique (M-SCAT) methodology is employed to identify the underlying reasons/ real causes behind the symptoms. Then, the corrective and preventive actions taken onboard are described, as well as the details of the person who identified the near miss and any witnesses.

VESSEL NAME: ____
DATE OF REPORT: ____

IN CASE THIS NEAR MISS DERIVES FROM **STOP WORK** INTERVENTION PLEASE INDICATE BY TICKING RELEVANT BOX (**STOP WORK Intervention**) ☐

NEAR MISS ☐ UNSAFE ACT ☐ UNSAFE CONDITION ☐ (Tick as appropriate)

DATE/ TIME AND LOCATION OF NEAR MISS/ UNSAFE ACT/UNSAFE CONDITION:

VESSEL'S LOCATION AT TIME OF NEAR MISS/ UNSAFE ACT/UNSAFE CONDITION:

WEATHER CONDITIONS AT TIME OF NEAR MISS/ UNSAFE ACT/UNSAFE CONDITION:

Give full details below using as much space as needed to give a complete description of the near miss, unsafe act & unsafe condition i.e., where, when, how it happened and who was involved, what was the cause in your opinion and what action has been taken

DESCRIPTION OF NEAR MISS UNSAFE ACT/UNSAFE CONDITION

RESULTS OF SHIPBOARD INVESTIGATION INTO CAUSE

Immediate Causes

Substandard Acts	**Substandard Conditions**
☐Under the influence of medicine/alcohol/drugs	☐Cargo
☐Failure to follow procedures/instructions	☐Congestion/ restricted space for action
☐Failure to secure	☐Defective tool/equipment
☐Failure to use proper PPE	☐Incorrect material
☐Failure to inform/warn	☐Electric current hazards
☐ Improper lifting	☐Exposure to chemicals
☐ Improper loading	☐Exposure to high/low temperature
☐ Improper placement	☐Noise level over threshold
☐ Improper position for task	☐Radiation hazard over threshold
☐ Incorrect navigation or ship handling	☐Presence of flammable/explosive atmosphere
☐ Making safety devices inoperable	☐Exposure to dangerous atmosphere causing suffocation or poising
☐ Operating at improper speed	☐Inadequate guard/barrier
☐ Operating equipment without authority	☐Insufficient /Excessive illumination
☐ Removing safety devices	☐Inadequate/Improper PPE

☐Inadequate servicing of equipment/machinery/device	☐Inadequate ventilation
☐ Using defective tool/equipment/machinery/device	☐Inadequate warning system
☐Foul play/Sabotage	☐Incorrect/ Inadequate tool/equipment
☐Substandard act by external party	☐Outdated charts/publications and other documents
☐failure to comply with customers/stakeholders requirements	☐Poor housekeeping/order
☐Other (specify)	☐Inadequate condition of floor/surface
	☐Extreme adverse sea/weather conditions
	☐Inadequate port and berthing facilities
	☐Other (specify)

Basic/Root causes	
Personal Factors	**Job Factors**
☐Inadequate Physical/Physiological Capability	☐Unclear Organizational Structure
☐Inadequate Mental/Psychological Capability	☐Inadequate leadership
☐Physical/Physiological Stress	☐Inadequate Supervision/Coaching
☐Mental/Psychological Stress	☐Inadequate Management of Change
☐Lack of Competence	☐Inadequate Supply Chain Management
☐ Improper Motivation	☐Inadequate Maintenance/Inspection
☐ Other (specify)	☐Excessive Wear/Tear
	☐Inadequate Tool/Equipment/Machinery/Device
	☐Inadequate Product/Service Design
	☐Inadequate Work/Production Standards
	☐Inadequate Communication/Information
	☐Other (specify)

DETAILS OF CORRECTIVE & PREVENTIVE ACTION TAKEN SO FAR	
Name of person who identified Near Miss, Unsafe act, Unsafe condition:	
Witness Report(s) attached:	
Number these reports if more than one near miss unsafe act, unsafe condition reported on the same day.	No:

END OF FORM 1 "NEAR MISS REPORT"

In addition to providing basic details of the event, it is noted that the main purpose of the near miss report is to identify the causes that led to the failure in operation. Although the hazard was prevented, instead of focusing on what went well and which barriers of the complex system worked, more focus is placed on the failure and the contributory factors. This is a Safety I and more reactive approach.

Considering an example of a near miss, where a ship is at an anchorage and a crew member is working on a platform overboard for ship's hull painting and the rope that holds him brakes we create several potential scenarios, where 1, 2 and 3 are near misses and 4 is a major incident:

1. the life belt saves him when he falls
2. he falls into the water due to bad maintenance of his delt, but he has a lifejacket on so he floats on the water waiting for help.
3. he falls into the water due to bad maintenance of his delt, but he has a lifejacket on, so another crew member observing the work helps him immediately
4. he falls into the water due to bad maintenance of his delt without a lifejacket, while no one is observing to help him and finally he is drowned.

This example demonstrates how a common origin can result in varied and potentially fatal consequences. Failing to intervene after any of the initial three occurrences increases the risk of a similar incident proving fatal for another team member in the future. In essence, the "causal chain" leading to a harmful incident is disrupted just before it occurs.

However, in the chain of events, we note some aspects of the normal operation that led to a successful outcome, although there was an unexpected occurrence (the rope's breaking). The use of proper personal protective equipment (PPE), for instance, or the proper maintenance of equipment or the continuous monitoring of a person working aloft can prevent the hazard. These are important factors that can be used from a resilience engineering perspective. In scenarios 1-3 the system is resilient, which means that it responds and recovers from the unexpected disturbance. In scenario 1, the system is more resilient compared to scenario 3, as it recovers more quickly.

Considering the above example, we conclude that the near miss report form can be revised to include resilience sections.

During the review of the existing near miss form, it is suggested that the structure and the main details, like date and time, location and narrative should remain unchanged. Moreover, the sections related to the investigation of the causes and the corrective/preventive actions taken shall also remain as it is, in order to have a more holistic view on the event. However, from a resilience engineering perspective, it is suggested that integrations/adaptations that should be made, which include but are not limited to the following:

- Include information on what went right and actions taken to prevent escalation.
- Note best practices identified for the prevention of the event, including resilience behaviors, like monitoring and anticipating.
- Describe how the individuals and the system adapted to the changing conditions.
- Note how the event deviated from normal operation.
- List any system, technology or equipment involved and highlight effective use or deviations from normal functioning.
- Identify grounds for improvement and propose updates in policies, procedures and equipment.
- Evaluate the training, skills and competencies of the involved crew.
- Identify training needs and make suggestions with specific topics related to the event
- List success factors, i.e. factors that contributed to the prevention of the hazard.

Taking into consideration the above factors, the Form 1 “Near Miss Report” is revised to include new sections that incorporate the resilience engineering aspects which are highlighted with green color in the following RE Form 1 “Near Miss Report”.

The new sections are listed below:

- Equipment/ technology used at time of near miss/ unsafe act/unsafe condition.
- Description of what went right / actions taken to prevent escalation.
- Success factors.
- Follow-up actions/monitoring required.

- Updates in policies, procedures and equipment suggested.
- Resilience behaviors and best practices identified.
- Training needs identified.
- Lesson learnt.
- Follow-up date.
- Training date.

To determine potential success factors, in other words barriers or controls that effectively worked and prevented the hazard, the root cause analysis (RCA) methodology previously adopted (DNV-GL M-SCAT) for the identification of immediate and basic root causes and the performance influencing factors (PIFs) of OCIMF have been reviewed. Personal and job factors are distinguished and the list, although not exhaustive, is incorporated in the new form, including the following:

- Good mental capability
- Clear organizational structure
- Good physical capability
- Adequate leadership
- High level of competence/skills
- Adequate supervision/coaching
- Practice surrounding use of procedures/instructions
- Adequate management of change
- Strong Motivation
- Proper maintenance/inspection
- Adequate supervision/monitoring
- Use of proper equipment/tools
- Recognition of Safety criticality of the task
- Adequate product/service design
- Adequate work/production standards
- Effective communication/information
- Procedures accessible, helpful, understood and accurate for task.

- Use of proper PPE
- Use of safety devices
- Opportunity to learn and practice
- Others

VESSEL NAME: ____
DATE OF REPORT: ____

IN CASE THIS NEAR MISS DERIVES FROM **STOP WORK** INTERVENTION PLEASE INDICATE BY TICKING RELEVANT BOX (**STOP WORK Intervention**) ☐

NEAR MISS ☐ UNSAFE ACT ☐ UNSAFE CONDITION ☐ (Tick as appropriate)

DATE/ TIME AND LOCATION OF NEAR MISS/ UNSAFE ACT/UNSAFE CONDITION:

VESSEL'S LOCATION AT TIME OF NEAR MISS/ UNSAFE ACT/UNSAFE CONDITION:

WEATHER CONDITIONS AT TIME OF NEAR MISS/ UNSAFE ACT/UNSAFE CONDITION:

EQUIPMENT/ TECHNOLOGY USED AT TIME OF NEAR MISS/ UNSAFE ACT/UNSAFE CONDITION:

Give full details below using as much space as needed to give a complete description of the near miss, unsafe act & unsafe condition i.e., where, when, how it happened and who was involved, what was the cause in your opinion and what action has been taken

DESCRIPTION OF NEAR MISS UNSAFE ACT/UNSAFE CONDITION

DESCRIPTION OF WHAT WENT RIGHT / ACTIONS TAKEN TO PREVENT ESCALATION

RESULTS OF SHIPBOARD INVESTIGATION INTO CAUSE

Immediate Causes

Substandard Acts	Substandard Conditions
☐Under the influence of medicine/alcohol/drugs	☐Cargo
☐Failure to follow procedures/instructions	☐Congestion/ restricted space for action
☐Failure to secure	☐Defective tool/equipment
☐Failure to use proper PPE	☐Incorrect material
☐Failure to inform/warn	☐Electric current hazards
☐Improper lifting	☐Exposure to chemicals
☐Improper loading	☐Exposure to high/low temperature
☐Improper placement	☐Noise level over threshold
☐Improper position for task	☐Radiation hazard over threshold

☐Incorrect navigation or ship handling	☐Presence of flammable/explosive atmosphere
☐Making safety devices inoperable	☐Exposure to dangerous atmosphere causing suffocation or poising
☐Operating at improper speed	☐Inadequate guard/barrier
☐Operating equipment without authority	☐Insufficient /Excessive illumination
☐Removing safety devices	☐Inadequate/Improper PPE
☐Inadequate servicing of equipment/machinery/device	☐Inadequate ventilation
☐Using defective tool/equipment/machinery/device	☐Inadequate warning system
☐Foul play/Sabotage	☐Incorrect/ Inadequate tool/equipment
☐Substandard act by external party	☐Outdated charts/publications and other documents
☐failure to comply with customers/stakeholders requirements	☐Poor housekeeping/order
☐Other (specify)	☐Inadequate condition of floor/surface
	☐Extreme adverse sea/weather conditions
	☐Inadequate port and berthing facilities
	☐Other (specify)

Basic/Root causes

Personal Factors	Job Factors
☐Inadequate Physical/Physiological Capability	☐Unclear Organizational Structure
☐Inadequate Mental/Psychological Capability	☐Inadequate leadership
☐Physical/Physiological Stress	☐Inadequate Supervision/Coaching
☐Mental/Psychological Stress	☐Inadequate Management of Change
☐Lack of Competence	☐Inadequate Supply Chain Management
☐ Improper Motivation	☐Inadequate Maintenance/Inspection
☐ Other (specify)	☐Excessive Wear/Tear
	☐Inadequate Tool/Equipment/Machinery/Device
	☐Inadequate Product/Service Design
	☐Inadequate Work/Production Standards
	☐Inadequate Communication/Information
	☐Other (specify)

Success Factors

Personal Factors	Job Factors
☐Good mental capability	☐Clear organizational structure
☐Good physical capability	☐Adequate leadership
☐High level of competence/skills	☐Adequate supervision/coaching
☐Practice surrounding use of procedures/instructions	☐Adequate management of change
☐Strong Motivation	☐Proper maintenance/inspection
☐Adequate supervision/monitoring	☐Use of proper equipment/tools
☐Recognition of Safety criticality of the task	☐Adequate product/service design
☐Others (specify)	☐Adequate work/production standards
	☐Effective communication/information
	☐Procedures accessible, helpful, understood and accurate for task.
	☐Use of proper PPE
	☐Use of safety devices
	☐Opportunity to learn and practice
	☐Others (specify)

DETAILS OF CORRECTIVE & PREVENTIVE ACTION TAKEN SO FAR

FOLLOW-UP ACTIONS/MONITORING REQUIRED	
UPDATES IN POLICIES, PROCEDURES AND EQUIPMENT SUGGESTED	
RESILIENCE BEHAVIORS AND BEST PRACTICES IDENTIFIED	
TRAINING NEEDS IDENTIFIED	
LESSONS LEARNT	
Name of person who identified Near Miss, Unsafe act, Unsafe condition:	
Witness Report(s) attached:	
Follow-up date:	
Training date:	
Number these reports if more than one near miss unsafe act, unsafe condition reported on the same day.	No:

END OF RE FORM 1 “NEAR MISS REPORT”

In the following table 6 we summarize the existing sections of the subject near miss report and the updates that are suggested in our case study for the integration of Safety II and resilience engineering theories.

Table 6 Adopted approach vs Resilience Engineering in Near Miss reporting.

Existing form based on Safety I approach	Additions based on Safety II and RE principles
Basic details: vessel name, report date, stop work intervention, near miss date, time, location and weather conditions.	Equipment/ technology used at the time of the near miss
Full description of the near miss	Description of what went right / actions taken to prevent escalation
Results of the shipboard investigation into cause	Success Factors, including personal and job factors
Immediate & basic/ root causes including personal and job factors	Follow-up actions/monitoring required and follow-up date.
Details of corrective and preventive actions taken so far	Updates in policies, procedures and equipment suggested Resilience behaviors and best practices identified
Details of person who identified the near miss and any witness reports	Training needs identified and training completion date Lessons Learnt

4.4 Discussion

The main research questions that guided this study were: (a) Which of the existing tasks in the operation of a ship managing company could adopt a resilience engineering perspective? (b) How can the four abilities of resilient systems (i.e. learn, monitor, respond and anticipate) be applied in existing safety tasks and operations in the operation of a shipping company? and (c) How can the principles of resilience engineering be integrated in the safety management system of a shipping company?

Although there are not any previous works concerning the resilience engineering approach in the established procedures and operations of a ship managing company, the application in various facets of the maritime industry is shown in this study. From bridge resource management to incident reporting systems, emergency response planning, behavioral based safety and maintenance practices, the RE theories' principles are evident in the context of maritime operations. Additionally, comparing these findings to the application in other industries, such as aviation, healthcare and oil and gas, highlights the effectiveness and adaptability of resilience engineering principles across diverse operational contexts. This assessment across the different industries reveals commonalities in safety practices and resilience strategies, which enhance the understanding of how the shipping operations can benefit from the methods established in other sectors.

Moreover, our study revealed that the four abilities of RE can be integrated into maritime operations. The ability to respond, involves putting in place a robust and comprehensive framework for response, which necessitates adaptive emergency response procedures, drills and simulations, as well as advanced communication systems. The monitor ability can be integrated into the existing SMS procedures of a company to go beyond compliance and emphasize dynamic surveillance for early risk detection. This can be attained by implementing sophisticated monitoring systems, establishing a reporting culture and adopting advanced surveillance and navigational systems. To continually enhance the learning ability, the Company should place emphasis on cultivating a continuous learning culture by establishing robust incident investigation systems, conducting regular safety audits and implementing a feedback loop for sharing insights and real-time information. Lastly, the ability to anticipate includes a proactive approach towards safety, which can be developed by conducting thorough and comprehensive risk assessments, implementing predictive maintenance strategies and providing continuous training to crew members.

This study has shown that there is room for the introduction and practical application of the resilience engineering principles in Shipping and this can be obtained by the integration into the Safety Management Systems. We looked into the safety procedures of a shipping company and contemplated how these can be updated to integrate the RE concept. We observed one of the SMS's forms, the Near Miss Report, which was selected as a suitable tool for our investigation, as it refers to an event that was prevented, although there was a deviation from normal operation. We considered a near miss as a source to achieve safety not as a failure. This means that some barriers worked well and contributed to the prevention of the hazard. So, we concluded that the subject form can be updated to include some sections that adapt to the proactive theory and contribute to the identification of positive factors.

Considering an example of a working aloft near miss, we decided that the existing SMS form can be revised to include positive aspects of the near miss, such as description of what went well, success factors identification list, suggested follow up actions and policies and procedures' updates as well as lessons learnt and training needs. As the near miss reporting is already included in the company's established KPIs, instead of solely monitoring the factors that contributed to failures, incidents and near misses, the company could take advantage of the new sections in the form to establish new KPIs, including lessons learnt from near misses and best practices followed in the event of a near miss. These can be circulated within the company and its fleet vessels and campaigns, to be analyzed and utilized towards continuous improvement and resilience.

5. Conclusions

The maritime sector is inherently complex, involving interactions between technology, human factors and the environment. In the coming years, the industry is going to face risks related to several challenges, such as extreme weather events, natural disasters, global disruptions (i.e. pandemics), cyber attacks etc. The evolving challenges and the need for a deeper understanding of safety management lead to the establishment of new safety approaches. Safety II and Resilience Engineering seem to be offering a comprehensive framework, by considering the interactions between different components and the dynamic nature of organizations.

The ISM Code has been a cornerstone in promoting safety in the maritime industry, providing a structured framework for shipping companies. The ISM Code's effectiveness was proved by the reduction of accidents and incidents at sea since its introduction. While the ISM Code has contributed to incident prevention, it is important to note that the effectiveness also depends on the commitment and implementation by shipping companies. TMSA has also been a useful tool for shipping companies, providing industry best practices and KPIs to assess and measure their managements systems. From our study we conclude that Safety II can potentially enrich the process by encouraging a more proactive and adaptive safety culture. The two approaches can be complementary, with Safety II providing additional insights into adaptability and resilience.

By understanding everyday work, learning from variability and success, shipping companies can foster a safety culture that promotes adaptability and continuous improvement. Safety II contributes to the companies' commitment to safety excellence, ensuring the well-being of its crews and the reliability of its maritime operations. Safety II provides a holistic framework for the maritime industry, acknowledging that safety is not just the absence of failures but a dynamic interplay of adaptive practices and resilient systems that contribute to the prevention of incidents and the overall improvement of operational safety.

In terms of safety, the human factor has been at the top of the international shipping agenda. However, the importance of human performance to safety in shipping has only begun to be considered in depth and analyzed in recent years. The focus on human performance coincides with the shipping industry entering a new era of Safety II, which focuses more on the dynamics and added value of the human element and controlling the variability of its performance than on the conventional approach of his failure and error. In this new context, skills and attributes related to human performance are expected to appear increasingly among the demands of global shipping. Therefore, it is considered necessary to view human ability as a resource for emergency safety, not only as a source of the problem.

As we move forward, several opportunities for future research and development emerge. Firstly, there is a need for further exploration of the specific application of Safety II and Resilience Engineering in different segments of the maritime industry, considering the development of advanced technologies, such as autonomous vessels and real-time data analytics, which could be incorporated into safety management systems to enhance decision-making and overall system resilience. Furthermore, research efforts should be directed towards the development of training programs and tools.

In conclusion, this thesis reviewed the concepts of Safety II and Resilience Engineering and examined their application in the context of a shipping company. Understanding the complexities of everyday work at sea and the need to build adaptive capacities to respond to unforeseen challenges is of outmost importance. Through in-depth analysis of a particular case study, we gained valuable insights into the potential benefits of a more holistic and adaptive approach to maritime safety management. The case study emphasized the value of focusing on success and performance variability, rather than following a more traditional approach to safety, which focuses solely on failures and errors. Overall, these concepts have the potential to transform safety management practices, leading to a safer, more adaptive, and resilient maritime industry.

Appendix I

***Resilience* definitions in different domains (Quinlan, et al., 2015)**			
Resilience	Definition	Emphasis	Key References
Engineering resilience	System's speed of return to equilibrium following a shock	Return time to recover, efficiency, equilibrium	Pimm (1984)
Ecological resilience	Ability of a system to withstand shock and maintain critical relationships and functions	Buffer capacity, withstand shock, persistence,	Holling (1996)
Social-ecological resilience	(i) Amount of disturbance a system can absorb and remain within a domain of attraction; (ii) capacity for learning and adaptation (iii) degree to which the system is capable of self-organizing	Adaptive capacity, learning, innovation	Carpenter et al. (2001)
Social resilience	Ability of groups or communities to cope with external stresses and disturbances as a result of social, political and environmental change	Social dimensions, heuristic device	Adger (2000)

Development resilience	Capacity of a person, household or other aggregate unit to avoid poverty in the face of various stressors and in the wake of myriad shocks over time	Vulnerability, robustness	Pasteur (2011) and Barrett & Constas (2014)
Socioeconomic resilience	Socioeconomic resilience refers to the policy induced ability of an economy to recover from or adjust to the negative impacts of adverse exogenous shocks and to benefit from positive shocks	Economic response capacity	Mancini et al. (2012)
Community resilience	A process linking a set of adaptive capacities to a positive trajectory of functioning and adaptation after a disturbance	Adaptive capacity, disturbance, social	Norris et al. (2008)
Psychological resilience	An individual's ability to adapt to stress and adversity. Resilience is a process and can be learned by anyone using positive emotions	Coping, adaptation, process	Tugade, Fredrickson & Feldman Barrett (2004)

Bibliography

Adhita, I. G. M. S., Fuchi, M., Konishi, T. & Fujimoto, T., 2023. *Ship navigation from a Safety-II perspective: A case study of training-ship operation in coastal area,* https://doi.org/10.1016/j.ress.2023.109140: Elsevier Ltd..

AGCS, 2023. *Safety and Shipping Review 2022, An annual review of trends and developments in shipping losses and safety,* s.l.: Allianz Global Corporate & Specialty (AGCS).

AMSA, n.d. *Australian Government - Australian Maritime Safety Authority.* [Online]
Available at: https://www.amsa.gov.au/vessels-operators/incident-reporting

API RP 1009, 2015. *Model Emergency Response Program for Oil Spill Response in Arctic Waters.* s.l.:American Petroleum Institute.

Aven, T., 2021. *A risk science perspective on the discussion concerning Safety I, Safety II and Safety III,* s.l.: The Author. Published by Elsevier Ltd..

Bastan, O., Benesl, T. & Fiedler, P., 2018. *Resiliency, the Path to Safety II,* s.l.: IFAC (International Federation of Automatic Control) Hosting by Elsevier Ltd. All.

Bastan, O., Fiedler, P., Benesl, T. & Arm, J., 2019. *Redundancy as an important source of resilience in the Safety II concept,* s.l.: IFAC (International Federation of Automatic Control) Hosting by Elsevier Ltd.

Bates, D. W., Saria, S., Ohno-Machado, L. & Shah, A., 2014. *Big data in health care: using analytics to identify and manage high-risk and high-cost patients.* s.l.:Health Affairs, 33(7), 1123-1131..

Battles, J., King, H. B. & Henriksen, K., 2019. *Advances in Patient Safety: New Directions and Alternative Approaches. Vol. 3: Performance and Tools.* s.l.:Agency for Healthcare Research and Quality (US).

Braithwaite, J., Wears, R. L. & Hollnagel, E., 2017. *Resilient Health Care: Turning Patient Safety on Its Head.* s.l.:International Journal for Quality in Health Care, 29(3), 342–345..

Ceylan, B. O., Akyuz, E. & Arslanoglu, Y., 2022. *Modified quantitative systems theoretic accident model and processes (STAMP) analysis: A catastrophic ship engine failure case,* https://doi.org/10.1016/j.oceaneng.2022.111187: Elsevier Ltd.

Chen, D. & Tian, H., 2012. *Behavior Based Safety for Accidents Prevention and Positive Study in China Construction Project.* Open access under CC BY-NC-ND license. doi: 10.1016/j.proeng.2012.08.092 ed. s.l.:Elsevier Ltd.

CHIRP, n.d. [Online]
Available at: https://chirp.co.uk/

Clark-Ginsberg, A., 2016. *What's the Difference between Reliability and Resilience?.* DOI:10.13140/RG.2.2.20571.46885 ed. s.l.:Available online at ResearchGate.

Costa, V. B., Urbina, L. M. S. & Machado Cardoso-Junior, M., 2021. *Project Management Process Resilience: Assessing and Improving the Project Review Process Using FRAM.* s.l.:Instituto Tecnológico de Aeronáutica, Pça. Mal. Eduardo Gomes, 50, 12228-900, São José dos Campos, Brazil, Available online at researchgate.com.

Dekker, S., 2011. *Drift into Failure: From Hunting Broken Components to Understanding Complex Systems.* s.l.:Ashgate Publishing, Ltd..

Dekker, S., 2012. *Just Culture: Balancing Safety and Accountability, 2nd Ed,* s.l.: Ashgate.

Dekker, S., 2014. *The Field Guide to Understanding 'Human Error'.* s.l.:CRC Press.

Ditlevsen, O., Haugen, S. & Wang, P., 2019. *Marine Maintenance Reliability: A Case Study.* s.l.:Reliability Engineering & System Safety, 185, 327-334..

Fletcher, D. & Sarkar, M., 2013. *Psychological resilience: A review and critique of definitions, concepts and theory.* s.l.:European Psychologist. Vol. 18/1, pp. 12-23.

Fossen, T. I., 2011. *Handbook of Marine Craft Hydrodynamics and Motion Control.* s.l.:John Wiley & Sons.

Furuta, K., 2015. *Reflections on the Fukushima Daiichi Nuclear Accident, Chapter 24 Resilience Engineering,* DOI 10.1007/978-3-319-12090-4_24: Resilience Engineering Research Center, Graduate School of Engineering, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan.

Gawande, A., 2010. *The Checklist Manifesto: How to Get Things Right.* s.l.:Metropolitan Books.

Grotberg, E., 1997. *The international resilience project: findings from the research and the effectiveness of interventions,* s.l.: Proceedings of the 54th Annual Convention of the International Council of Psychologists.

Helmreich, R. L. & Merritt, A. C., 2001. *Culture at work in aviation and medicine: National, organizational and professional influences.* Aldershot, UK: Ashgate.

Hernqvist, M., 2011. *Information to Maritime Administrations and Training Providers, Maritime Resource Management,* Gothenburg, Sweden: The Swedish Club Academy.

Hollnagel, E., 2004. *Barriers and Accident Prevention,* s.l.: Ashgate, Aldershot.

Hollnagel, E., 2012. *FRAM: the Functional Resonance Analysis Method. Modelling Complex Socio-Technical Systems,* DOI:10.1201/9781315255071: Ashgate.

Hollnagel, E., 2012. *Resilience engineering and the systemic view of safety at work: Why work-as-done is not the same as work-as-imagined,* s.l.: Bericht zum 58. Kongress der Gesellschaft für Arbeitswissenschaft vom 22 bis 24 Februar 2012. GfA-Press, Dortmund. p. 19-24..

Hollnagel, E., 2013. *Resilience engineering in practice: A guidebook.* s.l.:Ashgate Publishing Ltd..

Hollnagel, E., 2014. *Safety-I and safety-II,* London: CRC-Press.

Hollnagel, E., 2016. *Functional Resonance Analysis Method FRAM. A Practical Introduction.* Padua, Italy, European Comission, Research and innovation: https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5c1754eab&appId=PPGMS.

Hollnagel, E., Hounsgaard, J. & Colligan, L., 2014. *FRAM-the Functional Resonance Analysis Method - a handbook for the practical use of the method,* s.l.: Center for Quality.

Hollnagel, E., Leonhardt, J., Licu, T. & Shorrock, S., 2013. From Safety-I to Safety-II: A White Paper. *European Organisation for the Safety of Air Navigation,* Volume www.eurocontrol.int.

Hollnagel, E., Paries, J., Woods, D. D. & Wreathall, J., 2011. *Resilience engineering in practice: A guidebook,* s.l.: Farnham, UK: Ashgate.

Hollnagel, E., Wears, R. & Braithwaite, J., 2015. *From Safety-I to Safety-II: A White Paper,* s.l.: The Authors, published online at Research Gate.

Hollnagel, E., Woods, D. D. & Leveson, N. C., 2006. *Resilience engineering: Concepts and precepts,* s.l.: Aldershot, UK: Ashgate.

Hudson, P. T., 2007. *The new science of safety.* s.l.:Occupational Health & Safety, 76(6), 24–28..

ICS, 2020. *The International Chamber of Shipping Annual Review.* [Online]
Available at: https://www.ics-shipping.org/publication/annual-review-2020/

IMO, 1974. *International Convention for the Safety of Life at Sea (SOLAS).* s.l.:International Maritime Organization (IMO).

IMO, 1978. *International Convention on Standards of Training, Certification and Watchkeeping for Seafarers,* London, England: International Maritime Organization (IMO).

IMO, 2008. *Guidance on near-miss reporting - MSC-MEPC.7/Circ.7.* London: International Maritime Organization (IMO).

IMO, 2018. *The International Safety Management (ISM) Code,* London, England: International Maritime Organization (IMO).

Intelligence, L. L., n.d. [Online]
Available at: https://www.lloydslistintelligence.com/

International Maritime Organization (IMO), 1999. *Resolution A.893(21) - Guidelines for Voyage Planning.* London: IMO.

International Maritime Organization (IMO), 2010. *International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW).* London: IMO.

International Maritime Organization (IMO), 2019. *Model Course 1.22 - Bridge Resource Management.* London: IMO.

Ismail, F. et al., 2012. *Behaviour Based Approach for Quality and Safety Environment Improvement: Malaysian Experience in the Oil and Gas Industry.* s.l.:Procedia - Social and Behavioral Sciences 35 (2012) 586 – 594.

Kim, H., 2013. *A Resilience Engineering Approach to Assess Major Accident Risks.* PK8200 Risk Influence Modelling, NTNU - Trondheim Norwegian University of Sience and Technology.

Kruk, M. E., Myers, M., Varpilah, S. T. & Dahn, B., 2021. *Kruk, M. E., Myers, M., Varpilah, S. T., & Dahn, B. T. (2021). What is a resilient health system? Lessons from Ebola.* s.l.:The Lancet, 389(10074), 1910-1912..

Kujala, P., Lahtinen, M. & Hanninen, M., 2016. *Resilience Engineering in the maritime domain- A literature review.*. s.l.:Safety Sience, 88, 211-218.

Leape, L. L. et al., 2013. *Perspective: a culture of respect, part 2: creating a culture of respect.* s.l.:Academic Medicine, 88(6), 857-862..

Leonhardt, J., Macchi, L., Hollnagel, E. & Kirwan, B., 2009. A White Paper on Resilience Engineering for ATM. *European Organisation for the Safety of Air Navigation (EUROCONTROL).*

Leveson, N., 2020. *Safety III: A Systems Approach to Safety and Resilience.* s.l.:Aeronautics and Astronautics Dept., MIT Engineering System Lab.

Leveson, N. G., 2011. *Engineering a Safer World: Systems Thinking Applied to Safety.* s.l.:MIT Press.

Lofquist, E. A., 2010. *The art of measuring nothing: The paradox of measuring safety in a changing civil aviation industry using traditional safety metrics,* s.l.: Safety Science, Vol. 48, pp. 1520-1529.

Mallam, S., Nazir, S. & Renganayagalu, S. K., 2019. *Rethinking Maritime Education, Training, and Operations in the Digital Era: Applications for Emerging Immersive Technologies.* https://doi.org/10.3390/jmse7120428 ed. s.l.:Journal of Maritime Science and Engineering MDPI.

Mannan, S., 2012. *Lees' Loss Prevention in the Process Industries: Hazard Identification, Assessment and Control.* s.l.:Butterworth-Heinemann.

Martins, J. B., Carim Jr., G., Saurin, T. A. & Costella, M. F., 2022. *Integrating Safety-I and Safety-II: Learning from failure and success in construction sites,* s.l.: Elsevier Ltd..

Muecklich, N., Sikora, I., Paraskevas, A. & Padhra, A., 2023. *Safety and reliability in aviation – A systematic scoping review of normal accident theory, high-reliability theory, and resilience engineering in aviation,* s.l.: Elsevier Ltd..

Nedcon Maritime, 2014. [Online]
Available at: https://nedcon.ro/985/

OCIMF, 2017. *Tanker Management and Self Assessment 3, A Best Practice Guide.* 3rd Edition ed. s.l.:Oil Companies International Marine Forum (OCIMF).

OCIMF, 2022. *Oil Companies International Marine Forum (OCIMF).* [Online]
Available at: https://www.ocimf.org/programmes/sire-2-0

Owen, D. et al., 2017. *Exploring Resilience in Aviation and Maritime Transport – And How Human Factors Can Help.* available online at https://www.resilienceshift.org/ ed. s.l.:The Resilience Shift.

Patriarca, R. et al., 2020. *Framing the FRAM: A literature review on the functional resonance analysis method,* https://doi.org/10.1016/j.ssci.2020.104827: Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/BY-NC-ND/4.0/).

Patterson, M. & Deutsch, E., 2015. *Safety-I, Safety-II and Resilience Engineering,* s.l.: Curr Probl Pediatr Adolesc Health Care.

Peng, C., Zhen, X. & Huang, Y., 2022. *Human-automation interaction centered approach based on FRAM for systemic safety analysis of dynamic positioning operations for offshore tandem offloading,* https://doi.org/10.1016/j.oceaneng.2022.113249: Elsevier Ltd..

Ponomarov, S. Y. & Holcomb, M. C., 2009. *Understanding the concept of supply chain resilience.* s.l.:The International Journal of Logistics Management, 20(1), 124-143..

Ponomarov, S. Y. & Holcomb, M. C., 2009. *Understanding the concept of supply chain resilience.* s.l.:The International Journal of Logistics Management, 20(1), 124–143..

Praetorius, G., Lundh, M. & Lützhöft, M., 2011. *Learning from the past for pro-activity – A re-analysis of the accident of the MV Herald of Free Enterprise,* https://www.researchgate.net/publication/260319355: Chalmers University of Technology, Department of Shipping and Marine Technology, Gothenburg, Sweden.

Qiao, W., Liu, Y., Ma, X. & Lan, H., 2021. *Cognitive Gap and Correlation of Safety-I and Safety-II: A Case of Maritime Shipping Safety Management,* https://doi.org/10.3390/su13105509: Sustainability 13, 5509.

Quinlan, A. E., Berbes-Blazquez, M., L. Jamila, H. & Peterson , G. D., 2015. *Measuring and assessing resilience: broadening understanding through multiple disciplinary perspectives,* s.l.: Journal of Applied Ecology, British Ecological Society.

Ranasinghe, U., Jefferies, M., Davis, P. & Pillay, M., 2020. *Resilience Engineering Indicators and Safety Management: A Systematic Review.* s.l.:Safety and Health at Work, 127-135 journal homepage: www.e-shaw.net available at ScienceDirect.

Righi, A. W., Saurin, T. A. & Wachs, P., 2015. *A systematic literature review of resilience engineering: Research areas and a research agenda proposal,* s.l.: Elsevier Ltd..

RINA, n.d. [Online]
Available at: https://www.rina.org/en/business/transport-infrastructure/resilience-engineering

Salas, E., Burke, C. S., Bowers, C. A. & Wilson, K. A., 2010. *Team training in the skies: Does crew resource management (CRM) training work?.* s.l.:Human Factors, 52(5), 631–649..

Salihoglu, E. & Besikci, E. B., 2020. *The use of Functional Resonance Analysis Method (FRAM) in a maritime accident: A case study of Prestige,* https://doi.org/10.1016/j.oceaneng.2020.108223: Elsevier Ltd.

Saurin, T. A. & Gonzalez, S. S., 2013. *Assessing the compatibility of the management of standardized procedures with the complexity of a sociotechnical system: Case study of a control room in an oil refinery,* http://dx.doi.org/10.1016/j.apergo.2013.02.003: Elsevier Ltd and The Ergonomics Society.

Saurin, T. A., Righi, A. W. & Henriqson, E., 2013. *Characteristics of complex socio-technical systems and guidlines for their management: the role of resilience,* s.l.: Pontificia Universidade Católica do Rio Grande do Sul, Porto Alegre (RS), Brazil.

Schröder-Hinrichs, J.-U., Praetorius, G., Graziano, A. & Kataria, A., 2015. *Introducing the concept of Resilience into Maritime Safety,* s.l.: Maritime Risk and System Safety (MaRiSa) Research Group, published online at Research Gate.

The Swedish Club Academy, 2011. *Information to Maritime Administrations. Maritime Resource Management.* s.l.:The Swedish Club Academy AB.

Tian, W. & Caponecchia, C., 2020. *Using the Functional Resonance Analysis Method (FRAM) in Aviation Safety: A Systematic Review,* s.l.: Journal of Advanced Transportation.

Turan, O. et al., 2016. *Can we learn from aviation: safety enhancements in transport by achieving human orientated resilient shipping environment.* doi: 10.1016/j.trpro.2016.05.132 ed. s.l.:Transportation Research Procedia 14 1669 – 1678 Published by Elsevier B.V..

UNCTD, 2022. *Review of Maritime Transport.* [Online]
Available at: https://unctad.org/publication/review-maritime-transport-2022

Uyanık, T., Karatug, C. & Arslanoglu, Y., 2021. *Machine learning based visibility estimation to ensure safer navigation in strait of Istanbul,* s.l.: Appl. Ocean Res. 112,.

Wahl, A., Kongsvik, T. & Antonsen, S., 2020. *Balancing Safety I and Safety II: Learning to manage performance variability at sea using simulator-based training.* s.l.:Reliability Engineering and System Safety 195, Elsevier Ltd.

Wears, R. L., Hollnagel, E. & Braithwaite, J., 2015. *Resilient Health Care, Volume 2: The Resilience of Everyday Clinical Work.* s.l.:CRC Press.

Weick, K. E. & Sutcliffe, K. M., 2007. *Managing the Unexpected: Resilient Performance in an Age of Uncertainty.* s.l.:John Wiley & Sons.

Wickens, C. D., 2017. *An introduction to human factors engineering.* s.l.:Pearson.

Wiegmann, D. & Shappell, S., 2003. *A Human Error Approach to Aviation Accident Analysis.* 1st Edition ISBN 9781315263878 ed. London: Ashgate Publishing Ltd..

Wildavsky, A., 1989. *Searching for safety,* s.l.: New Brunswick: The Social Philosophy and Policy Center Transaction Books.

Wood, D., 2009. *Escaping failures of foresight,* s.l.: Safety Sience 47:498–501.

Woods, D., 2003. *Creating foresight: How resilience engineering can transform NASAs approach to risky decision making*, s.l.: Work 4 (2), 137–144.

Woods, D. D., 2015. *Four concepts for resilience and the implications for the future of resilience engineering.,* s.l.: Article in Reliability Engineering and System Safety.

Woods, D. D. & Hollnagel, E., 2006. *Joint Cognitive Systems: Foundations of Cognitive Systems Engineering.* s.l.:CRC Press.

Yu, L., Li, G. & Weng, L., 2021. *A three-step methodology to complement underreporting maritime accident records,* s.l.: J. Transport. Saf. Secur. 1–19.