BEHAVIOURAL-BASED SAFETY LEADERSHIPS IMPACT ON ORGANISATIONAL SAFETY CULTURE AND INCIDENT CAUSATION IN THE HIGH-RISK MARITIME ENVIRONMENT

by

CJ Manjarres-Wahlberg

DISSERTATION

Presented to the Swiss School of Business and Management Geneva

In Partial Fulfillment

Of the Requirements

For the Degree

DOCTOR OF BUSINESS ADMINISTRATION

SWISS SCHOOL OF BUSINESS AND MANAGEMENT GENEVA

January 2024

BEHAVIOURAL-BASED SAFETY LEADERSHIPS IMPACT ON ORGANISATIONAL SAFETY CULTURE AND INCIDENT CAUSATION IN THE HIGH-RISK MARITIME ENVIRONMENT

by

CJ Manjarres-Wahlberg

APPROVED BY

____
<Milica Popović Stijačić, PhD>, Chair

____
<Member’s Name, Degree>, Committee Member

____
<Member’s Name, Degree>, Committee Member

RECEIVED/APPROVED BY:

____
<Associate Dean’s Name, Degree>, Associate Dean

DEDICATION

This dissertation is dedicated to my loving husband Edgardo Manjarres Trujillo, who has stood by me through thick and thin over the past 14 years. His constant love and unwavering support during the challenging process of completing this Doctoral Degree has been amazing. For three years I dedicated weeknights and weekends, foregoing family time, to engage in study, research and to write. He made this scholarly journey more manageable. His steadfast support is something I will always be thankful for. Especially when the stress of full-time work, the added work of the Sea Heritage Foundation, to which I am Chairman, and my study commitments were weighing heavily on my shoulders.

ACKNOWLEDGEMENTS

This dissertation is so much more than just a piece of academic work. My journey through the Doctoral Degree has had many challenges, highs, lows and hardships while being one of the most rewarding experiences and important chapters of my professional life. It has taken my experience as a junior sailor joining the Royal Australian Navy in 1996, a decade of military service, followed by my experience and exposure within the offshore oil and gas, merchant navy and marine construction sectors since leaving the military.

First, I would like to thank SSBM Geneva for their support. I took on this process knowing that it would be a challenge with my busy full-time job and my volunteer work with the Sea Heritage Foundation. To say I underestimated the magnitude of the task, is a serious understatement.

As HSE Manager and Designated Person Ashore (Aust) for Heron Group NZ, my full-time job is busy with an average ten-to-twelve-hour day with three hours of travel daily when I am not travelling interstate.

Additionally, the Foundation has been extremely busy over the three years I have been working on this Doctorate. To complicate matters my hard drive back up with my degree suffered a critical data failure in late July 2023 resulting in the loss of two of my case studies. Both had to be completely re-written from scratch. And last but by no means least my day-to-day family commitments. My life has been nothing short of organised chaos over the past three years with little spare time.

The Degree process, however, did provide an unexpected consistent calmness in my chaotic life. This surprisingly gave me a sense of peace once I switched into study mode late at night at home, in a hotel or when catching the train between Sydney and Wollongong to get in an additional 3 hours of study in a day or during quiet moments in my cabin or on the bridge aboard the MV Cape Don.

My Professor, Jaka Vadnjal, PhD has been the perfect mentor. He provided up-front direct, honest feedback, along with careful guidance, and encouragement when needed. His no-fuzz approach ensured I stayed on track in a process with many rabbit holes where one can become overwhelmed easily if you do not have a plan and stick to the plan. And yes, I did become overwhelmed on several occasions when I went down a rabbit hole. The gravity of the task required to develop this body of work weighed heavily on me at times.

Additionally, I would also like to acknowledge and thank the Directors of Heron Group NZ, specifically Heron Construction NZ. Greg and Matt Kroef provided valuable access to their fleet officers and crews between New Zealand and Australia during my research phase of this Doctorate. The experience and professionalism of these mariners is visible within the results obtained in the research, demonstrating a high level of organisational safety culture with Heron Construction NZ.

Thank you to the naval officers of the Royal Australian Navy, Royal New Zealand Navy and Royal Navy, who made time during busy operational periods to complete my surveys and interviews.

I would also like to single out two special people for thanks.

Firstly, Lieutenant Commander Dirk Orreil, RAN who I joined the Royal Australian Navy with in 1996 as a recruit Signalman. Dirk and I shared a cabin together during our basic signals course, graduating as Signalman together before entering the fleet. My time as a Signalman on my first ship, Destroyer Escort HMAS Torrens remain some of my fondest memories in the Navy. Fast forward 28 years, now a Lieutenant Commander and Principal Warfare Officer, Dirk made time to complete a face-to-face interview in the middle of moving countries for a new posting as Deputy Naval Attache at the Australian Embassy in Washington DC. Thank you, shipmate.

Secondly, a special note of thanks also goes to Professor Ana Casaca, PhD in Lisbon, Portugal. Ana provided guidance with my MV Rhosus case study over the year I researched the disaster. My passion for this case study resulted in me presenting it to the World of Shipping International Conference in Portugal online. I also intend to further my work in this space in the future by approaching the Ukrainian National Maritime University to discuss ongoing joint research into Ukrainian seafarer safety leadership and organisational safety culture.

Thirty-four officers and ratings from five countries, including the Atlantic, Indian and Pacific Oceans, and the Tasman and South China Seas, participated in my surveys and interviews at sea and ashore. With your important contributions, this volume of work was possible.

It is my heartfelt wish that this body of work will make a difference in the maritime industry to help further ongoing research into behavioural safety leadership.

To the friends and colleagues who have helped review my various draft documents to provide honest feedback, thank you for making time in your already busy schedules and for the difficult conversations which have improved this paper.

My journey towards completing my Doctorate has been an immense undertaking and tremendous labor of love over the past three years. Throughout this period, I’ve gained a wealth of knowledge that has not only furthered my own personal leadership, but has also provided a solid foundation for future research and development into organisational safety culture and behavioural-based safety leadership.

Thank you.

CJ Manjarres-Wahlberg

14th January 2024

DECLARATION

This dissertation contains no material which has been used towards the award of any other degree held by the Executive Doctor of Business Administration candidate.

To the best of my knowledge, I have referenced and acknowledged all published work which has supported this dissertation.

CJ Manjarres-Wahlberg

14th January 2024

ABSTRACT

The impact of behavioural-based safety leadership on organisational safety culture and incident causation within the high-risk maritime environment has been researched in detail in this dissertation. The research discusses the hazards, risks and challenges associated with living and working at sea within the dynamic naval and merchant navy environments. The study explored the critical factors of leadership in shaping positive safety behaviours and the impact behavioural-based safety leadership has on reducing incident causation.

The research is grounded in a comprehensive review of existing academic and grey literature, which establishes a theoretical foundation encompassing safety leadership theories, organisational safety culture, and incident causation models. This background provides a context for understanding the complex link between leadership behaviours and safety outcomes within the high-risk maritime environment.

The research uses a mixed-methods approach, combining quantitative data from surveys with maritime professionals and qualitative insights from case studies and interviews. This triangulation methodology provides a detailed investigation into the relationship between safety leadership behaviours, organisational safety culture and incident causation. Key findings include the identification of specific antecedents and leadership behaviours that positively influence safety culture including, gender diversity and mindset, safety training and evolving practices. Identified behaviours include effective communication, commitment to safety, and the ability to inspire and motivate workers/crew towards safety-oriented goals, with participants stating that their understanding of safety leadership included such things as leading by example, being the sample of good safety onboard, and walking the walk.

The study findings demonstrate that these results correlate with lower incident causation rates and an improved safety culture. The dissertation also highlights the vital role of leaders in setting safety standards, modelling positive safety behaviours and fostering a positive safety culture where safety is openly discussed, supported and addressed in a collaborative approach between workers and management.

Additionally, participants identified barriers to effective safety leadership within the maritime environment, including operational pressures, time, money, cultural factors, and resistance to change. The study recommends overcoming challenges with training and implementing a proactive safety culture from the top down.

In conclusion, this dissertation highlights the critically important role of behavioural-based safety leadership in ensuring a positive organisational safety culture while reducing incident causation rates in the high-risk maritime environment. It provides a pathway for maritime professionals to improve safety performance while suggesting a framework for future research into this vital area of social science.

KEYWORDS

Active safety leadership, Antecedent, Behavioural-based safety, Safety leadership, Organisational safety culture, Beirut explosion, MV Rhosus, MV Sewol, Tianjin explosion.

LIST OF ABBREVIATIONS

AIS	Automatic Identification System
AMSA	Australian Maritime Safety Authority
BBS	Behavioural-Based Safety
BAI	Board of Audit and Inspection of Korea
CAST	Casual Analysis based on STAMP (see below)
FEM	Fabrica de Explosivos Mozambique
HAZMAT	Hazardous Materials
HAZCHEM	Hazardous Chemicals
HMAS	His Majesties Australian Ship
HSE	Health Safety and Environment
IMO	International Maritime Organisation
IOSH	Institute Occupational Health Safety (United Kingdom)
ITWF	International Transport Workers Federation
KMST	Korea Maritime Safety Tribunal
MNZ	Maritime New Zealand

MV	Motor Vessel
NZ	New Zealand
SLSES	Safety leadership self-efficacy scale
STAMP	System-Theoretic Accident Model and Processes
STCW	Standards of Training, Certification and Watchkeeping
TNT	Trinitrotoluene
VTS	Vessel Traffic System

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I:

INTRODUCTION

1.1 Introduction

Rates of workplace accidents in high-risk work environments in Australia continue to occur. Research by Lützhöft et al. (2011) identified safety culture as a significant risk element within the maritime environment. Without ongoing safety management and established safe systems of work, injury, illness, and death can occur. In the Australian context, incident and injury rates have fluctuated despite Australia being one of the most regulated safety cultures in the Western world, with 141 severe incidents reported in 2019, up from 92 in 2016 (KAMIS et al., 2020). With an ever-growing number of hazards competing for attention, this trend is despite our abundance of training and incident causation knowledge. Of particular note are high-risk work environments, including offshore oil and gas, aviation, construction, rail, maritime and mining sectors. All of these have increased hazard risk profiles due to the very nature of the environments they operate compared to other industries due to the complexity and greater physical demands which expose workers to hazards such as falls from height, line of fire, plant/equipment, high-powered tools, biological, chemical, ergonomic, auditory and respiratory factors (IOSH, 2010). Conducting research into the collective identification of safety behaviour antecedents while reviewing active safety leadership of the wider high-risk industry can gain insight into how the research can influence positive outcomes on dangerous safety behaviours, safety culture and incident causation in the high-risk work environment. Furthermore, with intervention, companies will see an increase in overall efficiency, profitability and safety performance once unconscious safety behaviours have been identified and effective behaviour-based safety strategies implemented and monitored as part of an ongoing safety management system in line with current international standards organisation requirements.

1.2 Research problem

Since its initial inception in the 1970s, behavioural safety has experienced a series of developmental transformations (Cooper, 2009), including the employee-led review approach in the 1980s, which involved peer-to-peer and workgroup-based observations (Hopkins, 2006), followed by the safety cultural approach during the 1990s whereby employees would monitor the behaviour of other employees and workgroups with managers monitoring their own safety behaviours. In this model, feedback was essential to the positive safety culture environment (Chandler & Huntebrinker, 2003), encouraging engagement, feedback, and continuous improvement in workplace safety. Research has further shown that if reinforcement of safe work behaviours occurs, this encourages a repeat of the same safe behaviours, as discussed in research by Skinner (1953) about positive reinforcement theory.

Hazard identification in the high-risk environment is a complex and subjective sphere of influence with many contributing factors. According to (Chen & Tian, 2012), "mishaps occur due to a random combination of many contributing factors”. "Traditionally, they are categorised due to unsafe conditions or unsafe practices". Additionally, human antecedents of leadership have been studied widely in academia, with organisational factors needing more research directed in this evolving sphere of safety. It is a common belief among OHS Professionals that research creates significance and understanding. The field of human and organisational factors and behavioural safety leadership could be better researched to provide a more comprehensive understanding on how to identify antecedents which can mitigate hazards, reducing incident causation factors. In 1976 Fitch et al. introduced one of the initial strategies for theoretical incident reduction by combining behaviour techniques with traditional safety measures such as procedures to reduce hazards.

However, the fundamental understanding of how we identify hazards and their contributing factors, including organisational, environmental, educational, and human, which can significantly influence our behavioural response to hazards, requires further research and understanding. In research regarding the organic nature of construction, Wilson (1989) identified the reliance on decision-making roles in a changing and, at times, unstable environment, the use of role or site-specific training and education for workers to carry out non-standardised operations was seen to be beneficial (Wilson, 1989). This further reaffirms the need to understand the antecedents which lead the understanding of safety behaviours affecting safety performance.

Safety professionals should not focus on how "workers" behaviour can directly prevent injury. However, how collectively, as a society, we can re-educate workforces to understand more about their critical role within behavioural safety to transition from *"have to"* to *"want to, am proud to"* behaviours where safety behaviour is an intrinsic motivation and second nature (**Safety Leadership**, 2021).

Behaviour underpins everything we do daily, not just the workplace. In fact, behaviour is a natural output of thoughts and feelings, which are pre-cursers to actions, behaviours and performance (Safety Leadership, 2021). We make hundreds of unconscious safety behaviour decisions daily, from putting our keys in our pockets and putting our seatbelts on to locking the front door when we leave home. Many of our thoughts and feelings are subconscious; subsequently, we base many of our decisions on external factors from our environments and past and lived experiences.

Perception is likewise an under-researched human factor/safety behaviour equation component. Perception creates a pathway where inputs from external environmental factors can positively or negatively affect behavioural response (Cooper, 2003). Key elements that further impact this include the worker's personality, disposition, experiences, education and attitudes. These perceptions provide a window into the antecedents that precede a worker's reactive behaviour to a hazard (Cooper, 2003). While considerable academic research is available regarding leadership and management as factors that impact safety behaviours, including worker hazard identification, a gap exists in the literature regarding the psychology behind behavioural safety leadership and its relationship to organisational safety culture in the high-risk maritime environment, resulting in incident causation.

1.3 Purpose of research

This research has five main research objectives:

1) To identify and compare, where possible, behavioural-based safety, safety leadership and organisational safety culture.

2) To assess the impact of the antecedents of behavioural-based safety leadership and organisational safety culture in the three case studies.

3) To determine if the immediate environmental conditions (workplace) and supervisors/managers' personal experiences impacted the incidents.

4) To further the research conducted by Kim et al. (2021) into maritime leadership behaviours and the adapted use of the Safety Leadership Self-Efficacy Scale (SLSES) in the maritime context to support changes to the current STCW Table A-11/2 (Masters and chief officers), Table A-III/2 (Chief engineering offices and second engineers), Table A-II/1 (Officers in charge of a navigational watch), (EDU Maritime, 2010), (ref to Appendix G).

5) To formulate recommendations to identify antecedents of behavioural safety to improve safety leadership and organisational safety culture in the high-risk maritime environment.

Table 1: Standards of training, certification and watchkeeping (STCW).

Standards of Training, Certification and Watchkeeping Regulations Explained			
STCW Regulation	**Department**	**Rank/Apppointment**	**Conditions for Officers**
Regulation A-II/1	Master and Deck	Officers in charge of a navigational watch	Mandatory training for certification of Officer in charge of a navigation watch on ships of 500 gross tonnage or more. The holder of a Certificate of competency has completed approved education and training that meets the standard of competence specified in Section A-II/1 of the STCW Code.
Regulation A-II/2	Master and Deck	Masters and chief officers	Mandatory minimum requirements for certification of Masters and Chief mates on ships of 500 gross tonnage or more. The holder of a Certificate of competency has completed approved education and training and has met the standard of competence specified in Section A-II/2 of the STCW Code for Master and Chief mates on ships over 500 gross tonnage.
			The standard of education and training for Master and Chief mates serving on ships between 500 and 3000 gross tonnage may be varied. The holder of a Certificate of competency for service on ships less than 3000 gross tonnage is restricted to the capacities and limitations listed on their certificate.
Regulation A-III/2	Engineering	Chief engineering offices and second engineers	Mandatory minimum requirements for certification of Chief engineer and Second engineer officers on ships powered by main propulsion machinery of 3000 kilowatts propulsion power or more. The holder of a Certificate of competency has completed approved education and training and meets the standard of competence specified in Section A-III/2 of the STCW Code.

Source: AMSA (2010)

1.4 Significance of the study

By understanding the antecedents of safety behaviours that lead to dangerous safety outcomes, we can identify the contributing factors that lead to dangerous behaviour pathways. In working partnership with management, safety professionals can then develop and direct training and educational resources towards industry collaboration improving the quality and buy-in of the wider high-risk maritime industry, improving organisational safety culture and safety leadership outcomes in the process while significantly impacting incident causation. Moreover, the interventions and subsequent strategies will increase overall efficiency, safety performance and profitability for shipping companies.

1.5 Research purpose and questions

1) To identify antecedents which affect organisational and or individual safety behaviours and human factors that affect impact safety leadership behaviours in the high-risk maritime environment.

2) Assess and compare the relative contributions of these factors in shaping safety leadership behaviours and their outcomes in the workplace; and

3) To outline a conceptual framework for the introduction of Safety Leadership Self-Efficacy Scale (SLSES) with behavioural safety elements included to increase awareness of unconscious safety behaviours to implement realistic, measurable processes to improve safety leadership behaviours and safety performance within the high-risk maritime environment.

CHAPTER II:

REVIEW OF LITERATURE

2.1 Theoretical framework

It is widely recognised that a correlation exists between leadership and safety in the workplace. A systematic behavioural safety process fulfils these conditions (Cooper, 2010), supported by many major incident investigations. However, while a significant amount of research has been conducted by academia into safety behaviour, leadership, and management Christian et al. (2009), more research is needed regarding how unconscious behavioural safety and safety leadership can benefit workplaces. Behaviour accounts for everything we do in our personal and professional environments. How one drives to work, interact with others, approach a task, undertake a task, problem-solve or respond to an emergency. Therefore, the literature review has been broad in its subject matter to capture the wide range of empirical materials published in academic and grey literature.

Northouse (2013) defines *leadership* as how an "individual influences a group of individuals to achieve a common goal." (Cooper, 2014) stated that the organisation's safety leadership plays a crucial role in preventing major safety accidents, reducing accident rates, improving working conditions, and enhancing employee motivation, which can drive improved financial performance. This paper supports this notion "and acknowledges the relationship between safety leadership and enhanced safety performance" (Halle, 2023). Additionally, over the past 31 years, empirical studies have shown that excellence in business leadership, such as transparency, communication, and integrity, is reflected in the skills used for managing Safety (Bass , 1985; Cooper, 2015). Wilson identified the reliance on decision-making roles concerning safety leadership in a changing and, at times, unstable environment (Wilson, 1989). Behaviour is a natural output of thoughts and feelings leading to pre-cursors to actions, behaviours, and performance. Cooper (2015) further established two effective safety leadership types. Positional and inspirational, stating that positional leaders lead by their positional power. Individuals comply with directives out of necessity. In contrast, inspirational leaders naturally evoke genuine passion and enthusiasm for their leadership roles and inspire others (Zenger et al., 2009).

In parallel, research conducted by the Institute of Occupational Safety and Health (IOSH) in the United Kingdom proved that front-line managers can significantly influence how people behave preventing work-related incidents (Conchie & Moon, 2010). Furthermore, society expects our leaders and managers to act as good role models.

A common belief among OHS Professionals is that research creates a more robust understanding. Fitch et al. (1976) published one of the initial strategies for minimising conceptual incidents by integrating behavioural techniques with conventional safety measures, like mitigating hazards. The field of human and organisational factors and active safety leadership could, therefore, be further researched to provide a proper understanding of the antecedents that correspond to the skills which would help identify and mitigate hazards, resulting in a reduction of incident causation factors.

Hence, it is essential to establish a clear understanding of safety leadership within the context of this research to define the remainder of this paper.

2.1. Preliminary literature review objectives

Aims of the literature review:

1) To describe the background of behavioural-based safety leadership and organisational safety culture in the occupational health and safety industry.
2) To conceptualise safety leadership and its impact on safety culture
3) To discuss different models of safety leadership, safety leadership development and safety leadership within the maritime industry specifically.
4) To discuss the validation of a Safety Leadership Self-efficacy Scale (SLSES) in the maritime context and the inclusion of unconscious behavioural safety into the scale.

2.2 Theory of reasoned action

Rutter and Bunce (1989) stated that the theory of reasoned action is a psychology research model that forecasts behaviour based on known beliefs, attitudes and behaviours. Ajzen, (2012) determined that a person's intention could be determined by their behaviour patterns. Theory of reasoned action is widely used in understanding and predicting human behaviours.

2.3 Human society theory

Human society theory in research is a range of theoretical frameworks used to study human society, its depth and the complexities of its social structures, culture, economic and political institutions and their influence (Harrington, 2011). Additionally, Human society theory takes an analytical approach to human behaviour, social settings and values and how they contribute to shaping the societies we live within. Researchers use these theories to interpret social phenomena.

2.4 Grounded theory

Grounded Theory has been used in this dissertation due to its social science and human study bases. Glaser and Strauss (2017) developed a conceptual thinking theory and the 'Grounded Theory' approach to qualitative research. Gray et al. (2017) further determined that qualitative research was a systematic and subjective approach to describing lived experiences. Importantly for this dissertation, Holloway and Wheeler (1996) discussed how researchers could explore behaviours as well as life experiences using a holistic grounded theory approach as demonstrated within this research.

2.5 Literature review

2.5 Introduction

It is widely recognised that a correlation exists between leadership and safety in the workplace. A systematic behavioural safety process fulfils these conditions Cooper, (2010), supported by many major incident investigations. However, while a significant amount of research has been conducted by academia into behavioural-based safety leadership, and management, Christian et al. (2009), limited specific scientific research regarding how unconscious behavioural safety and safety leadership can benefit workplaces is available. Behaviour accounts for everything we do in our personal and professional environments. How one drives to work, interact with others, approaches a task, undertakes a task, problem-solves or responds to an emergency. This literature review has, therefore, been broad in its subject matter review to capture the wide range of empirical materials published in academic and grey literature.

The safety landscape has evolved significantly in the past 43 years. Safety leadership, behavioural-based safety, and safety culture have varied definitions, thoughts, and understandings depending on an individual's geographical location, work experience, culture, and exposure to physical and psychological work environment. This literature review has been conducted to review empirical, grey, qualitative, and quantitative material to determine if additional research can increase the existing body of knowledge into identifying and influencing behavioural-based safety, unconscious safety behaviours, antecedents, and active safety leadership on safety culture and incident causation in the high-risk work environment.

Behavioural safety has undergone evolutionary changes since its inception in the 1970s (Cooper, 2009), including the employee-led review approach in the 1980s involved peer-to-peer and workgroup-based observations (Hopkins, 2006). The safety cultural approach followed this during the 1990s, whereby employees would monitor the behaviour of other employees and workgroups, with managers monitoring their safety behaviours. In this model, Chandler and Huntebrinker (2003) found that feedback was essential to a positive safety culture environment, encouraging engagement, feedback, and continuous improvement in workplace safety. Research has further shown that if reinforcement of safe work behaviours occurs, this encourages a repeat of the same safe behaviours, as discussed in positive reinforcement theory by Skinner (1953).

This research complements existing safety literature in several areas by providing a systematic review specifically regarding safety leadership, antecedents of the safety behaviour, unconscious safety behaviour influences, and safety leadership on safety culture and incident causation.

2.5.1 Hazard and risk perception in the workplace

Hazard identification in the high-risk maritime environment is a complex and subjective sphere of influence with many contributing factors. According to Chen and Tian (2012), incidents "occur due to a random combination of many contributing factors".

"Traditionally, factors are categorised due to unsafe conditions or unsafe practices", with research by Hasanspahic et al. (2021) demonstrating that human behaviour contributes to approximately 80% to 85% of incidents in the marine industry.

However, the fundamental understanding of how we identify hazards and the contributing factors, including organisational, environmental, educational, and human factors, can significantly influence our behavioural response to hazards. Risk perception requires further research and understanding. In a study conducted by Wilson (1989) identified the reliance on decision-making roles in a changing and unstable work environment. Using site-specific education for workers to carry out non-standardised operations Wilson, (1989) further reaffirms the need to understand better the unconscious safety behaviours affecting safety performance.

Safety professionals should not focus on how "workers" behaviour can prevent injury. Nevertheless, how, collectively, we can re-educate workers to understand their critical role within behavioural safety to transition from a "have to" to a "want to, am proud to" (Safety Leadership, 2021) mindset of behaviours. This change in attitude where safety behaviour is intrinsic motivation and second nature is the path to success in large-scale, cross-border behavioural change (Safety Leadership, 2021).

Behaviour underpins everything we do daily, not just in the workplace. Behaviour is a natural output of thoughts, feelings, pre-cursers to actions, behaviours, and performance. We make hundreds of unconscious safety behaviour decisions daily, from putting our keys in our pockets, looking left and right when crossing the road, putting our seatbelts on, or locking the front door when we leave home without thinking. Many of our thoughts and feelings are subconscious. Subsequently, we base many of our decisions on external factors from our environments, depending on where we live relative to our place of work, for example.

One may drive for 30 minutes; within those 30 minutes, one will drive past any number of various road signs and signals. Within microseconds, one has identified the sign or signal, understood its meaning, and decided on a course of action.

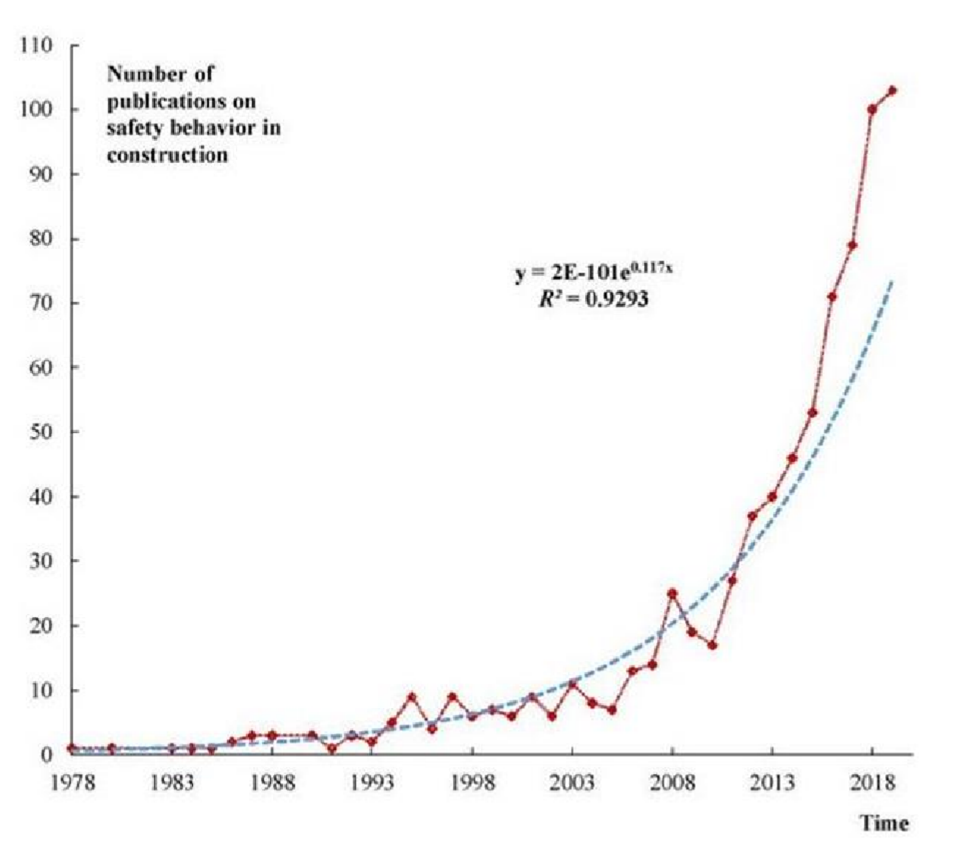
In most cases, this process occurs within milliseconds. When considering the meaning and distance of a sign or signal, readability, visibility, sign/signal vertical offset, sign letter height and vehicle speed (Priambodo & Siregar, 2018). It is remarkable how quickly the human brain can view, calculate, and manoeuvre under pressure. This unconscious safety behaviour process also occurs within the high-risk work environment.

Likewise, perception is an under-researched component of the human factor/safety behaviour equation. Perception creates a pathway where inputs from external environmental factors can positively and negatively affect behavioural response (Cooper, 2003). Critical elements further impacting this include the worker's personality, disposition, experiences, education, and attitudes. These perceptions provide a window into the antecedents that precede a worker's reactive behaviour to a hazard (Cooper, 2003). Considerable academic research regarding leadership and management as factors that impact safety behaviours is available. However, a gap exists in the literature regarding understanding the psychology behind unconscious safety behaviours and their relationship to active safety leadership, resulting in incident causation.

2.3 Understanding active safety leadership, leadership styles, and their influence

Cooper (2014); Conchie and Moon (2010) conducted a wide-ranging review of various safety aspects in high-risk work. The study uncovered mixed antecedents of behaviour and accidents. Other academic reviews have targeted particular aspects of safety research, such that by Xin and Pelled (2003) of construction safety research within the scope of human-centred safety management. However, this review is unique in its focus on the antecedents of safety behaviour; despite considerable advancements and research into safety behaviours the majority of research was construction related with 753 articles related to safety behaviour in the construction industry (Xia et al., 2020). This research shows increased academic literature on safety behaviour, its correlation to occupational health and safety, and global safety management systems (Xia et al., 2020). Specifically, the present study intends to investigate identifying and influencing behavioural safety leadership antecedents, and their impact on organisational safety culture and incident causation in the high-risk maritime environment which has far less academic research available.

Figure 1: Growth of academic literature on employee safety behaviour in construction between 1978 and 2019. Data depicts the results of research conducted on 753 articles identified as relating to safety behaviour.



Source: Xia et al. (2020).

Despite the lack of specific maritime research. The importance of research by Xia et al. (2020) cannot be understated. The systematic review of 101 papers into the antecedents of safety behaviour from the countries isolated in (figure 2) identified 83 elements categorised into the following below five groups which can also be applied to the high-risk maritime environment. However, further research to quantify this is required.

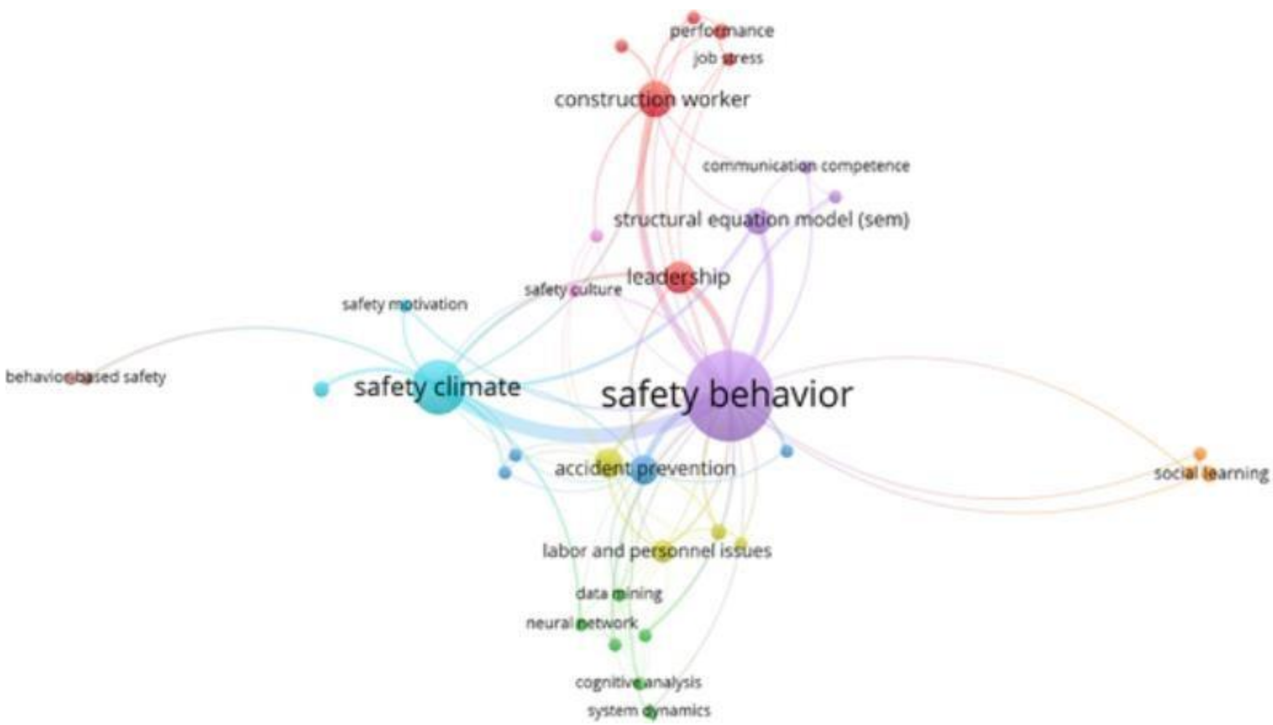
1) Individual characteristics
2) Workgroup interactions
3) Work and workplace design
4) Project management and organisational management
5) Family, industry, and society

Figure 2: Identifies the international locations of contributions to antecedents of safety behaviour research.

Source: Xia et al. (2020)

In a systematic review of 101 academic papers and journal articles, 83 factors influencing employee safety behaviours were identified. Of particular note, the relationship between safety behaviour and safety leadership was reflected in research by Xia et al. (2020). This determined (figure 3) a connection between co-occurring keywords in the academic literature on antecedents of safety behaviour.

Figure 3: Keywords in academic literature on antecedents of safety behaviour.



Source: Xia et al. (2020)

After a systematic review of safety behaviours, human factors, safety leadership, and organisational safety culture, it is evident that the causes of safety behaviour are multifarious. It is widely accepted within the safety profession that various contributing factors from different systems likely collaborate to create an environment in which an individual decides to comply with safety rules and participate voluntarily in safety activities or, conversely, not to comply (Griffen & Neal, 2000). Therefore, referring to the bioecological system theory, (Bronfenbrenner, 1994) proposed that safety behaviours are merely a purported element of a more complex system, and that safety behaviour can be described as follows.

1) Self
2) Work
3) Home
4) Industry
5) Society

The antecedent analysis and classification model of safety behaviour helps researchers and practitioners to establish a comprehensive understanding of possible contributions to safety behaviour. To further comprehend the underlying mechanisms of how these "five systems" work together to influence safety behaviour, Xia et al. (2020) proposed a resource flow model to demonstrate why, how, and under which conditions safety behaviour is more likely to occur or decrease. Xia et al. (2020) theorised that contextual demands and resources from multiple areas, including home, work, the work-home interface, and social systems, act as contextual factors that influence safety behaviour. The following characteristics should be considered to understand the safety behaviour paradigm and its relationship with unconscious safety behaviours. Physical condition, psychological condition, personal traits, group identity and cohesiveness, co-worker influence, work and workplace physical environment and supervisor influence can all contribute in varying ways to the holistic understanding of safety behaviours (Xia et al., 2020)

2.4 Leadership conditions

2.4.1 Physical condition

The physical condition of the workforce is a factor to consider in the safety approach of individual workers, primarily due to the intensive physical nature of work in the high-risk work environment. External factors outside the work environment can also affect workers' safety behaviour Zhang et al. (2015). Considering these antecedents, it is reasonable to conclude that they could contribute to unsafe behaviours Zhang et al. (2015). Murray et al. (1997) theorised that a worker's unsafe behaviour could also be due to the failure of hazard perception, identification and mitigation.

2.4.2 Psychological condition

The reviewed literature also recognised the role of individual psychological conditions in the occurrence of safety behaviour (Patel & Jha, 2016). When confronted with a potential hazard, Zhang et al. (2015) determined that a workers cognitive function may fail due to either misunderstanding information, delayed response, mis aligned perception or failing to take appropriate action. This process can then impact a worker's unsafe behaviour Zhang et al. (2015); Conchie and Moon (2010).

Destructive emotions and emotional exhaustion can also negatively influence worker safety behaviour Ju et al. (2016); Zhang et al. (2015). Conchie and Moon (2010) further determined that role autonomy is the strongest precursor to a supervisors participation in proactive safety leadership behaviours. The frequent contact between supervisors and workers was associated with increased encouragement of active safety leadership in the work environment.

2.4.3 Personal traits

Work performance theory tells us that a worker's performance and behaviour are affected by what the individual knows, what they can do, their knowledge, skills, and motivation Campbell et al. (2015). Construction workers' safety knowledge, safety skills, and safety motivation were related to safety behaviour Liu et al. (2018); Sun (2015); Zhang et al. (2015). The stronger an employee's resolve to act safely, the greater the likelihood that their safety performance will correlate with safe behaviour Jitwasinkul et al. (2016); Choi and Lee, (2018).

Further research conducted by Choi and Lee (2018) provided insight into social norms and social identifications/influence within safety behaviour. The research provided a model for how social factors influence a worker's safety behaviour and suggested a sociopsychological approach to reinforcing positive safety behaviours.

Oceania is of particular interest due to Australia's geographical location and the importance of understanding geopolitical and social antecedent's relationship to safety behaviours. Sawacha et al. (1999) identified that "predisposition, experience, education, training, cultural backgrounds, contractual conditions, and organisational settings can affect workers safety behaviour". Although the research was beneficial, it has limitations in the sample size of participants, with no test subjects in Oceania or Europe. This therefore provides future research opportunities to determine how geopolitical and social antecedents in Oceania complement current research or provide greater insight into geographical-specific safety behaviours. Understanding how Oceania, specifically the

Australian context, compliments or contradicts Sawacha's research would also be beneficial.

2.4.4 Workgroup identity and cohesiveness

The high-risk work environment is typically characterised by a workforce of sub-contractors Schwatka and Rosecrance, (2016) of varying skills, trades, backgrounds, and education. While some roles may be highly paid, this does not necessarily correspond with an extensive or high educational achievement. Often, in some roles within high-risk work, the remuneration reflects the risk, remoteness, and physical difficulty of the job/role. These elements can lead to a disconnected workforce from senior management Choi et al. (2017).

2.4.5 Co-worker influence

Safety violations by co-workers can affect associated worker safety violations. Additionally, routine safety violations by co-workers may lead to increased perceived production pressures, leading them to perform regular safety violations by thinking such behaviours are acceptable Liu et al. (2018). In some cases, workers demonstrate unsafe behaviour because of negative peer pressure and do so to avoid being persecuted Choudhry and Fang, (2008). In an experiment with a multi-user virtual reality system, Shi et al. (2019) validated that co-workers can influence workers' safety behaviour in two opposing ways:

1) Positive reinforcement by demonstrating preferred behaviours, and
2) Negative reinforcement by demonstrating negative consequences of inappropriate behaviours.

As a chartered risk professional, one has seen both these behaviours applied in the private sector's high-risk environment.

2.4.6 Work and physical workplace environment

The high-risk environment has a multitude of hazards Liu et al. (2018). A worker's perception of the risks and hazards within the workplace can influence their safety behaviours via cognition and emotional responses Xia et al. (2020). Engineering safety in design elements into the initial stages of workplace design, can increase workers' safety behaviours by providing an environment with a high level of safety consideration as detailed within academic literature (Pybus, 1996). Workers will perceive risk differently based on past exposure, knowledge and experience. Therefore, perceived risk and risk acceptance can determine worker safety behaviours Choi and Lee, (2018). The design and consideration of safety within the larger context of the work cycle and work environment can therefore prevent poor safety behaviours Arcury et al. (2013).

2.4.7 Supervisor influence

Research conducted by Conchie and Moon (2010) on behalf of the Institute of Occupational Safety and Health (IOSH, UK) determined that the supervisor or foreman is a key person who influences safety behaviours and accident prevention in the workplace. If the supervisor showed poor support for safety, workers could question the leader's behaviour Xin and Pelled, (2003). Additionally, supervisors may adjust safety rules in pursuit of production Liang and Zhang, (2019). In this environment, workers can ignore supervisors' instructions and even flout safety rules Liu et al. (2018). Conversely, supervisors can be instrumental in demonstrating positive worker safety behaviours when they model safe behaviours, putting safety before production, openly discussing safety issues or concerns, and encouraging a positive reporting culture in the workgroup (Schwatka & Rosecrance, 2016). These elements could improve workers' safety climate and safety behaviours Zhang et al. (2015).

Effective safety leadership by supervisors does have a significant impact on workers, injury rates, insurance premiums, productivity, and work efficiency (Cooper, 2015).

2.5 Leadership and unconscious safety behaviours

Leadership theory has existed for many years, with the relationship between supervisor's leadership styles and worker safety behaviour well established by Conchie and Moon, (2010). In the high-risk work environment, there are two predominant leadership types. Positional and Inspirational. Positional leaders lead through the authority of their role, whereas inspirational leaders lead with passion and are usually genuine about their work Zenger et al. (2009). Safety leadership is a concept derived predominately from the leadership framework with specific reference to transformational leadership Mulln and Kelloway, (2009). However, several leadership styles are relevant and essential to this current research, challenging in the high-risk work environment Zhang et al. (2015). Current safety leadership awareness and efforts to address incident causation have not adequately addressed Australia's incident and injury rates (Safe Work Australia, 2021). This is further complicated by the diverse and ever-changing challenges within high-risk work environments such as mining, heavy construction, oil and gas, maritime, aviation, and rail sectors and a transient sub-contractor workforce (Safe Work Australia, 2013).

Future research into the financial implications of unconscious safety behaviours that affect lost time injury, medical expenditure, and worker's compensation premiums would provide insight into how further advances can benefit the industry as a whole. For instance, education in recognising and managing unconscious safety behaviours would significantly justify the inclusion of unconscious safety behaviours training into the global mainstream safety education literature and teachings.

Neame et al. (2015) recognised the need to formulate a clear and well-defined concept of safety leadership to reduce ambiguity in the leadership literature concerning safety leadership. IOSH in the United Kingdom also identified the need to establish a well-constructed definition of Active Safety Leadership which was defined as "the coaching of employees on safety and encouraging employees to raise safety concerns" (Conchie & Moon, 2010). A study by Cooper (2015) determined effective safety leadership as "the process of defining the desired state, setting up the team to succeed and engaging in discretionary efforts that drive the safety value."

In their 2010 study, Lu and Yang examined the influence of safety leadership on safety behaviour in the context of the maritime container terminal operations environment. They delineated safety leadership into three primary elements: safety motivation, safety policy, and safety concern. Lu and Yang (2008) also concluded that safety leadership is a sub-system of organisational leadership, with their findings focused on specific elements of safety leadership within the realms of transformational and transactional leadership.

2.5.1 Antecedents of active safety leadership

Established academic research into antecedents of safety behaviours shows a correlation between behaviour and safety performance (Conchie & Moon, 2010).

The absence of a clear conceptualisation of safety behaviour in general safety literature requires a unified definition within the industry to promote increased understanding Beus et al. (2016); Christian et al. (2009). Consequently, the fundamental understanding of safety behaviour in the generic safety literature and the safety sphere can be better understood and applied. Beus et al. (2015) defined safety-related behaviour as "workplace behaviours that affect the extent to which individuals or the workplace are free from physical threat or harm". This encompasses actions that reduce physical danger or injury, whether rule prescribed or discretionary, and actions that expose individuals in the workplace to greater physical danger, whether deliberate or inadvertent behaviour Christian et al. (2009); Griffin and Neal, (2000).

Based on the work performance theory by Griffin and Neal (2000), distinctions were made between two types of safety behaviours: compliance and participation.

In research by the Institute of Occupational Safety and Health (IOSH) in the United Kingdom, IOSH defined *Active Safety Leadership* as "the coaching of employees on safety and encouraging employees to raise safety concerns" (IOSH, 2010). This research will further demonstrate the importance of active safety leadership.

2.5.2 Safety compliance

Safety rules are prescribed and correspond to task performance, defined as "the core activities that individuals need to carry out to maintain workplace safety" as detailed by Neal et al. (2000).

2.5.3 Safety participation

Safety participation is voluntary and relates to specific actions that do not directly enhance an individual's safety but instead contribute to fostering a culture that promotes safety Neal et al. (2000). One sample indicator for measuring safety participation is "I put in extra effort to improve the safety of the workplace."

In the United Kingdom, IOSH leads academic research into antecedents and their correlation with safety leadership and behaviour. A study by the Conchie and Moon, (2010) identified the following antecedents of active safety leadership.

2.6 Antecedents of active safety leadership

2.6.1 Personality

IOSH determined that leadership is linked to extraversion, neuroticism, openness, conscientiousness, and agreeableness. Extraversion shows the most vital link as a significant antecedent. This was followed by openness, agreeableness, and conscientiousness, having positive links with active safety leadership (Özbağ, 2016) and leaving neuroticism with a harmful link. IOSH revealed that individuals with high degrees of extraversion, openness, conscientiousness and agreeableness are more likely to participate in proactive safety leadership behaviours compared to those individuals characterized by neuroticism (Özbağ, 2016).

2.6.2 Emotional intelligence (EI)

Individuals can read and use emotions (their own or others). EI has been shown to benefit both safety and non-safety sectors (Geller, 2001), (Barling et al., 2002). Awareness of one's emotions allows a leader to adapt their behaviour to specific situations, specifically safety. Geller (2001) also proposed that such behaviours were characteristic of active safety leadership.

2.6.3 Locus of control

It is an individual's perception of their control over external events affecting safety. Individuals with an internal locus believe they can control incidents or accidents. Conversely, individuals with an external locus of control perceive incidents or accidents are beyond their influence (Jones & Wuebker, 1993).

2.6.4 Motivation

The motivation that fuels our actions is associated with proactive safety leadership Conchie and Moon, (2010). Internal and external motivation sources have been linked to safety behaviours Neal and Griffin, (2006). Extrinsic motivation has been linked to safety participation and engagement behaviours. Conversely, intrinsic motivation has been linked to individuals motivated by enjoying conducting a task or job and finding something a challenge Barbuto and Scholl, (1999).

2.6.5 Experience

A correlation exists between specific skill sets, job-relevant experiences, training, and experience (Bettin & Kennedy, 1990). In the context of safety leadership, an individual's experience in a role or level of management and personal experiences in such positions can impact their safety leadership (Conchie & Moon, 2010).

2.6.6 Accident exposure

An individual's interaction with incidents or accidents has been demonstrated to influence their leadership behaviours. This can relate to both a physical or witnessed experience, which can then reinforce positive safety behaviours to prevent reoccurrence (Conchie & Moon, 2010).

2.6.7 Self-efficacy

An individual's assessment of their ability to achieve or attain or sustain specific behaviours, otherwise known as self-efficacy (Kim et al., 2021) has been shown to influence various aspects such as initiation, intensity, and continuation of behaviour. This affects an individual's job, task, or role involvement. When applied to the safety leadership and behaviour sphere, supervisors with high self-efficacy will be likelier to engage in active safety leadership than those with low self-efficacy (Conchie & Moon, 2010; Kim et al., 2021). More on self-efficacy in the research phase of this study.

2.7 Transformational and transactional leadership

A literature review of effective leadership behaviours for the British Health and Safety Executive (HSE) by Lekka and Healey (2021) stated that safety leadership research was focused on transactional-transformational leadership or leader-member exchange. Transformational leadership can be described as the actions of leaders that motivate and inspire followers to exceed expectations and surpass personal self-interest for the benefit of the organisation Avolio and Bass (2004). Transformational leadership comprises four behaviours (Bass, 1985): idealized influence, inspirational motivation, intellectual stimulation, and individual consideration and is characterised by value-based and individual interaction, which can result in better buy-in, communication exchange, and more significant concern for welfare (Zohar, 2002). Idealised influence stems from trust and occurs when leaders uphold exemplary ethical behaviour, thereby becoming role models for their team. Inspirational motivation happens when leaders articulate a compelling, value-driven vision for the organisation and motivate employees to concentrate on shared objectives. Leaders demonstrate intellectual stimulation by prompting workers to voice their concerns, question established norms, rethink assumptions, and approach problems or issues creatively. Furthermore, those who show individual consideration understand and acknowledge the needs and capabilities of their team mates. Kapp (2012) determined that by tailoring their leadership style, they aim to guide and mentor their workers to help them achieve high results. Each of these four aspects of transformational leadership carries consequences for safety leadership (Kapp, 2012).

Conversely, transactional leadership relies on impersonal hierarchical relationships and encompasses three dimensions including "constructive, corrective, and laissez-faire leadership" (Zohar, 2002). Constructive leadership can provide tangible incentives, such as higher salaries or promotions, necessitating clear communication between the leader and follower. Meanwhile, corrective leadership keeps an eye on individual performance compared to set benchmarks, identifying and rectifying mistakes (Zohar, 2002). Laissez-faire leadership renounces all leadership responsibility to only engage with workers in emergencies giving them full control of their work, be it good or bad. Transformational leaders foster a nurturing and positive atmosphere, serve as exemplars for others, communicate a distinct vision, express care for worker well-being, mentor their teams, and motivate and stimulate employees to excel Lekka and Healey (2012).

2.8 Transactional leadership

Based on an ABC (Antecedents-Behaviours-Consequences) model, Zohar (2002) studies of transactional safety, it was determined that safety leadership aims to promote safe working practices by altering the antecedents or consequences across three longitudinal studies and observations of work practices. Each study focused on the content of the interaction between the supervisors. Superiors praised fellow supervisors who engaged with workers and discussed safety issues on a weekly basis Pilbeam et al. (2016). Over several weeks, employees adopted safer working behaviours; an improvement was noted as the safety content of interactions with supervisors increased in response to supervisors receiving feedback on their performance from their superiors. The studies demonstrated that senior management could influence safe working behaviours through direct and effective one-to-one interactions between supervisors and workers Pilbeam et al. (2016). In the context of the ABC model, supervisors offered both verbal and non-verbal written feedback (both positive and negative) to workers regarding their adherence to safe working practices. This feedback was framed within the scope of training and goal setting (the antecedents) for desired behaviours Pilbeam et al. (2016). This was achieved by directly communicating and giving feedback to the worker (Kapp, 2012; Zohar, 2002). It was further established by Pilbeam et al. (2016) that creating appropriate objectives towards established and agreed goals and rewarding positive actions that enhance safety performance and promote a positive safety culture was ideal.

2.9 Transformational leadership

The Canadian researchers Barling et al. (2002), Kelloway et al. (2006), and Inness et al. (2010) studied safety leadership, while the UK-based group Conchie and Donald (2009), examined the significance of trust in the dynamics between supervisors and workers in the high -risk environment. The primary focus of leadership behaviours was to foster open dialogue with workers to promote safe work practices Pilbeam et al. (2016). The following behavioural activities of transformational leadership are noted by Kelloway et al. (2006):

1) "Expressing satisfaction when jobs are performed safely
2) Rewarding achievement of safety targets
3) Continuous encouragement for safe working practices
4) Maintaining a safe working environment
5) Suggesting new ways of working more safely (employee-led)
6) Encouraging employees to discuss safety at work openly
7) Talking about personal values and beliefs in the importance of safety
8) Behaving in a way that demonstrates a commitment to safety
9) Spending time to demonstrate how to work safely and
10) Listening to safety concerns"

These studies investigated transformational leadership within the supervisor-worker dynamic, indicating that such leadership boosts workers engagement in safety, thereby improving safety outcomes Pilbeam et al. (2016). Additionally, Ozbilir (2021) stated “the relationship between leadership and safety participation” may influence safety culture and the management/supervisor trust with workers.

2.10 Limitations of transactional v transformational safety leadership

Current empirical research on safety leadership, using a transactional-transformational delves into the dynamics between the supervisor-worker relationship Pilbeam et al., (2016) within high-risk settings (manufacturing, service, oil and gas, mining, aviation, and construction), the maritime industry wasn’t found to be included in this research. The emphasis of current empirical research on supervisors and workers uncovers additional research opportunities to explore the impact of leader-follower dynamics Pilbeam et al. (2016) within the shipboard environment.

2.11 Leader-worker exchange

The underpinned psychology of an individual in literature by Long (2013) established the theory of third-generation leadership of the individual leader having a self-directed internal locus of control with a commitment to collaborative behaviour. Further to Long's point, the neuroscience of the Locus of control, whereby the individual believes that outcomes of actions result from their inputs and abilities, including the ability to reason with others, account for leadership within the third-generational leadership model (Long, 2013).

The Locus of control framework developed by Julian B. Rotter in 1954 is widely researched and applied in psychology with applications to education, health, and occupational safety. The application of Locus of control is highly relevant to safety leadership as it can directly affect an individual's behaviour. A person's "locus" can be conceptualised as internal (individual believes they can control their life) or external (individual believes they are not in control of their life). It is especially relevant to the high-risk work environment because they do not rely on just one leadership style to be an effective safety leader.

Current literature acknowledges that safety leaders generally embrace one of three primary leadership styles: “1) transformational, 2) transactional and 3) servant” (Cooper, 2015).

2.12 Behavioural-based safety and leadership

The maritime shipping industry is a complicated sociotechnical system integral to international trade's ongoing viability (Subramanyam & Dhankher, 2022).

Unfortunately, as is the case with other high-risk environments, significant change has been initiated for the most part by disaster and loss of life. The sinking of the Herald of Free Enterprise in 1987 led to the IMO adopting the International Safety Management (ISM) Code for the Safe Operation of Ships at Sea (Safety4Sea, 2019).

The beginning of Behaviour-based safety was founded on the behaviour modification theory by Skinner (1950); Skinner (1953). Throughout the past century, human failure has been repeatedly claimed to be the leading cause of maritime incidents (Behaviour based safety, 2015) and that human error is the primary contributing factor for up to 70%

of incidents (Galierikova, 2019). It has been further stated by leading shipping classification society DNV (Behaviour Based Safety, 2015) that mariners tend to respond to emergent situations in a manner which is based on a flawed understanding of the situation at hand. This could be for several reasons, including misconceptions, outdated knowledge, insufficient training, or miscommunication leading to unsafe behaviour. Dejoy (2005) established that behaviour can be managed along with safety culture by altering the contributing factors which contribute to unsafe behaviour and the operating environment; with this said, taking into consideration the above statements from DNV (Behaviour Based Safety, 2015), it can be well established that indeed a gap is present in the understanding of behaviour-based safety theory and its practical implementation within the global maritime environment.

However, as DNV is one of the world's leading shipping classification societies, founded in 1864 in Norway, currently with over 12,000 ships and mobile offshore fleet vessels registered under its name, this statement by DNV is not taken lightly. It can be interpreted to support the need for formalised behavioural safety leadership training. Choudhry (2014) determined that safety behaviour can be improved by systematically monitoring safety behaviour and providing feedback when unsafe behaviours are observed Cooper (2015).

Therefore, behavioural safety can reduce incidents and injuries (Cooper, 2014) by addressing several causes, while technical safeguards are more successful at removing a single hazard. Based on a review of incident reports (Huange et al., 2020), it was determined that management leadership is the most empirically validated strategy for creating an environment for change.

Behavioural-based safety is a proactive method for altering unsafe behaviours to safe behaviours of workers using positive reinforcement (Skinner, 1953; Ocon & McFarlane, 2007) and positive intervention before incidents occur.

Additionally, if we apply the theory of Dejoy (2005) that the two dominant psychological approaches to safety improvement are safety culture and behaviour-based safety, and while both have opposing views on how to motivate workers, Choudhry (2014) agree that as a collective, both have multiple benefits to safety performance improvement.

Workers can sometimes not conform to safety procedures despite having the knowledge and tools. This phenomenon, known as the 'human factor' element in incident causation, is primarily related to environmental factors influencing decision-making (Ocon & McFarlane, 2007). Behavioural-based safety aims "to change a person's mindset, habits, and actions to avoid "at-risk" behaviours" (Subramanyam & Dhankher, 2022).

Behavioural interventions can benefit worker safety and corporate organisations by reducing injury, illness, and related costs. The flip side is increased collaboration and efficiency because workers are engaged. The capacity of personnel to follow rules, procedures and safe work standards in the ever-changing and dynamic high-risk maritime environment can benefit immensely from a structured behavioural-based safety system supported by senior management.

Cooper (2015) has firmly established over decades of research that inspirational leaders who passionately believe in what they do are successful leaders due to their use of language, tone of voice, body language, interaction with peers and subordinates, and also by the employment of empathy. Inspirational leaders use these items to effectively communicate their intent and expectations to others to elicit a reaction and a desired response. This morphs into a transformational leader who can visualise, direct and describe to motivate others to act safety (Clarke, 2012).

In summary, behavioural-based safety leadership is a multi-functional social construct that requires further targeted research to increase the depth and breadth of knowledge in the sphere of the high-risk maritime environment, which in my professional opinion has multiple benefits to the global maritime workforce.

2.13 Conclusion

Organisations worldwide spend varying amounts of money to improve the safety of their workers. The success of these programs depends on many factors, including, but not limited to, the organisation, environmental, management structure, education and culture of the workplace or in this case vessel.

Cooper (1998), widely recognised as one of the world's leading authorities in behavioural safety, determined that unsafe behaviours trigger 80% to 90% of all accidents. This supports the notion that behaviour underpins everything and that if unsafe behaviours are identified and corrected, lost-time incidents and associated costs can be significantly reduced. Behaviour is a natural output of thoughts and feelings and precursor to actions, behaviours, and performance (Safety Leadership, 2021).

Cooper (2014) stated that an organisation's safety leadership plays a crucial role in preventing major safety accidents, reducing accident rates, improving working conditions, enhancing employee motivation, which can therefore drive improved financial performance. This paper supports this notion and acknowledges “the relationship between safety leadership and enhanced safety performance” (Halle, 2023). Additionally, over the past 31 years, empirical studies have shown that excellence in business leadership, such as transparency, communication, and integrity, is reflected in the skills used for managing safety Cooper (2015).

Cooper (2015) further established two effective safety leadership types, positional and inspirational, stating that positional leaders lead by their positional power. Individuals comply with directives out of necessity. In contrast, inspirational leaders naturally evoke genuine passion and enthusiasm for their leadership roles and inspire others (Zenger et al., 2009).

This literature review provides a comprehensive exploration of the dynamics of safety leadership and its profound impact on organisational safety culture, particularly within the high-risk environment. Drawing upon a wide array of empirical and theoretical research, it underscores the critical role that both positional and inspirational leaders play in shaping safety behaviours and reducing incidents. The use of extensive referencing which continues throughout the case studies and journal article reviews strengthens the paper by providing a robust, evidence-based argument for the importance of safety leadership. Referencing authoritative sources lends credibility and demonstrates a comprehensive understanding of the subject matter, ensuring that the review’s conclusions are well-supported. It also highlights the breadth of research and the variety of perspectives considered, offering a multidimensional understanding of safety leadership and behaviour. Furthermore, the review highlights the necessity of better understanding unconscious safety behaviours and the various antecedents influencing them, from individual characteristics to broader organisational and societal factors.

A solid foundation for the argument is established that an intricate blend of leadership styles, behavioural understanding, and continuous research is essential for advancing safety practices. While it indicates that substantial strides have been made in identifying effective leadership strategies and safety interventions, gaps do still exist, especially concerning unconscious safety behaviours in the high-risk maritime environment.

In moving forward, the fostering of a robust organisational safety culture requires more than just adherence to procedures and guidelines; it requires an ongoing commitment by all levels of management, top down to leadership development, employee engagement, and a deeper psychological understanding of safety behaviours.

Safety leaders, researchers, and maritime safety professionals need to continue exploring and implementing multifaceted, evidence-based strategies to enhance best practice safety outcomes. The goal is a proactive, informed approach to safety management where leadership is as much about inspiring and motivating as it is about governing and guiding, leading to a safer, more productive work environment for all at sea and ashore.

CHAPTER III:

METHODOLOGY

A suitable research plan and supporting methodology are prerequisites for drawing valid conclusions in academic research. This dissertation was designed to incorporate qualitative and quantitative approaches to explore the impact of behavioural-based safety leadership on organisational safety culture in the high-risk maritime environment. This chapter will describe the methods selected for the empirical study, including the theoretical constructs, research purpose and questions, research design, population sample, data collection, analysis, and research limitation challenges.

3.1 Overview of the research problem

Behaviour underpins everything we do daily, not just in the workplace. We make hundreds of unconscious safety behaviour decisions daily, from putting our keys in our pockets, putting our seatbelts on, locking the front door when we leave home, and turning our headlights on at night. For example, it takes up to one and a half hours to drive from home in Woolloomooloo, Sydney, to Port Kembla, Wollongong, South of Sydney, 91km. In 90 minutes, the drive takes the vehicle past well over 1000 road signs and signals. Within microseconds, one can visually identify a signal or sign and its content registered in the brain. The brain uses the unconscious cognitive function to decide to either (1) follow a safe path by stopping at a red light or (2) take a risk, accelerate through the red light and speed so I do not have to stop. This process occurs in microseconds, mainly in the subconscious, without being physically aware.

While significant academic research is available regarding human factors, leadership and management as factors which impact safety behaviour, we expect our "leaders and managers" to be inspirational to their workers through the practical demonstration of safe work practices, otherwise known as behaviours in executing their duties (Chonchie & Moon, 2010).

However, we must fully understand the paradigm of identifying hazards and correlating the contributing antecedents that influence our cognitive response (positive or negative) to those hazards via unconscious safety behaviours. Furthermore, identifying which antecedents promote positive safety behaviour decisions in workers requires addressing within the research.

3.2 Operationalization of theoretical constructs

The Theoretical concept of this dissertation's research is based on empirical observations of ship officers, senior ratings, and shipping company management ashore. Typically, these are variables that are not directly measurable. However, through operationalisation, researchers can collect, analyse, and process data that is not ordinarily measurable or observable.

Creswell (2013) defined a research paradigm as a process of collecting and analysing information to increase our understanding of a topic or issue. Antwi and Hamza (2015) explained paradigms as systems of interrelated practice and thinking using three primary dimensions—ontology, epistemology, and methodology.

Ontology is the subject or reality to be researched. Epistemology describes the relationship between the researcher and the subject being studied, and methodology is how the researcher will conduct research into the subject Antwi and Hamza (2015). Three paradigms have been implemented in this research study.

1) Humanistic

   It was adopted throughout the literature review, empirical research, data collection and analysis.

2) Positivist

   It was adopted in the empirical research to analyse safety behaviour, leadership and culture.

3) Interpretive

   Adopted in the final stage of the research study.

3.3 Meta-theoretical constructs

The following meta-theoretical concepts will be included in the research.

1) Behaviour-based safety
2) Occupational health and safety
3) Personality
4) Emotional Intelligence
5) Leadership

3.4 Research purpose and questions

1) To identify antecedents which affect organisational and or individual safety behaviours and human factors that affect safety leadership behaviours in the high-risk maritime environment.
2) Assess and compare the relative contributions of these factors in shaping safety leadership behaviours and their outcomes in the workplace; and
3) To outline a conceptual framework for the introduction of Safety Leadership Self-Efficacy Scale (SLSES) with behavioural safety elements included to increase awareness of unconscious safety behaviours to implement realistic, measurable processes to improve safety leadership behaviours and safety performance within the high-risk maritime environment.

By understanding the behaviours which lead to poor safety outcomes, we thus can identify the contributing factors which lead to poor safety behaviours. We can then develop and direct resources with the help of this research towards educating the wider maritime workforce to ensure improved safety leadership and safety culture outcomes.

3.5 Research methodology design

The author proposed empirical research will be conducted in six phases.

1) **Phase 1**. Develop research concept.
2) **Phase 2**. Develop research proposal.
3) **Phase 3**. A comprehensive literature review including grey literature from an international cohort, including government and private sources.

4) **Phase 4**. Conduct an empirical case-study approach to one incident and review two peer-reviewed journal papers using the System-Theoretic Accident Model and Processes (STAMP) based on systems theory. All three are significant incidents within the global high-risk maritime environment.

1. Case study 1: MV Rhosus and the Beirut Explosion Disaster, which occurred in 2020, followed by;
2. Journal Review 2: System-Theoretic Accident Model and Processes (STAMP) review of the MV Sewol Korean ferry disaster 2013.
3. Journal Review 3: Tianjin Port Fire and Explosion Disaster China 2015.
4. Validation of a Safety Leadership Self-Efficacy Scale (SLSES) in the maritime context includes behavioural safety elements.

5) **Phase 5**. Conduct mixed methods research using qualitative and quantitative approaches, including surveys with Masters, officers, upper-level shore management, supervisors, and safety professionals regarding perceptions of behavioural-based safety, organisational safety, and human factors influencing safety leadership and safety behaviour. Conduct interviews with workers and safety professionals to identify perceptions.

6) **Phase 6**. Analysis of the findings.

3.6 Aims of phase 1

The aims of phase 1 research.

1) To conduct research into the current literature on behavioural-based safety leadership, organisational safety culture and incident causation within the high-risk work environment.
2) To assess and describe behavioural safety.
3) To conceptualise behavioural-based safety.
4) To discuss the different models of safety leadership and safety culture
5) To identify gaps within the current literature as areas of opportunity for further research.

3.7 Aims of Phase 2

The aims of phase 2 research.

1) To conduct an analysis of the case study, journal articles and self-efficacy scale to identify antecedents which contributed to negative safety behaviour outcomes leading to poor safety culture.
2) To identify negative safety leadership as a result of identified antecedents.
3) To identify negative organisational safety culture.

3.8 Aims of Phase 3

The aims of phase 3 research.

1) To conduct a series of surveys and interviews with seafarers (officers, ratings and maritime safety professionals) to assess their understanding of

the impact of positive or negative behavioural safety, safety leadership and organisational safety culture.

2) To review the survey data and then formulate recommendations for improvements to behavioural safety leadership, organisational safety and safety culture, which will positively impact incident causation outcomes in the maritime sector.

3.9 Aims of Phase 4

The aims of phase 4 research.

1) To deliver a considered dissertation body of research.

Figure 4: Research phase timeline

Source: Author's data

3.10 Research questions

The following research questions will be answered.

1) To identify antecedents which affect organisational and or individual safety behaviours and human factors that affect safety leadership behaviours in the high-risk maritime environment.
2) Assess and compare the relative contributions of these factors in shaping safety leadership behaviours and their outcomes in the workplace; and
3) To outline a conceptual framework for the introduction of Safety Leadership Self-Efficacy Scale (SLSES) with behavioural safety elements included to increase awareness of unconscious safety behaviours to implement realistic, measurable processes to improve safety leadership behaviours and safety performance within the high-risk maritime environment.

3.11 Methodology summary

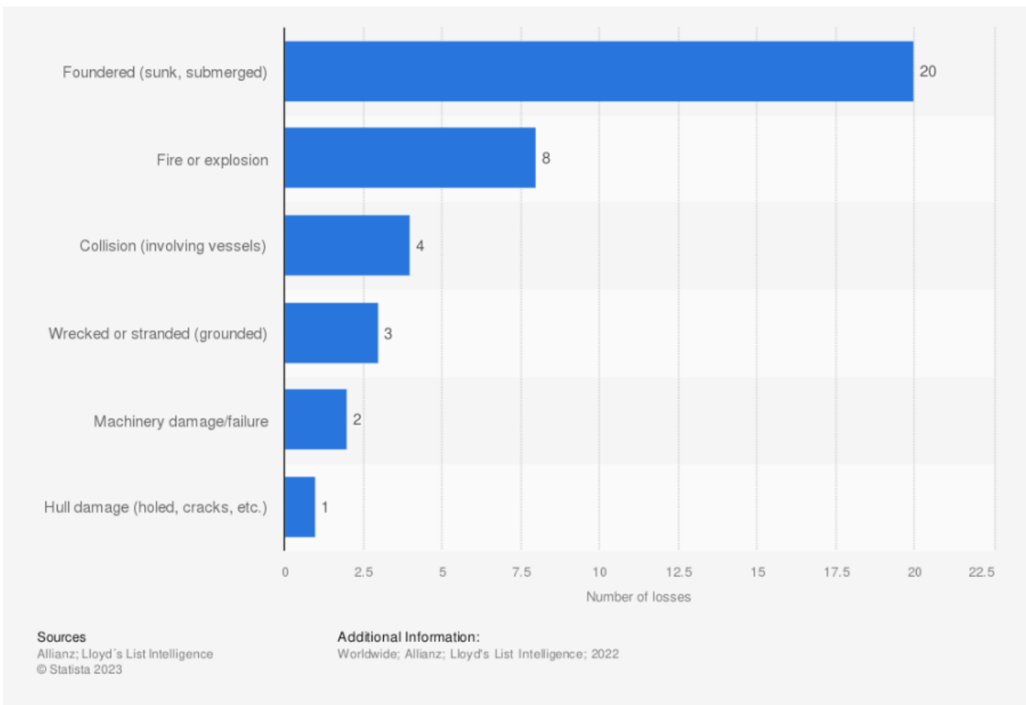
The research methodology for this dissertation encompasses a comprehensive, several-step, mixed-phased approach aimed at understanding the impact of behavioural-based safety leadership on organisational safety culture in the maritime industry. It involves the operationalisation of theoretical constructs through empirical observations and paradigms of humanistic, positivist, and interpretive nature. The methodology is structured into six phases, encompassing concept development, proposal formulation, comprehensive literature review, empirical case studies, mixed methods of qualitative and quantitative research, and data analysis. This approach seeks to identify antecedents affecting unconscious safety behaviours and assess their influence on safety leadership and culture, culminating in the development of a Safety Leadership Self-Efficacy Scale to improve safety performance in the high-risk maritime environment.

As of January 2023, the world's Merchant fleet consisted of approximately 105,500 vessels of at least 100 gross tons, with 56,500 of those ships being over 1000 gross tons (UNCTAD, 2022). Global naval vessel estimates include 5,511 naval ships (Global Firepower, 2023). Between 2011 and 2020 a total of 876 vessels over 100 gross tons were lost (ILO, 2015). Safety and Shipping Review Insights (2023) reported annual shipping losses have declined by 65% from what they were ten years ago with only 38 total losses in 2022 with fire the most expensive marine insurance claim. While the total number of Merchant and Naval ships currently sailing the world is high, this complexity also complicated how the author would select and conduct research for this dissertation. To solve this complex problem, the author undertook an analysis of the causes of ship losses worldwide. Cargo ships suffered the largest losses between 2013 and 2022 with foundering the primary cause followed by fire or explosion (Statista Research Department, 2023).

Therefore, knowing that fire was the most expensive marine insurance claim with fire and explosion also showing high results this evidence further supported research into the high-risk maritime environment. Selecting appropriate case studies for research then began. Given the significant impact of the Beirut explosion to infrastructure, human life, global trade and the role of the MV Rhosus, the sinking and loss of life with the MV Sewol in Korea and the explosion, damage to infrastructure and loss of life with the

Tianjin explosion in China the author selected these three incidents for analysis due to the contributing factors of organisational safety culture, human factors and assumed behavioural-based safety implications.

Figure 5: Causes of ship losses worldwide in 2022 by type.



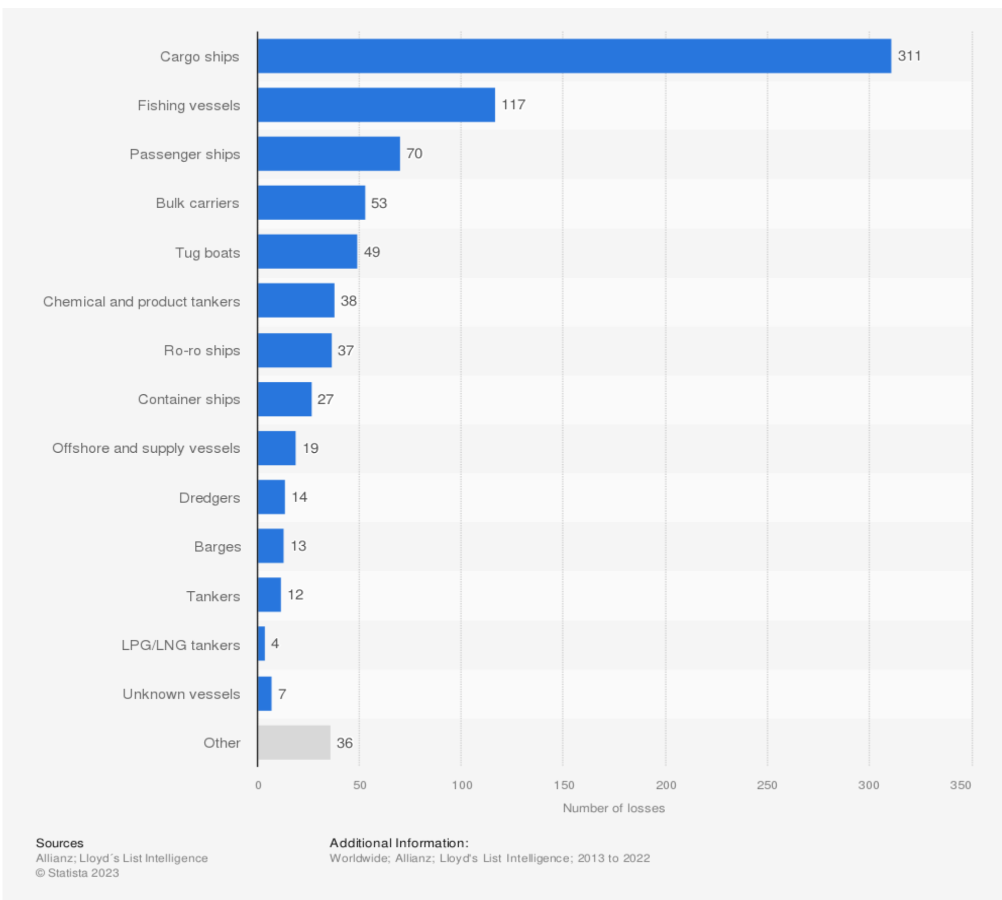
Source: (Statista Research Department, 2023)

By understanding the antecedents which lead to unsafe behaviours which then lead to poor safety outcomes, we can identify the contributing factors which lead to the poor safety behaviours. We can then develop and direct training and educational resources with the help of this research towards consultation the wider maritime workforce to ensure improved safety leadership and safety culture outcomes.

3.12 Role of the researcher

I am the Australian Health Safety and Environment Manager and Designated Person Ashore for Heron Group New Zealand (NZ), a marine construction and dredging company headquartered in Auckland, New Zealand with operations in Australia. In this role, I have day-to-day access and direct responsibility for the health and safety of onshore and offshore vessel crews and the maritime safety aspects of our vessel's compliance with

Figure 6: Number of ship losses worldwide between 2023 and 2022 by vessel type.



Source: (Statista Research Department, 2023)

International Maritime Organisation (IMO) regulations and conventions implemented by Maritime New Zealand (MNZ) and the Australian Maritime Safety Authority (AMSA). As with previous roles, I always endeavor to provide flexible and responsive management support to the company, employees, clients, and service providers that support our operations. With over 27 years of experience as a seaman and sailor in various roles at sea and ashore, I have seen multiple incidents and been involved in several. While this is a broad statement, taking into consideration my training, operational experience at sea, interactions with the chain of command in both the Royal Australian Navy, the Merchant Navy and commercial maritime industries and my unique understanding of organisational safety culture, human factors and their impact on risk management it is in my professional opinion that all the case study incidents discussed in this research could have been prevented if behavioural-based safety and safety leadership had been in place within all levels of the management structures of the companies, organisation's and government agencies involved. This has been a driving factor for this research project. Governments and regulators have all conducted numerous investigations, identified root causes and attempted to implement corrective actions and, in some cases, organisational change. How effective all that change has been is debatable as incidents have continued to occur.

However, given my experience and service around the world working alongside fellow seaman, sailors and officers, I have a sound understanding of maritime safety leadership from a personal, managerial and leadership perspective.

I am directly responsible for all aspects of this research study. The development and design of my survey questions after reviewing the research conducted by Kim et al. (2021), whereby I identified an opportunity to expand the research conducted by Kim et al. (2021) by extending the Safety Leadership Self-Efficacy survey to include several behavioural safety questions.

The research study questions discussed in Chapter IV were modified as the study progressed and evolved.

3.13 Population and sample

The population sample for this study includes senior ratings (sailors), ship officers including but not limited to fourth officers, third officers, second offices, first officers, chief officers and Masters (Captain). Additionally, this rank structure includes deck and engineering officers, officers who hold management positions ashore, such as the Fleet Manager, Operations Manager, Designated Person Ashore, HSE Manager and or maritime training officers who usually are officers with previous sea experience in charge of training programs for company vessel crews and professional development to meet the requirements of the IMO, STCW standards.

3.14 Participant selection

Participants were selected from responses to emails, LinkedIn posts and phone calls after word got around about my research project. Three individuals contacted me to ask if they could complete the survey and participate in the face-to-face interviews. Unfortunately, I declined these offers of participation as the individuals did not have experience as a senior rating, ship officer, or Master (Captain), or the relevant senior management roles officers occupy ashore that is needed to ensure inaccurate data responses did not compromise the quality of the research results.

3.15 Instrumentation

Phase one data collection was primarily undertaken initially by an online survey via the survey planet website platform. The survey link was distributed via email to military and shipping colleagues and also via several posts on LinkedIn to encourage a potential larger international participation in the survey.

Connections within the military, and professional membership with the Honorable Company of Master Mariners and International Association of Marine and Shipping Professionals were also used to reach potential participants for both phase one and two face-to-face interview via a Teams meeting online with Otter.ai speech to text transcription recording software.

The main component of research study 1 was an anonymous two-part survey (Questionnaire) of 71 multiple choices and 2 written answer questions expected to take 12 to 15 min to complete. Part 1 has a series of 38 questions, each linked to a specific area of safety motivation, management, initiatives, and behaviour. Part 2 includes a series of 34 questions linked to a safety leadership self-efficacy scale (SLSES) adapted to the maritime high-risk environment expanding on research by Kim et al., (2021).

Part 2 of the study is a face-to-face interview via Teams online for up to 60-minutes interview with audio or visual aids used to record the interview for transcription purposes. The supervising Professor, Jaka Vadnjal (SSBM), will monitor the interview outcomes but will not be a part of the interview process.

3.16 Interview guideline

An interview guide was developed to assist in the conducting of the face-to-face interviews. The guide provided an overview of how to conduct the interview and keep the subject matter on course with sixteen key interview points.

Part 2 interview questions:

Table 2: Part 2 Research Questions.

Number	Part 2 Research Questions
1	In general, what does safety behaviour mean to you?
2	Tell me about your experience of safety behaviour in your current organisation?
3	Tell me what you know about the Beirut Blast and MV Rhosus, the ship which carried the ammonium nitrate into Beirut that exploded in August 2020? or
4	Tell me what you know about the explosions in the Northern Chinese port of Tianjin in 2015 or
5	Tell me what you know about the MV Sewol Ferry capsize disaster in South Korea in 2014?
6	Having completed this survey and safety leadership training previously. Do you think the current IMO regulated safety leadership training is satisfactory? Please explain your answer.

Source: Aurthor's data

Phase one data collection was initially undertaken by an online survey via the Survey Planet website platform. The survey link was distributed via email to military and shipping colleagues and via LinkedIn posts to encourage more extensive international participation in the survey.

Connections within the military and professional membership with the Honorable Company of Master Mariners and International Association of Marine and Shipping

Professionals were used to reach potential participants for phase one surveys and phase two face-to-face interviews via a Teams meeting online with Otter.ai speech-to-text transcription recording software.

The main component of Research Study 1 was an anonymous two-part survey (Questionnaire) of 71 multiple-choice and two written-answer questions expected to take 12 to 15 minutes to complete. Part 1 has 38 questions, each linked to either safety motivation, management, initiatives, or behaviour. Part 2 includes 34 questions about a safety leadership self-efficacy scale (SLSES) adapted to high-risk maritime environments.

Part 2 of the study is a face-to-face interview via Teams online for up to a 45-minute interview, with audio or visual aids used to record the interview for transcription purposes. The supervising Professor, Jaka Vadnjal (SSBM), will monitor the interview outcomes but will not be a part of the interview process.

3.17 Data Collection procedures

Data collection for this study was conducted outside of business hours for most participants. However, some participants who were onboard ships when completing either the online or hard copy survey and face-to-face interview were still on call. Living and working on ships is a 24-hour job. If the officers or senior ratings were off watch, they could relax in the mess deck and let their hair down. Given the nature of shipping operations, the crew are either at work or resting. One is never 100% off the clock when at sea in case of an emergency.

For this research study, qualitative data collection using the grounded theory approach was beneficial in exploring the antecedents associated with the subject matter (Khan, 2014).

In phase one, a set of structured survey questionnaires was either issued to participants by an email link or they were handed a hard copy survey to complete and return in a sealed envelope. All participants were given clear instructions (ref Appendix A) regarding what was required and how their privacy would be protected during the research study.

In phase two, participants engaged in a semi-structured interview enabling the researcher to ask open-ended questions throughout the discussion. This approach allowed the interviewer to understand each participant's opinions and lived experiences better (Khan, 2014).

Additionally, face-to-face interviews also allowed the researcher to deep dive into any ambiguities or inconsistencies observed (Khan, 2014). Interestingly, this approach also allows the researcher to observe body language and mannerisms during the interview, which may aid in understanding a participant's specific lived experience, whether good or bad (Khan, 2014).

Participants were initially informed that the face-to-face interview may take up to 30 minutes. However, this initial estimate was incorrect and adjusted to between 45 minutes and 1 hour.

Table 3: Data Collection

Method	Instrument	Type	Medium	Documentation
Survey	Questionnaire	Individual participants	Online - 15	Transcripts
			Hard copy - 7 Rejected - 1	Written responses
Face-to-Face Interview	Interview guide Set questions		Completed - 2 Rejected - 2	Researcher notes

Source: Aurthor's data/survey plant

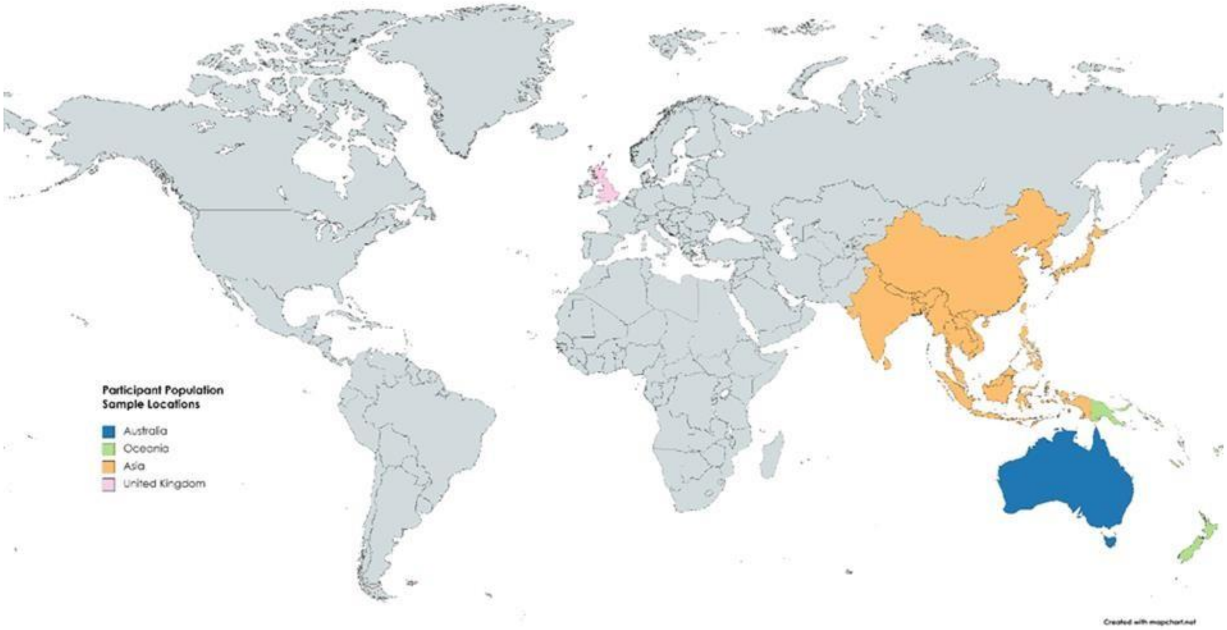
3.18 Data analysis

The reliability of any research depends on the size of the population sample. In theory, the more data there is, the more significant the population size (Graglia, 2023). This can then be further affected by the quantitative (words) and quantitative (numbers) data from the questions asked within the survey questions online and by the one-on-one, face-to-face interviews.

The survey results were reviewed using the Survey Planet dashboard. This software enabled a clear overview of the survey results.

Interview transcriptions recorded on Otter.ai were downloaded, read and edited to ensure all non-research relevant data was removed before the final version of the transcript underwent thematic analysis.

Figure 7: Participant Population Sample Locations



Source: Author's data/survey planet

*Table **4**: Participant Population Sample Location %*

Global Location	Percentage
Australia	52%
Oceania (PNG, New Zealand, Fiji, Somoa, Tonga, Solomon Islands, Tuvalu)	40%
Asia (China, India, Indonesia, Thailand, Philippines, Japan, Vietnam, Cambodia, Korea, Myanmar, Malaysia)	4%
United Kingdom (England, Scotland, Wales, Northern Ireland)	4%

Source: Author's data/survey planet

3.19 Research design limitations

This dissertation has been impacted by several limitations which require discussion.

The accuracy and dependability of the research findings from surveys and interviews would have been enhanced with larger sample sizes, especially regarding the interviews, which will be discussed in this chapter.

The survey's number of questions became a concern after several people who completed it mentioned its length and detail.

With 32 questions in Part One and 34 questions in Part Two, the average time to complete the survey was between 12 to 15 minutes. However, while 12 to 15 minutes may seem like little to the researcher, survey participants consider this period long and remains a severe limitation to further success.

The below list demonstrates the main limitations identified within the study.

1) Length of survey/time to complete (12 to 15 min to complete)
2) Number of questions (Part 1-32 questions, Part 2-34 questions)
3) Access to reliable Wi-Fi connection for respondents completing the survey at sea. A month after the survey was released, it was observed that the number of completed surveys was less than 20. After following up with several people who indicated they wanted to participate in the survey process, Information confirmed that the WI-FI onboard the tugboats and research vessel needed to be more reliable. They needed help accessing and completing the survey.

After speaking with Professor Vadnjal about this problem, the author asked for permission to hand hard copies of the surveys out to these participants to complete.

4) The professor discussed the potential additional complexity of integrating hard-copy surveys with online surveys. The solution to this dilemma was to manually input the data received from the hard-copy surveys into the Survey Planet online platform. All data was input into the Survey Planet database at the same time on the 19th of November 2023, taking the total number of surveys completed to 32.

   Industry participation included four naval officers, 17 merchant naval officers, two senior ratings, 12 tugboat crew members, and nine other maritime professionals in management or shore-based positions.

5) Interviews took much work to complete. The author did not consider the unreliable nature of WI-FI on some merchant ships and that some ships do not have independent WI-FI satellite systems installed, giving the crew access to WI-FI 24 hours a day to communicate with the outside world. This significantly impacted the researcher's ability to engage with more maritime professionals at sea.

Four individuals initially agreed to complete interviews, with one completed ashore and three completed while officers were onboard ships at sea. Of the three officers at sea, one WI-FI connection was so terrible that after repeatedly trying to connect for over an hour unsuccessfully, the author checked www.marinetraffic.com (online vessel tracking software connected to ships AIS locater beacon) showing the ship in the South China Sea near Japan out of range. Due to the person being at sea for lengthy periods, the interview could not be repeated. The author could not communicate with the officer again, and subsequently, a re-interview did not occur.

Another interview with an officer on a research vessel in the North Atlantic Ocean went ahead. We initially had some connection issues. However, after 15 minutes, the author believed he had overcome this after checking the recording, and we proceeded. However, when he returned to tidy up the script and work on interpreting the results, the author found a significant part of the recording blank. Unfortunately, nothing was recorded; The author determined that the WIFI connection with the video link wasn't strong enough to sustain the data recording on the connection.

The author attempted to contact another interviewee after indicating he would participate. Unfortunately, he did not respond to several emails and phone messages left to re-book a time for the interview. As a result, this interview did not take place.

Despite multiple attempts, only two recorded interviews were obtained in phase 2 of the research.

This invariably affected the validity of the research data findings generated from the survey and interview techniques.

It is also essential to note random variables such as nationality, culture, religion, personality, and where officers, ratings, and maritime professionals undertook their professional training, which are also unknown factors that may have impacted the responses to this research.

3.20 Conclusion

In conclusion, this dissertation uses qualitative and quantitative approaches to explore the impact of behavioural-based safety leadership on organisational safety culture in high-risk maritime environments.

The research addresses the overarching problem of understanding unconscious safety behaviours, highlighting the importance of identifying antecedents that influence cognitive responses to hazards by bridging gaps in knowledge regarding the correlation between hazards, antecedents, and cognitive responses in the maritime sector.

The operationalisation of theoretical constructs involves adopting three paradigms—humanistic, positivist, and interpretive. The study incorporates meta-theoretical concepts like behaviour-based safety, occupational health and safety, personality, emotional intelligence, and leadership. This led to the formation of research hypotheses, aiming to reduce adverse incidents and prevent loss of life through behavioural safety leadership while advocating for changes in safety leadership training requirements.

The research purpose and questions focused on identifying antecedents affecting safety leadership behaviours, comparing their contributions, and outlining a conceptual framework for a modified Safety Leadership Self-Efficacy Scale (SLSES). The latter includes behavioural safety elements to enhance awareness of unconscious safety behaviours to improve safety leadership and performance.

The research methodology involved a comprehensive literature review, empirical case studies, and surveys with various military and civilian maritime professionals worldwide. The six-phase approach encompassed data collection, analysis, and validation of the modified Safety Leadership Self-Efficacy Scale. The researcher, a seasoned professional with over 27 years of operational experience in the Royal Australian Navy, Merchant Navy, offshore oil and gas and marine construction industries, underscores the practical insights brought to the study.

The population and sample included senior officers, senior ratings, ships officers, and shipping management ashore, with the research instrumentation involving online surveys followed by face-to-face interviews.

The data analysis involves qualitative and quantitative methods, utilising the online Survey Planet dashboard and thematic research data analysis. The research limitation concerns, including the small sample sizes and challenges in survey completion at sea, were acknowledged. Areas for improvement and further research include expanding sample sizes, especially in unconscious behavioural safety research within the maritime context and availability and quality of WIFI access for crew at sea.

In summary, this dissertation provided a foundation for understanding and improving safety leadership, unconscious safety behaviours, and organisational safety culture in the high-risk maritime environment, acknowledging the need for ongoing research and advancements in this critical field to improve safety outcomes for shipping professionals at sea.

CHAPTER IV:

RESULTS AND DISCUSSION

4.1 Background

Leadership is a complex, multifaceted interaction between leaders and subordinates (Cooper, 2015). This chapter will discuss the research questions and findings of the research in detail.

In research conducted by Kim et al. (2021), researchers discussed the importance of safety leadership within the high-risk maritime industry and the Merchant Navy. The journal article introduced a new safety measurement tool called the Safety Leadership Self-Efficacy Scale to address the identified gap in safety leadership research within the high-risk maritime environment and validate the proposed scale.

The high-risk maritime environment is complex and dynamic, with shipping being among some of the most remote and dangerous occupations in the world (Hetherington et al., 2006). Accidents continue to occur despite significant attempts from the International Maritime Organisation, including measures taken by individual sovereign nations worldwide to implement various safety standards and regulations.

Leadership self-efficacy is the ability of an individual to believe in one's capabilities to organise and execute appropriate courses of action in a range of specific situations (Bandura, 1997). Additionally, leadership self-efficacy is an essential element in the overall leadership process as it impacts the development and execution of leaders' drive, strategies and goals (Harrald et al., 1998) in particular situations. The high-risk maritime environment has the unique added elements of restricted social interaction, remote working conditions, dynamic situations at sea, transient and multinational crews and extended isolation periods (Kim et al., 2021).

The harsh reality is that regardless of the lessons learned from multiple maritime disasters, including the Beirut explosion, SEWOL Ferry, Herald of Free Enterprise, Costa Concordia (Subramanyam & Dhankher, 2022), and Tianjin explosion the risk of the human factor element in incident causation will always remain. How we mitigate this risk to as low as reasonably practicable is a question that safety professionals will always find challenging to manage.

In research conducted in Norway by Naevestad et al. (2019), it was determined that the National safety culture was the most critical predictor of unsafe behaviours.

In research by Subramanyam and Dhankher (2022), they stated that introducing a SLSES survey can help reduce the risk of poor safety leadership and organisational safety culture, which previous research and this dissertation has shown can lead to unsafe behaviours.

This chapter will discuss three significant case studies and journal article reviews where organisational safety culture, safety leadership, human factors and behaviour-based safety were contributing factors. The complexity of these incidents will highlight the important role effective organisational safety culture, safety leadership, human factors, behavioural-based safety training can have to prevent such disasters from occurring.

4.2 CASE STUDY ONE RESULTS AND DISCUSSION

MV Rhosus And The Beirut Explosion Disaster (2020)

4.3 Introduction

Shipping is a capital-intensive industry responsible for the movement of 80% of the goods traded internationally (Llbres Phol, 2023). Given the scope of the international shipping trade due to the globalization process witnessed over the past decades, the goods being traded have varied.

According to Mullai (2007), 10 to 15 % of goods transported by sea are dangerous goods. Furthermore, the types and volumes of hazardous goods being transported are on the rise, with the number of different types of dangerous goods and compounds increasing in the thousands, which itself is another opportunity for research that provides its own logistical and administrative challenges. However, currently and in the foreseeable future, these cargoes will continue to be transported in bulk and packaged form by ships (Popek, 2019) as the only way to transport these items long distances.

Information concerning the transport of dangerous cargo by sea is provided in the International Maritime Dangerous Goods (IMDG) Code. It was developed for the maritime transport of dangerous goods in packaged form to enhance and harmonise the carriage of dangerous goods safely and prevent all types of pollution at sea. Dangerous goods transported by sea are classified into nine classes, each having one or more hazardous properties such as explosiveness, radioactive properties, flammability, toxicity, corrodibility, reactivity, infections, substance hazard and environmental hazard. The Code details the requirements for each substance, material or article, including packing, container traffic and stowage, segregation of incompatible substances, handling, emergency response action, and other aspects.

As will be seen, the MV Rhosus case results from a combination of several factors, including poor organisational safety culture, safety leadership, human factors, and port mismanagement. Considering the provisions of the IMDG Code and all IMO Conventions, which aim to improve the safety of life, cargo and the ship, the case study analyses the Beirut explosion disaster and the contributing factors with analysis of organisational safety culture, leadership and behavioural safety.

In order to achieve this objective, this case study is structured as follows:

Section 4.3 Concerns the introduction.

Section 4.4 Presents the literature review.

Section 4.5 Methodology.

Section 4.6 Limitations

Section 4.7 Reviews the vessel MV Rhosus.

Section 4.8 Assesses the incident.

Section 4.9 Implications of the Accident

Section 4.10 Lessons learned.

Section 4.11 Conclusion.

4.4 Literature Review

The body of literature on port explosions is limited, only recently has the issue drawn the attention of researchers, with significantly less research into behavioural safety in the maritime sphere available. Current research on the transport of dangerous goods primary surrounds risk management and its application within the marine environment (Zhang et al., 2019), other studies are more generalist in nature. For instance, a study conducted by Christou (1999) into ports revealed that 671 port accidents occurred from 1934 to 1995 across the world which resulted in 2,494 fatalities and 17,943 injuries. Of that, 54.8 % occurred in ports, with over 90 % fatalities and 30 % injuries also within ports. Later in 2004, Darbra and Casal conducted a study on 471 accidents in worldwide ports between 1941 and 2002 based on available data within the Major Hazardous Incidents Database System (MHIDAS). Additionally, Darbra and Casal (2004) revealed that 65 % of hazardous substance incidents recorded occurred on ocean-going vessels primary due to the increased frequency of movements within the port environment. Furthermore, 15 % of port accidents occurred during the loading and unloading, 11 % during storage with 10.8 % during processing Darbra and Casal, (2004). In further research by Darbra and Casal (2004) they revealed that of 471 accidents involving hazardous substances accidents frequency increased up to 83% over twenty years with 59 % in the past decade (Hakkinen & Posti, 2013).

A review of maritime and port-related hazardous noxious substances (HNS) was conducted by Hakkinen and Posti (2013). This review provided a worldwide overview of marine and port-related incidents involving HNS. The study revealed that the risk of an HNS incident is elevated in areas where the largest quantities of chemicals are transported, maritime traffic is higher, and at the ship-shore interface where loading of unloading occurs Hakkinen and Posti, (2013). Hakkinen and Posti (2013) further determined that little isolated research had been done regarding port regions.

The first incident deserving attention was the Port of Chicago Disaster, which occurred in 1944, where 320 sailors were killed in the explosion of a naval warehouse located on the Sacramento River 35 miles north of San Francisco (Allen, 1982; Vogel, 1982). Two papers were released about it. Allen (1982) investigated the events at Port Chicago leading up to and following the explosion, while Vogel (1982) presented evidence concerning the nuclear origins of the disaster even though such evidence is not conclusive; despite this outcome, the research highlighted the lethal hazards posed by nuclear weapons.

The second, port explosion mentioned in this paper, occurred in the Port of Tianjin, China, drew the research community's attention, more on this event in case study three. However, most of the work is descriptive since it analyses the sequence of events before, during and after the accident (Fu et al., 2016; Sun, 2015; Zhao, 2016), even though other studies from different perspectives were carried out. Zhang et al. (2018) analysed the China-Tianjin Port fire and explosion using the HFACS, STAMP, and AcciMap models and compared their outputs to assess the models' similarities and differences when applying systems thinking methods. From a civil engineering perspective, Li and Ma (2018) investigated the characteristics of the glass damage caused by the explosion. Other studies involved the recovery of a severely injured victim (Zhang et al., 2015), the analysis of human and organizational factors in Chinese hazardous chemical accidents (Zhang et al., 2018), the analysis of the perceived risk after the Tianjin port explosion and its impact on property value (McGarry et al., 2018) and the migration of potassium dichromate and butanone in the coastal soil–groundwater system (Liu et al., 2018).

The third explosion concerns the Beirut disaster. The Beirut disaster has highlighted how human factors, poor safety leadership by the ship owner led to a poor safety culture combined with port mismanagement and ineffective, dangerous goods procedures can devastate human life, government infrastructure, health care, and the national economy, not to mention domestic and international supply chains.

The Port of Beirut is Lebanon's main sea traffic entry port and a critical geographical shipping hub (Port of Beirut, 2022). The port is at the intersection of three continents: Europe, Asia and Africa stretching back to the 15th century BC (Mehan & Jansen, 2020). In 1960, the Lebanese government granted a private company a 30-year lease to run the Port of Beirut. In 1990 this ended, and the government took back operation of the port, commencing a series of renovations and improvements across the site. As of August 2020, the Port of Beirut consisted of a general cargo, passenger and container terminals along with a silo area (Port of Beirut, 2022). Shipping traffic into Beirut port has steadily increased, with nearly 3,000 ships in 2015 down to 2,242 in 2918, 2,132 in 2019 and 2,078 in 2020 (Port of Beirut, 2022).

However, the published research is still limited in number and is viewed from different perspectives without a direct link between the different published works. Cheaito and Al-Hajj (2020) presented a brief description of the blast. El Sayed M. J (2020) described the national and international emergency responses to the Beirut explosion and highlighted the explosion's impact on the Lebanese health care sector. Rigby et al. (2020) discussed ammonium nitrate after the Beirut explosion, given that it is widely used as a nitrogenous chemical fertilizer in agriculture. Agapiou (2020) illustrated the added value of open access and freely distributed satellite data, such that is provided by Copernicus radar and optical sensors, creating a damage proxy map of the blast area. Rigby et al. (2020) developed a method to calculate the explosive yield of blasts like the one in Beirut, based on an analysis of 16 short videos posted on social media. From a resistance perspective, Ismail et al. (2021) assessed the silos' structural response to the blast using a 3D laser scan.

4.5 Methodology

This case study adopted a research desk approach using external documentation gathered from the public domain. The information and sample data used came from multiple sources, including the world wide web, which I have attempted to cross-reference. The incident attracted international attention, which in the positive included comprehensive scientific analysis. However, due to the highly emotive nature and the plethora of information available in the public domain, a plethora of misinformation also flooded the web, which was unfounded. Therefore, I excluded from the research all the information whose credibility was impossible to prove and where bias has been proven through academic and scientific evidence. Finally, I acknowledge the intensely personal impact this event has had on the people of Beirut and the individuals reporting due to the disaster's sheer impact and emotional significance.

For the above reasons, the paper uses a qualitative interpretative phenomenological research approach (Alase, 2017) to analyse this case study to deal with these constraints. The advantages and disadvantages of this research approach are multifaceted. However, when applied to the Beirut explosion the advantages of this approach include research and analysis designed to understand the lived experience of people affected by the incident acknowledging the professional, personal, and social context (Hill & Knox, 2022). The key aspect of interpretative phenomenological research is to get as close to the lived experience as possible (Hill & Knox, 2022).

4.6 Limitations

I have attempted to conduct a scholarly investigation into this case study with an open mind and professional integrity. However, as is common with significant social research, the case study has limitations which require recording. First and foremost, the author is a maritime professional trained initially by the Royal Australian Navy followed by the Australian Maritime College and Orion University to the highest standards of naval and merchant seafaring. Secondly, I am a chartered risk professional and registered OHS Professional. Thirdly concerns the author's limited access to the people directly involved in the events within the case study reviews, including the inability to conduct face-to-face interviews with witnesses and crew members onboard the MV Rhosus. This research has taken over 24 months to complete for these reasons. This therefore provides the potential for bias towards the study. Contrary to Glaser and Strauss (2017), guidance that researchers should avoid engaging with supporting literature prior to starting their research, I find myself in disagreement with their statement. The intention of the case study is to educate oneself in the available published scholarly literature. Additionally, during the research phase, access to available factual government documents proved difficult due to the ongoing investigation into the disaster in the Lebanese courts. Human Rights Watch has been instrumental in providing access to such documents. However, not being able to access all documents relating to the ship’s cargo, maintenance registers, ships bridge log and crew statements has provided limitations in assessing the accuracy of information in the public domain leading up to the ship entering Beirut, its time in the custody of the Lebanese Government and the events post the crew being repatriated home.

4.7 MV Rhosus

This section deals with the Beirut blast. It will start by investigating the vessel that carried ammonium nitrate. Next, it looks into the events occurring before the explosion/blast until August 2020. The outcome of the analysis creates the pillars for the around the impacts of the incident.

Transporting the ammonium nitrate into Beirut was the MV Rhosus (see Figure 1). MV Rhosus was originally built in 1986 in Japan as a single-deck general cargo ship with two cargo holds. However, in 2008, the hull was lengthened to 86.6 metres.

Figure 8: MV Rhosus Underway.

Source: New York Times (2020)

Any vessel or ship which sails on the high seas requires registration in a country. That country then assumes responsibility for the standards under which the ship is registered. In this case, MV Rhosus was flying the 'Moldovian' flag. Moldova is a country with an unconfirmed number of vessels currently on its flag state registry. Moreover, Moldova is a flag of convenience state (ITWF, 2021).

A flag of convenience is whereby ships are registered in offshore countries. Owners often choose flags of convenience to the detriment of their country due to stricter regulations and costs (Offshore Energy, 2012). Lower registration costs, relaxed safety standards, poor maintenance practices, and below industry-standard employment contracts are commonly seen as incentives for ship owners to use a flag of convenience. Corporations registering ships in this manner do so to save money on wages, taxes and insurance. Thus, creating an environment where vessel owners can increase profits by reducing costs on the vessel or crewing makes a flag of convivence a preferred business practice (Hamad, 2016). Often to the crew's misfortune, when the cost outweighs the benefit, owners abandon their ships, cargo and the crew (Khalili, 2022). These aspects are considered significant factors in the accident that would take place in the Beirut disaster with the MV Rhosus.

It has also been identified that until the Beirut disaster, the Moldovian authorities had no procedures in place for carrying out flag state control inspections of vessels on its register to ensure safety standards to which it is a signatory (Carmanu, 2021) as a member of the International Maritime Organisation. This created a loophole of sub-standard ships and unethical ownership to operate vessels under the radar of a flag of convenience (Carmanu, 2021).

4.8 Analysis of the incident events

4.8.1 Between June 2013 and November 2013

In order to analyse the incident, it is necessary to go back to 2013. In early June, a company called Maritime Lloyd, a non-International Association of Classification Societies member (IACS), issued a certificate of seaworthiness for the MV Rhosus to enable lodging the ship's registration with the Flag State Republic of Moldovia Naval Agency (Belford et al., 2021). Maritime Lloyd, also a ship management company based in Cyprus, owned by Charalambos Manoli, was, according to the Organised Crime and Corruption Reporting Project (Belford et al., 2021) in Europe, MV Rhosus's official owner, not Igor Grechushkin as it might seem at first instance.

The registration document obtained from the Ministry of Economic and Infrastructure of the Republic of Moldovia Naval Agency by OCCRP (Belford et al., 2021) (see Annex) shows the relationships between the parties. Teto Shipping, a company registered in the Marshall Islands held by Igor Grechushkin had chartered the MV Rhosus from Briarwood Corporation, a company based in Panama and owned by Charalambos Manoli, the owner of Maritime Lloyd. The analysis revealed that four separate shipping companies owned by Charalambos Manoli were involved in the MV Rhosus to obtain its Moldovan flag registration (see Figure 9). These include Teto Shipping-Leasing (Marshall Islands), Braiarwood Corporation-ship owner (Panama) and Geoship Company SRL (Moldovian) and Acheon Akti-ship administration (Cyprus) (Belford et al., 2021).

Figure 9: Offshore Companies Obscuring Ownership of the MV Rhosus.

Source: Pasovic (2020)

Prior to the ill-fated voyage, which led to the MV Rhosus being detained in the Port of Beirut, she faced some problems. While in the Port of Seville, Spain, on 28 July 2013, the ship was boarded by Spanish officials for a port state inspection. Authorities cited 14 defects onboard, including issues with the ship's auxiliary power unit, corroded decks to fire safety (BBC News, 2020). As a result, the shipowner Charalambos Manoli utilized his Cypriot ship management company, Acheon Akti, as an intermediary to lease a replacement generator for the ship (Belford et al., 2021). As a result, the defective auxiliary power unit was replaced with a new rented Aggreko generator allowing the vessel to leave the port. However, payment for this equipment was never received in Seville, resulting in the debit being registered with Seville authorities (Belford et al., 2021). This debt became part of Beirut port authorities' detainment charges in November 2013 (Belford et al., 2021). It is believed that the ship then returned to Batumi, Georgia before the ammonium nitrate was loaded for its next voyage in September, which was to take the ship halfway around the world to Mozambique.

On 27 September 2013, MV Rhosus sailed from Batumi, Georgia. The bill of lading issued in Batumi (ref Appendix H) specifies the cargo as 2,750.4 MTS of High-Density Ammonium Nitrate (Human Rights Watch, 2021) IMO 5.1 manufactured by a local factory packaged in 2,750 heavy transport cargo bags. Ammonium nitrate is a key ingredient used in fertilisers for farming applications and explosives used widely in the mining sector, where it is combined with other hydrocarbons (Mehan & Jansen, 2020). Ammonium nitrate is one of the world's most widely used agricultural fertilisers (Mehan & Jansen, 2020) whilst also having the ability to be very unstable if not stored correctly following correct

IMDG Code regulations. Moreover, the lading bill confirms the loading port as Batumi Port in the Black Sea and lists Beira, in Mozambique, as the discharge port. The cargo was to be received by Fabrica de Explosivos Mozambique (FEM) in Matola, Mozambique, with the vessel to transit the Suez Canal (Belford et al., 2021) (see Annex). This was confirmed by Human Rights Watch (2021) which obtained a copy of the vessel's bill of lading, this indicates that the MV Rhosus departed from Piraeus, Greece, carrying the stated cargo bound for Mozambique.

After leaving Georgia, the MV Rhosus called the Port of Tuzla, where new Captain Boris Prokoshev embarked the ship. However, unfortunately, it was in Piraeus where the problems began (Belford et al., 2021). The ship's original crew had left due to the non-payment of outstanding wages and was replaced by a Ukrainian crew, (Belford et al., 2021; Khalilil, 2020), this is important for later discussion. However, the new Captain soon realised the ship had problems when food and stores were returned to suppliers because the shipowner was neither paying for the supplies nor could afford to pay for the passage of the Suez Canal (Belford et al., 2021). This situation caused the ship to remain in Athens for up to four weeks while the shipowner looked for additional cargo to cover the costs related to the food, stores, and fees for transit through the Suez Canal (BBC News, 2020).

Figure 10: MV Rhosus Sailing Route.

Source: Organised Crime and Corruption Reporting Project (2020)

In early November 2013, Captain Boris Prokoshev received a call from Russian businessman Igor Grechushkin instructing him to make an unscheduled port visit to Beirut, citing power problems that would allow the ship to enter the port without prior paperwork (CBC News, 2021). The Captain proceeded to Beirut, docking on 21 November 2013 (Belford et al., 2021). According to Thomson (2020), the real reason for this deviation was to pick up an additional heavy machinery cargo from Beirut to Aqaba, Jordan, to pay for the Suez Canal transit.

On arrival in Beirut on 21 November 2013, the Lebanese authorities impounded the vessel for unpaid debts incurred from July in Seville, Spain. Another outstanding debt also followed this for the principal owner Charalambos Manoli from a bank loan with the FBME Bank Cyprus (Belford et al., 2021). Additionally, a port state control (PSC) inspection on the ship's arrival revealed that she had many deficiencies creating additional reasons for detaining the ship (Human Rights Watch, 2021). The MV Rhosus was considered a 'garbage ship' belonging to the 10 - 15 % of the world fleet, which does not comply with international safety regulations (Rozelier, 2020).

To facilitate a ship clearance with Port authorities, on 16 November 2013, the National Trading and Shipping Agency (MV Rhosus's port agent) compiled a transit manifest listing the cargo onboard the ship as 2,755.5 tonnes of High-Density Ammonium Nitrate IMO 5.0. Additionally, it prepared a notice and acknowledgement of the ship's arrival, detailing the cargo as 2,755.5 tonnes of Ammonium Nitrate IMO 5.1 (Human Rights Watch, 2021). Part 5 of the IMDG Code details the provisions for dangerous goods consignments relative to the authorisation of consignments, including advance notifications, marking, labelling and documentation. Specifically, Part 5.1 details the general provisions of the units/cargo (IMO, 2022). In this case, the transit manifest clearly identified the cargo as dangerous goods Ammonium Nitrate as required in the code (Human Rights Watch, 2020) (see Annex).

On 21 November 2013, the same agency produced a Unified List stating that the MV Rhosus departed from Piraeus, carrying 2750 big bags weighing 2755.500 m/tons in transit to Beira, in Mozambique (Human Rights Watch, 2021). This list did not identify the cargo as ammonium nitrate. Whether this is an intentional or a deliberate act to avoid declaring the cargo to Lebanese Port Authorities is unknown. However, once the Lebanese authorities realised the true nature of the cargo in transit, the General Directorate of Customs issued the MV Rhosus agent with a notice stating that, on "21 November 2013 the MV Rhosus arrived in Beirut Port with 2,750 bags of High-Density Ammonium Nitrate, the shipping agency did not describe the nature of the cargo on the ship's Unified List" (Human Rights Watch, 2021).

The additional cargo to be loaded consisted of machinery, a mix of heavy road rollers and excavators. This cargo was to be lashed to the ship's upper deck and offloaded at the Jordan Port of Aqaba before continuing to Africa. However, due to the ageing state of the ship and poor maintenance, on landing the first item onto the deck (cargo hatch containing the ammonium nitrate), the hatch cover buckled, "according to the ship's Ukrainian Boatswain, Boris Musinchak, causing damage to the hatch cover" (CBC News, 2021). Consequently, the Captain refused to load the remaining cargo stating that it could have destroyed the whole ship (Thomson, 2020). After an additional inspection, the vessel was deemed unseaworthy and was detained by Beirut port authorities (Human Rights Watch, 2021).

In this sequence of events, it is worth highlighting that the bill of lading and the Unified List are essential aspects of the investigation. These legal documents clearly show the loading port, type of cargo, the destination port of discharge, and cargo receiver. In the case of the Rhosus, the Unified List submitted to Beirut officials could be interpreted as a deliberate attempt to conceal the true identity of the cargo to avoid scrutiny from port authorities (Human Rights Watch, 2021) (see Annex).

Research has demonstrated that common elements in many dangerous goods incidents is not just the dangerous goods themselves. The problems begin long before the cargo is even loaded (Ellis, 2011). Freight forwarders, transport companies, stevedores, and warehouse facilities are all crucial links in the supply chain. Their duty of care includes ensuring that while they do not package or label the cargo, they are vital in its safe management. Cargo documentation, including bills of lading, is likewise crucial. They articulate to maritime cargo officers how to plan the loading, unloading, and subsequent placement onboard of received cargo within the ship. This process relevance cannot be underestimated by any means, especially when considering previous incidents such as the Hanjin Pennsylvania.

On 11 November 2002, the newly constructed container ship Hanjin Pennsylvania experienced an explosion followed by a devastating fire, spreading to containers and, unfortunately, fireworks onboard while at sea 160nm off the East Coast of Sri Lanka (P&I Club, 2022). The fire and consequent explosions damaged Hanjin Pennsylvania extensively. After investigation, it is believed the cause of the initial explosion was an undeclared cargo of calcium hypochlorite, which is classified as an oxidising agent that can become unstable at even mildly elevated temperatures (Kelman, 2008). This dangerous good has specific handling requirements under the IMDG Code, as does ammonium nitrate. Fire onboard any ship is a serious situation. However, fires on container vessels can quickly become major incidents due to several reasons. These include the variety of cargo onboard, incorrectly labelled cargo, access to ship's cargo holds by fire teams, container storage areas of the upper deck (Kelman, 2008), and the ability of the ship's crew to fight the fire.

Dangerous goods require special attention from shippers and vessel officers. Shipboard storage and location of dangerous goods can have disastrous implications if not stored properly onboard per the IMDG Code requirements. Cargo holds have higher thermal loads than elsewhere on board. Therefore, attention must be drawn to the cargo location on board in relation to the vessel's accommodation, engineering, and lifeboat areas so that access to life-saving equipment is not compromised by dangerous goods misplacement. Documentation needs to be prepared following relevant government and IMDG Code regulations while educating the shipper on the importance of accurate information to ensure the safety of the supply chain. A gold standard example of best practice dangerous goods management is notating the EmS number on the Bill of Lading (not currently required under the IMDG Code). The EmS numbers are located in IMDG Code chapter 3.2. and have two parts. The first with "F" for fire and the second "S" for spillage (IMO, 2022). If these Codes are marked on the bill of lading, this tells the vessel's cargo officer the need to implement appropriate measures to protect the ship, crew, and other cargo for safe transport (see Figure 4).

Table 5: EmS Code Numbers – IMDG Code.

Fire Schedules		
F	A	General Fire Schedule
F	B	Explosives substances and articles
F	C	Non-flammable gases
F	D	Flammable gases
F	E	Non-water reactive flammable liquids
F	F	Temperature controlled self-reactive and organic peroxides
F	G	Water reactive substances
F	H	Oxidizing Substances with explosive potential
F	I	Radioactive material
F	J	Non-temperature controlled self-reactive and organic peroxides
Spillage Schedules		
S	A	Toxic substances
S	B	Corrosive substances
S	C	Flammable, corrosive liquids
S	D	Flammable liquids
S	E	Flammable liquids, floating on water
S	F	Water soluble marine pollutants
S	G	Flammable solids and self-reactive substances
S	H	Flammable solids (molten material)
S	I	Flammable solids (repacking possible)
S	J	Wetted Explosives and certain self-heating substances
S	K	Temperature controlled self-reactive substances
S	L	Spontaneously combustible, water-reactive material
S	M	Hazard of spontaneous ignition
S	N	Substances reacting vigorously with water
S	O	Substances dangerous when wet (non-collectable articles)
S	P	Substances dangerous when wet (collectable articles)
S	Q	Oxidizing Substances
S	R	Organic substances
S	S	Dangerous goods with biohazard
S	T	Gases (flammable, toxic or corrosive)
S	U	Oxidizing gases
S	V	Explosive items and articles
S	W	Explosive chemicals
S	X	Toxic explosives

Source: Kallada (2020)

4.8.2 Between november 2013 and december 2019

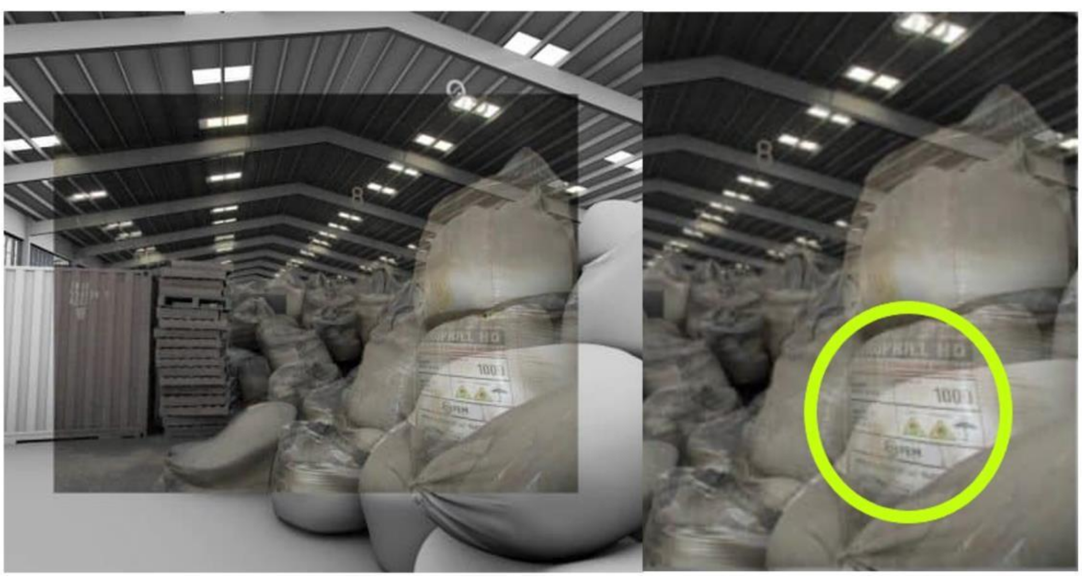
When the Lebanese authorities detained the ship, most of the Rhosus's crew disembarked, except for the Captain, Chief Engineer, 3rd Engineer, and Boatswain. Unfortunately, despite repeated attempts to establish contact and terms with the vessel owners and cargo charterers, it was apparent the shipowner had abandoned the crew (Belford et al., 2021) as food and provisions became scarce. Fortunately, Lebanese port authority officers (CBC News, 2021) were the saving grace providing food and water to the remaining crew to help them get by until they were permitted to leave by the court in 2014 (Belford et al., 2021). However, the Captain, now restricted to his rusting, leaking ship without money to effect repairs or pay for provisions for the remaining crew, was forced to develop an alternative plan. Since the only item of value left on board was the remaining fuel, he organised for the fuel to be transferred from the ship's tanks into a tanker dockside to provide cash flow for legal expenses (BBC News, 2020).

The remaining crew would spend the next 11-month in a legal battle with the Lebanese courts seeking approval to disembark and be repatriated home on compassionate grounds (CBC News, 2021). Moreover, in the application to the Lebanese courts, the crew's lawyer stated: "the imminent danger the crew was facing given the dangerous nature of the cargo" (CBC News, 2021). This "imminent danger" statement, if taken seriously by port authorities and correct dangerous goods practices been implemented, could have averted the disaster six years later. This was also articulated by the Captain to Beirut port authorities in official correspondence detailing the dangerous nature of the cargo in January 2014 (Human Rights Watch, 2021). According to journalist Nakhoul (2020) reporting on the initial investigations in 2020 “owing to the risks associated with retaining the Ammonium Nitrate on board the vessel, the port authorities discharged the cargo onto the port’s warehouses”. In repeated correspondence during 2014, leading up to removing the ammonium nitrate from the MV Rhosus into hanger 12, numerous references are made to the dangerous nature of the cargo and its risk to the port if the ship was to sink or explode (Human Rights Watch, 2021). Nevertheless, despite the alarming number of times this was mentioned within multiple government communications, in-action continued to prevail.

Between November 2013 to December 2019, Human Rights Watch (2021) revealed that 90 items of correspondence were exchanged between 18 separate offices and organisations. The following obtained from Human Rights Watch (2021) details correspondence exchanges included the National Trading and Shipping Agency (MV Rhosus’s maritime agent), the Directorate of Land and Maritime Transport, Anti-Narcotics and Money Laundering Section (within Customs Administration), Customs Anti-Smuggling Service, Beirut Fire Brigade, General Directorate of Customs, Customs Manifest Department, Beirut Harbour Master, Maritime Transport Service, Ministry of Public Works and Transport, Directorate General of Land and Maritime Transport, Baroudi and Associates Law firm, Case Authority’s lawyer, General Security’s office at Beirut’s Port, Director of Political and Consular Affairs at the Ministry of Foreign Affairs, Ukrainian embassy, and the Judge of Urgent matters (Human Rights Watch, 2021). Clearly, this indicates a dysfunctional process within the Lebanese government with systematic, bureaucratic failures. The ship and cargo remained in port pending auctioning or disposal (Human Rights Watch, 2021). After the Lebanese court ruled, the crew could return home, with the ship officially handed into the care of the Lebanese government (Human Rights Watch, 2021). The cargo was offloaded on October 23 and 24, 2014, and stored in Hanger 12, which remained until the disaster on 4 August 2020.

Given the condition of the warehouse when the ammonium nitrate was moved in, its continual deterioration, and the added dangers of the fireworks and tyres, one must ask the question. Who was the port officer responsible for dangerous goods storage in Beirut Port, and why were these items not stored under the international best practice standards? Figures 11 and 12 below clearly show the layout of the reconstructed warehouse ammonium nitrate, fireworks, and tyres from photos obtained after the blast from port workers. The second image shows international best practices comparing British and Australian standards for the correct storage of ammonium nitrate (Forensic-Architecture, 2021).

Figure 11: Reconstructed Hanger 12 Layout



Source: Forensic-Architecture (2020)

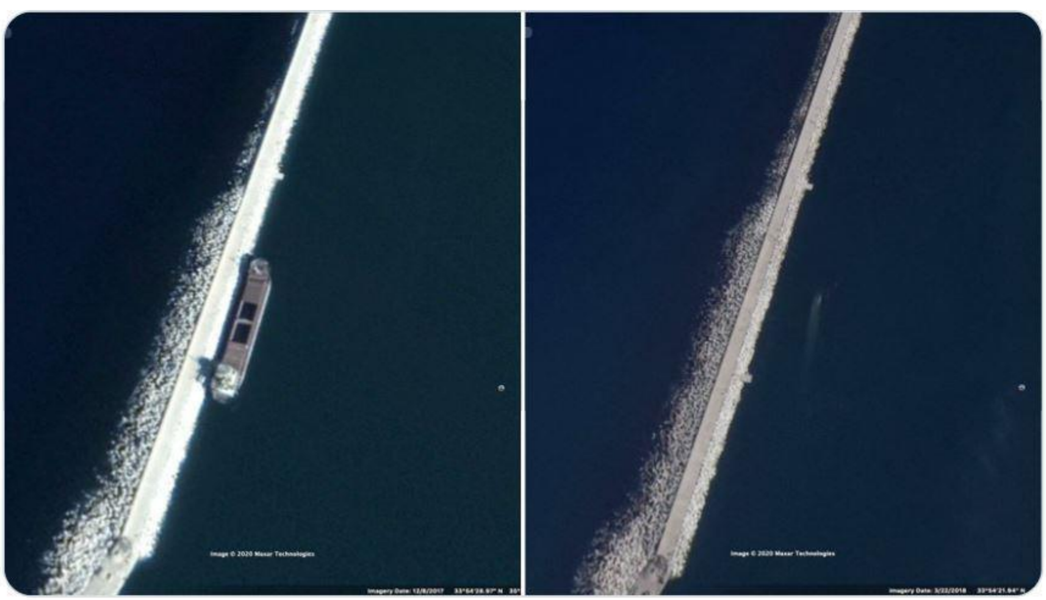
Figure 12: Incorrect Hanger 12 Layout of Ammonium Nitrate in Beirut v British and Australian Dangerous Goods Standards.

Source: Forensic-Architecture (2020)

Port officials recognised the dangers of ammonium nitrate. The then-director of Lebanese customs Shafik Merhi sent several letters warning of the risks of keeping the material at the Port. However, research has demonstrated that he never received a reply (Belford et al., 2021) from the Lebanese government. Between 2015-2016 it is believed that up to 15 separate items of correspondence were sent between port authority officials and the Lebanese government to have the cargo moved or disposed (Belford et al., 2021; Human Rights Watch, 2021). These unfavourable storage conditions, as witnessed in Beirut, would result in a series of fires and subsequent explosions leading to the devastating of the port and surrounding downtown city area, which will be discussed further within this paper.

Captain Prokoshev also stated that “the ship had a hole in the hull” (CBC News, 2021) close to the wind waterline, which required regular pumping out by the crew to maintain the vessel’s stability. After the crew was repatriated home, the Lebanese government towed the ship to an outer Harbour mooring. Subsequently, with no duty crew onboard to monitor the slow ingress of water, the vessel gradually took on seawater, sinking at her mooring sometime in February 2018. However, the Lebanese government did not re-float or salvage her despite sinking and being a navigational danger to other ships (see Figures 13 and 14). This highlights an embedded poor safety culture within the shipping organisation starting from the ship owner down to the frontline crew responsible for the day-to-day running of the ship.

Figure 13: MV Rhosus (left) at Mooring at the Outer Beirut Harbour in 2014 After the Cargo of Ammonium Nitrate was Removed and (right) after sinking at her mooring in 2018.



Source: Koettl (2021)

Figure 14: MV Rhosus Sunk at Her Mooring Lying on her Starboard Side.

Source: Koettl (2021)

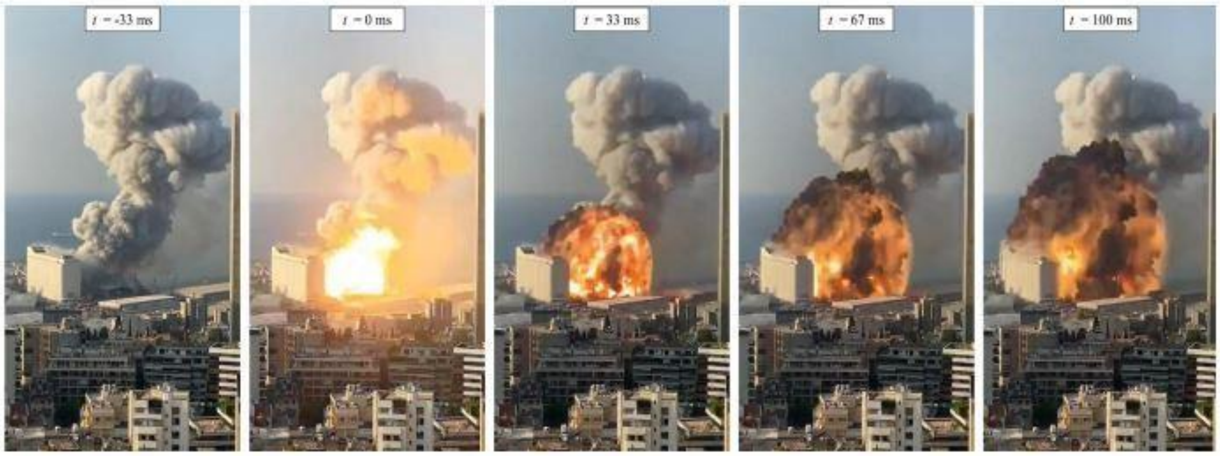
Again, correspondence was sent back and forth by port and government officials from 2018 until the final correspondence was sent to the office of the Prime Minister on 22 July 2020 (Human Rights Watch, 2021). While a decision was made to re-float the ship for sale, the funds required for the work were not made available for the appointed expert to assess the vessel or cargo in Hanger 12 before he commenced the work (Human Rights Watch, 2021). In December 2019, other letters were submitted to several Lebanese Government departments (Human Rights Watch, 2021). However, astonishingly, the systematic inaction of Lebanese Government officials once again led to the incident being unresolved.

4.8.3 August 2020

In January 2020, a judge commenced investigating reported damage sustained by Hanger 12 where the ammonium nitrate was stored. An access door was broken, with a large hole in the structure's southern wall. On 4 June, state security ordered port authority welders to fix the door and hole in the wall. State security also ordered physical security guards to protect the warehouse's contents because of the dangerous nature of the ammonium nitrate until repairs could be completed (Samia Nakhoul, 2021).

On 7 February, the government-appointed second expert commenced an assessment of the ammonium nitrate in Hanger 12. However, the expert did not complete the report, reportedly because he was unable to perform an evaluation without a list of the materials he was due to inspect (Human Rights Watch, 2021). In August, Syrian workers were directed to complete repairs. As welding was conducted, sparks started a fire, igniting the combustible materials stored in the warehouse. The fireworks (first explosion) created enough heat to ignite the remaining contents of the warehouse, eventually causing the ammonium nitrate to explode (second explosion). Evidence suggests the welding work was not adequately supervised, with no welding screens or blankets to protect from sparks or fire extinguishing equipment readily available as a safety precaution—standard practice for hot works especially given the dangerous nature of the warehouse contents (Fakih et al., 2021). At the time of the explosion, the MV Rhosus was lying on her starboard side, already submerged on the bottom of the harbour.

Figure 15: Beirut Explosion Images Taken from Video Footage.



Source: Rigby et al. (2020)

Many people will have heard “a picture is worth a thousand words”. This could not be truer in the MV Rhosus and the Beirut disaster case. Careful frame-by-frame analysis of the blast has informed investigators of the location of the ammonium nitrate, the sequence it burned, how it burned, what the other items that were located in the warehouse, how these items influenced the fire and subsequent blast and the blast radius extent.

Research conducted by Forensic Architecture (FA) based at the University of London has undertaken extensive blast analysis of the explosion. After careful analysis and recreation using digital modelling, spatial and architectural analysis, interviews, academic collaboration, immersive technologies, and cross-referencing, FA determined the arrangement of all dangerous goods within the warehouse. Before the explosion, the thick black smoke visible in the blast imagery was found to be 1000 tyres and twenty-three tonnes of fireworks, also located within warehouse (Forensic-Architecture, 2021). Moreover, FA at Goldsmiths determined the sequence of events on the day of the incident using various open-source materials, including documents, photos, videos, geo-locating, and 3-D modelling. As the fire and heat source evolved, the fire behaviour displayed a distinctive series of smoke plumes and smoke colour changes, providing insight into the materials' behaviour as it burned within the warehouse (Forensic-Architecture, 2021).

The events' sequence leading to the blast was determined in a collaboration between Collett, (2021) and Forensic-Architecture, (2020):

1740: The first smoke plume was detected in the northeast corner of the warehouse. Smoke was also visible from windows and roof vents (Collett, 2021; Forensic-Architecture, 2020).

1754: The fire brigade arrives four minutes after receiving the call, hearing fireworks exploding within the warehouse. The smoke plume changes direction with its colour becoming darker, indicating the fire evolving and heat source expanding (Collett, 2021; Forensic-Architecture, 2020).

1807: a second smoke plume was detected, followed by more explosions in the northeast corner, indicating the heat source and fire further evolving as the fireworks continued to explode outside the warehouse now (Collett, 2021; Forensic-Architecture, 2020).

1808: a sizeable spherical plume was observed in the northwest corner (Collett, 2021; Forensic-Architecture, 2020).

1808: the most significant detonation occurred, located centrally within the warehouse, demonstrating a single point detonation of an estimated half the 2750 sacks of ammonium nitrate (Collett, 2021; Forensic-Architecture, 2021).

Within 9 seconds, a significant red and black plume reaching 755m above the warehouse appeared (see Figure 9). The blast was “equal to the hourly energy generated by three million solar panels or 400 wind turbines” (Sheffield, 2021). A recent assessment by engineers from the University of Sheffield determined that “the explosion was the equivalent of between 500-1100 tonnes of TNT, equating to 1/20th the size of the bomb used on Hiroshima” in 1945, making it one of the biggest non-nuclear blasts on record (Sheffield, 2021).

The storage of dangerous goods, whether HAZMAT/HAZCHEM or a combination of both near dense, populated areas, is unfortunately not isolated. In Beirut, the risks were compounded by the port facilities' hazardous materials/hazardous chemicals management and non-compliant storage in warehouse 12 (Human Rights Watch, 2021). This was further complicated by the dense urban areas and the vibrant downtown area of the city, all too close to the port (Mehan & Jansen, 2020) at the time of the explosion.

4.9. Implications of the accident

The following paragraphs discuss the implications of the accident from the flag of convenience, economic, safety and environmental perspectives and lessons learned.

4.9.1 Flags of convenience

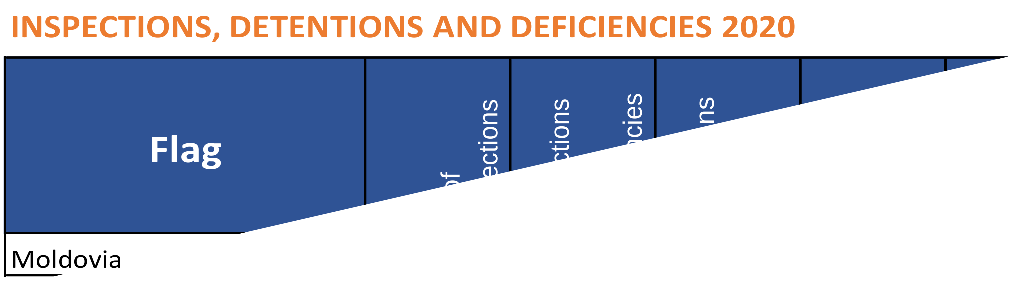
Ships, similarly, to individuals, are linked to a nation; while an individual has a passport, a vessel is identified by its flag (Coles & Watt, 2009). Once registered to that flag nation, the vessel takes on the regulations and protections of that nation. Flags of convenience date back centuries when Spain dominated the West Indies trade routes, and English ships would adopt the Spanish flag for market access (Thuong, 1987). Flags of convenience, ITF Global (2021) claims that when 'a ship sails under a flag of convenience, it means it is operated or taxed under the laws of a country in order to save money'.

Often, shipping companies use a flag of convenience to maintain anonymity and evade safety, environmental shipping safety standards, and high labour costs (The Senate, 2017). Or, as the International Transport Workers Federation argues, "where beneficial ownership and control of a vessel is found to lie elsewhere than in the country of the flag the vessel is flying, the vessel is considered as sailing under a flag of convenience" (ITF, 1947). The various companies owned by Charalambos Manoli, Teto Shipping, a company registered in the Marshall Islands, Briarwood Corporation, the company in Panama, which chartered the MV Rhosus and Maritime Lloyd also owned which issued the certificate of seaworthiness (Belford et al., 2021) all operated under cover of a flag of convenience. The reasons for adopting another nation's flag remain the same: quite simply, money.

In contrast to the past, today's ship owners operate under a complicated sphere of international requirements and operating variables. The global economy dominates the modern shipping market. As worldwide commerce expands at a rate more than double that of the general world economic growth rate (Van Fossen, 2016), the flag of convenience will continue to dominate the global maritime trade markets (Dicken, 2015).

Within the shipping industry, it is not uncommon for ships to be sold several times during their lives and be linked to different flags of convenience. In the case of the MV Rhosus, the ship changed ownership seven times once the Rhosus was built in 1986. During this period, the ship flew the Japanese flag on three occasions, South Korea once, Belize once, Panamanian once, Georgian once, and finally, the Moldovian flag leading into the Beirut disaster. The MV Rhosus, original owners, named the ship Daifuku Maru No. 8 and owned the vessel for 16 years.

Table 6: Paris MoU Inspections, Detentions and Deficiencies 2020



Source: Paris Memorandum of Understanding on Port State Control (Paris MoU, 2020)

4.9.2 Maritime Safety

The disaster devastated Beirut's port and downtown area, highlighting the latent dangers of incorrectly storing dangerous goods in the port environment. Not only did the blast destroy significant infrastructure and the port's primary grain silos, but it also sparked fears of food shortages in a nation that imports nearly all its food which was already reeling from a crippling economic crisis (Mehan & Jansen, 2020). Furthermore, the storage of additional dangerous goods (fireworks, tires) close to the ammonium nitrate with the reported deterioration of ammonium nitrate storage bags and visibly discoursed crystals (Forensic-Architecture, 2021) suggests negligent professional conduct by those who issued orders to move and store the cargo without ensuring stringent IMDG Code regulations were in place and followed.

The analysis carried out indicates several contributing factors. First, a risk assessment on the condition of the ammonium nitrate should have been conducted by a competent authority, with that assessment then being used to determine the appropriate handling and storage location for the materials before they were moved off the ship. Second, the ammonium nitrate should not have been stored in warehouse 12 under any circumstances. The cargo should have been allocated to a dangerous goods area within the port or given the close proximity to Beirut, a location off-site remote from the Port with this area known to all port employees and emergency service personnel. Third, the Lebanese government should have followed prescribed International Maritime Dangerous Goods (IMDG) Code regulations which clearly outline appropriate handling, storage, and management of cargos such as ammonium nitrate and fireworks. Fourth, the implementation of an established IMDG Code system could have prevented the ammonium nitrate, fireworks, and tyres from being stored together, let alone allowing hot works to have occurred in the immediate vicinity of these dangerous cargos without a permit to work system in place to manage the risk of fire. Finally, the competent authority should have implemented a risk assessment framework by adapting the current IMO formal risk assessment to address identified gaps in maritime dangerous goods transport.

Governments and regulatory agencies must adopt a site-specific systematic approach to port safety management to ensure IMDG Code guidelines are adopted, implemented, and audited to ensure ongoing compliance with the Code. Particular attention to the systematic implementation of emergency management procedures encompassing site-specific oceanographic, meteorological and environmental elements to ensure a comprehensive risk analysis to restrict the spread of environmental pollutants (Ernst et al., 2015).

4.9.3 Safety leadership, management and training

The International Maritime Organisation (IMO, 2014) defines leadership as" a process where one group of individuals is influenced by an individual trying to achieve a common goal". However, Wu (2008) defines safety leadership as "the influence on followers to achieve organisational safety goals under the circumstances of organisational and individual factors". Therefore, it is reasonable to conclude that for someone to be an effective leader, they need the support of their subordinates (followers) to achieve the desired goal.

Leadership in the maritime environment is different than in the land-based environment. Apart from the obvious sea/land aspect. Ships spend long periods at sea away from family and friends, exposed to a mirid of hazards, (Hasanspahić et al., 2021) with limited access to external support or emergency services. Captains or Masters have and continue to this day to wield significant authority in this domain due to the ongoing unique environment they operate within. With this authority comes a serious responsibility for the safety of life at sea for those onboard the vessel. Unlike the land environment, the maritime environment places workers together in a confined vessel to do repetitive work for long periods without stepping ashore. While onboard workers are expected to work as a team, the ship is therefore separated into different departments to facilitate workflow; for example, the deck (bridge and decks), engine (mechanical and electrical) and galley departments (catering and accommodation) (Hasanspahić et al., 2021).

Each department within the ship has a team of officers and ratings with an officer in charge of the day-to-day running of the department reporting to their senior officer. The Captain or Master is the most senior officer onboard and has overall responsibility for the ship, its crew and onboard cargo.

Research by Sánchez-Beaskoetxea et al. (2021) determined that almost 80% of maritime accidents are based on human factors and the human element of various activities onboard ships. This statement alone indicates the importance of safety leadership within the maritime environment, especially taking into consideration the increasing number of ships transporting cargo across the world. This research raises several important questions. Namely, is human behaviour alone examined or should the understanding of the decision making which leads to the human behaviour be examined. Or should both be considered as outputs of the human system as a whole?

Captain Prokoshev joined the MV Rhosus in 2013, the exact condition of the ship at that time is unknown. However, what we do know from photographic evidence showing the corroded condition of the ship's upper decks and reported of deficiencies during port state inspections in Spain and Lebanon along with the ships age it is reasonable to determine the general seaworthy condition of the ship was likely not at a level which a classification society would grant a certificate of survey. This is especially noteworthy given the knowledge that in early June 2013 a company called Maritime Lloyd, a non-International Association of Classification Societies member (IACS), issued a certificate of seaworthiness for the MV Rhosus to enable lodging the ship's registration with the Flag State Republic of Moldovia Naval Agency (Belford et al., 2021). Maritime Lloyd, a ship management company based in Cyprus, owned by Charalambos Manoli, the ship's owner. The fact that the ship owner has used deception to issue a false certificate of seaworthiness to a flag state which at that time did not have any mechanism in place to physically inspect any vessel on its register indicates the ship wasn't suitable for inspection by a recognised International Association of Classification Society Member.

As detailed within, this incident has many contributing factors. However, one which has not drawn much attention was the safety culture onboard the ship leading up to the incident and the safety leadership of the Captain Boris Prokoshev.

While significant attention has been allocated to the ship owner, deceptive certificate of seaworthiness, flag of convenience used to avoid increased costs of maintaining international safety standards and crew labor costs, this research highlights the importance of safety leadership training and its influence on organisational safety culture on the outcome of the incident.

Why did the Captain feel it was acceptable to sail on a ship which was not potentially seaworthy, why did he not protest to the ship owner, or did he and why did he not show better safety leadership to the crew knowing the current state of the vessel prior to the ammonium nitrate being loaded in Batumi Port. Finally, knowing the potential implications of the cargo when he entered the Port of Beirut and the questionable reasons for the ships entry into the Port knowing the likely outcome of a Port State Inspection onboard the ship?

Unfortunately, despite attempts to reach the Captain to comment on these questions the author was unable to determine factual answers. Perhaps we will never know the actual answer to these questions. However, it is reasonable to determine the general state of safety culture within the ranks of senior Ukrainian merchant officers with regards to the leadership and safety training received via analysis of research conducted by the Ukrainian, Odessa National Maritime University in 2022.

In this recent research by the Ukrainian University between 2018 and 2020, 918 seafarers completed questionnaires focusing on the human factor element of accidents involving ships of the world fleet with interest in ships maintenance work or any decision taken, which could lead to failure due to the lack of leadership (Bychokovsky & Melnyk 2022).

The MV Rhosus incident is highly relevant to this research. The Odessa National Maritime University determined that they could not expect proper implementation of IMO Regulation A. Resolution A.947(23), adopted on 27 November, 2003, ‘Human Element, Vision, Principles and Goals (for the Organisation which also includes environment, maritime safety and leadership without assistance of crewmembers, which are duly prepared, educated, trained, responsible, willing to grow-increase safety onboard a ship to the highest standards (Bychokovsky & Melnyk 2022).

Respondents were asked questions about leadership styles. When asked “What do you know about inclusive leadership?” None of the respondents of any age group were able to answer the question indicating that none of the 918 seafarers had knowledge of this leadership type.

This is a disappointing finding given the Odessa National Maritime University, identified inclusive leadership as a leadership style which suites the marine industry best (Bychokovsky & Melnyk 2022) within the same research, making special reference to the Deloitte six signature traits of inclusive leadership (Dillon et al., 2016).

Key results (below) indicate that a serious gap in leadership training exists within the Ukrainian maritime training framework which would have contributed towards the state of organisational safety, state of mind and subsequent leadership of the Captain and leadership actions onboard the MV Rhosus in the lead up to the ship entering Beirut. While these are important findings it is important to also note that organisational safety culture human factors and leadership are several of many factors which influenced this disaster.

Table 7: Odessa National Maritime University Research 2018-2022 findings.

Source: Adapted from Bychkovsky and Melnyk (2022)

Table 8: Odessa National Maritime University Research 2018-2022 findings. Composition of respondents.

<table>
<tr><th>Sequence No.</th><th>Age of Respondents</th><th>% of TTL Qty</th><th>Experience at Sea in Years</th><th>Rank</th><th>% of Respondents</th></tr>
<tr><td rowspan="4">1</td><td rowspan="4">20 to 30</td><td rowspan="4">71</td><td rowspan="2">0 to 5</td><td>Rating</td><td>39</td></tr>
<tr><td>Officer</td><td>7</td></tr>
<tr><td rowspan="2">5 to 10</td><td>Rating</td><td>25</td></tr>
<tr><td>Officer</td><td>29</td></tr>
<tr><td rowspan="4">2</td><td rowspan="4">30 to 50</td><td rowspan="4">24</td><td rowspan="2">10 to 20</td><td>Rating</td><td>27</td></tr>
<tr><td>Officer</td><td>44</td></tr>
<tr><td rowspan="2">Over 20</td><td>Rating</td><td>Nil</td></tr>
<tr><td>Officer</td><td>29</td></tr>
<tr><td rowspan="4">3</td><td rowspan="4">Over 50</td><td rowspan="4">5</td><td rowspan="2">10 to 20</td><td>Rating</td><td>Nil</td></tr>
<tr><td>Officer</td><td>Nil</td></tr>
<tr><td rowspan="2">Over 20</td><td>Rating</td><td>Nil</td></tr>
<tr><td>Officer</td><td>100</td></tr>
</table>

Source: Adapted from Bychkovsky and Melnyk (2022)

It is clear from this research that older officers and ratings within the Ukrainian maritime sector have not been educated in effective safety leadership principles despite Ukraine adopting the IMO Manila amendments in 2010 when they became a signatory to the International Maritime Organisation and subsequent international convention on standards of training, certification and watchkeeping (STCW-78), as amended which includes leadership training. It is, however, clear from the research by (Bychokovsky & Melnyk 2022) that changes have been made to the current training curriculum to new entrants to the maritime industry with required training now being delivered in line with IMO requirements.

Unfortunately, it appears that refresher training for older existing maritime officers and ratings is not currently in place and therefore these senior officers and ratings who are responsible for the management of ships, crews and cargos who are in positions of authority over the younger entrants into the maritime industry have not received this important training. The question must be asked. How does the Ukrainian Inspectorate for Training and Certification of Seafarers expect safety leadership training to improve the safety of Ukrainian ships if the very officers commanding these ships have not received such training and education themselves. Senior officers are operating without key knowledge which could significantly impact the safety outcomes of their ships, crews and cargo. This is the very reason why the IMO introduced such important changes to the convention on standard of training, certification and watchkeeping (STCW-78), as amended.

Is it therefore possible to determine that if Captain Prokoshev had received mandated training in line with IMO regulations his leadership leading up to and during this devastating chain of events may have been different, would it have been enough to provide the training and knowledge for him to ensure the safety of his ship, crew, cargo and so avoided the disaster which occurred in Beirut?

Given the limited research that has been carried out on safety leadership with respect to the MV Rhosus incident from a maritime leadership-behavioral-unconscious safety perspective; I therefore, determine that the present case study contributes to the body of the literature considering it draws attention to pertinent issues that improve ship safety management practices.

4.10 Lessons learned

The Beirut disaster highlighted how mismanagement and ineffective, dangerous goods procedures could have devastating effects on human life, government infrastructure, health care, and the national economy, not to mention domestic and extended international supply chains. As a result, considerable time, money, and consultation have been dedicated to developing the IMDG Code to avoid situations such as the Texas, Tianjin, and Beirut disasters. Unfortunately, however, history continues to repeat itself with devastating similarities and consequences.

An important aspect raised by accidents of this type is the necessity to identify the root causes of shipping and port accidents, particularly the extent to which human factor errors contribute to these accidents. Research has identified human factor error as the predominant element in most maritime accidents (Harrald et al., 1998). It is widely recognised within the human factors and safety professions that human error is universal in the sense that all humans make errors (Harrald et al., 1998). Furthermore, human errors were linked to approximately 80% of marine accidents by Sánchez-Beaskoetxea et al. (2021). However, the studies varied in their meaning of `cause' (Harrald et al., 1998) since researchers can encounter problems when analysing historical human factor incident data. The difference between types of human error can be varied and many. For instance, was an error a wrong decision or poor judgment? Or was the incorrect decision a result of fatigue, insufficient knowledge, or stress (Harrald et al., 1998)? Was this the individual's first voyage? What is their level of experienced and time at sea? Additionally, the education and nationality of the incident investigator can also provide grounds for bias with the quality and usability of the incident data recorded (Harrald et al., 1998).

In the above-discussed implications, there is the opportunity for implementing measures leading to the following improvements at both the management and governance levels.

1. **Restructure of the customs and port management authorities:** to become more functional and collaborative with other Governmental departments.
2. **Establishment of a dedicated Customs Agency:** to manage imports and exports specifically.
3. **Establishment of a dedicated Port Authority:** which has total authority over the management of the Port facility, including transport in and out and all storage areas within the port area.
4. **Establishment of a National Emergency Management Agency**: to oversee multi-governmental department responses to crisis events providing ongoing emergency management training to all government and non-government departments and coordination between National and local government bodies.
5. **Establishment of a National Occupational Health, Safety, and Environmental (OHSE) Agency:** to oversee and regulate OHSE matters within Lebanon. As part of this Agency, a Chemical and Dangerous Goods Institute should be established to oversee and regulate all hazardous materials in Lebanon. Other measures linked to the proposed Agency include establishing a legislated safe work system framework to provide regulation and supportive codes of practice guidelines under which the country can adopt safe work practices under the National OHSE

legislation. Furthermore, the established body would provide internationally accredited training and certification in OHSE such as construction safety, maritime safety, road safety, logistics safety, food safety, environmental safety, occupational hygiene, and hazardous materials / dangerous goods management to appointed inspectors within the OHSE Agency to specialise in road, maritime, and air transport chain of responsibility management in partnership with an internationally recognised body such as the Institute of Occupational Safety Health, in the United Kingdom to ensure consistency in training and the highest standards of education are delivered to address the skills deficiency currently evident from the research.

6. **Establishing Lebanese National chain of responsibility laws**: to ensure the safe transport of goods by heavy vehicles which would integrate with the OHSE framework.
7. **Implementation of effective safety leadership training across the international maritime industry:** I further propose that behavioural safety leadership training be included into IMO mandated courses to close the gap in understanding how safety behaviour can add value to the overall safety management and organisational safety culture of a ships/vessels safety management system.
8. Implement a review and monitoring body to conduct ongoing research into the effectiveness of safety leadership training within the Ukraiian National Maritime University and provide recommendations for its delivery, monitoring and effectiveness.

Finally, as demonstrated in this case study, safety leadership and the understanding of safety behaviours were significant factors in this incident's outcomes. If only by applying James Reasons Swiss Cheese Model (Reason, 1997), it would be adequate to determine that if practical training had been in place, this incident and its ongoing devastating effects could have been avoided.

4.11 Conclusions

This case study has provided an overview and insight into the Beirut port explosion disaster. Another example of a completely avoidable disaster with far-reaching implications. A systematic poor organisational safety culture and safety leadership by the ship owner and ships officers which flowed into flag of convenience and onboard safety failures. Compounded with multiple governmental failures within a chaotic, mismanaged Beirut Port safety management system, this provided a perfect environment for incident causation and human factor error.

Numerous avenues of opportunity were available where positive intervention by the ship owner, the Captain or the Lebanese Government over the preceding seven years could have prevented the explosion in August 2020. However, as has been demonstrated within the research, the ship owner, Ukrainian Government, Captain and Lebanese governments all failed in their duty of care to, including but not limited to:

4.11.1 Ship owner

A ship owner has the following responsibilities:

1) Provide a ship which was fit for purpose and seaworthy under the International Maritime Organisation SOLAS regulations and employment standards for seafarers under the Maritime Labour Convention 2006, as amended.
2) Ensure the safety of the ship by providing adequate maintenance and repair.
3) Not accepting cargo which the ship was not in a seaworthy condition to take.
4) Creating an environment of poor safety culture and safety compliance with International Maritime Organisation standards in preference for financial gain.
5) Giving unlawful instructions to the Master of a vessel for financial gain.

4.11.2 Captain

1) Not upholding his responsibility to not operate the vessel if it is unsafe.
2) Ensure the safety of the vessel, people, marine safety equipment, and the operation of the vessel.
3) Implement and comply with the safety management system and flag state policies for the vessel and its operations.
4) Do not unreasonably place the safety of another person at risk.

4.11.3 Ukrainian government

1) Not implementing adequate IMO Convention on Standards of Training, Certification and Watchkeeping (STCW-78), as amended processes to ensure that

senior Ukrainian officers and ratings would receive mandated training in line with IMO requirements.

2) Not ensuring that senior Ukrainian trained officers and ratings complied with IMO regulations.

3) The Ukrainian Inspectorate for Training and Certification of Seafarers should ensure moving forward that adequate measures are put in place to ensure that all Ukrainian senior officers and ratings receive IMO mandated safety leadership training within a specific timeframe to ensure achievable measurable goals are met for the full implementation of IMO Convention on Standard of Training, Certification and Watchkeeping (STCW-78), as amended.

4.11.4 Lebanese government

1) Establish an appropriate dangerous goods framework to identify, handle, store, transport, and manage dangerous goods in the Port of Beirut.

2) Apply fundamental risk and emergency management procedures to reduce the risk of injury and illness to employees and the public.

3) Establish a port emergency management framework to manage and oversee all dangerous goods management, training, and coordination of all desktop and practical response training for port authority workers and emergency response staff.

4) Address apparent inadequate safety management practices within the port of Beirut to comply with IMO revised recommendations on the safe transport of dangerous goods and related activities in port areas 2007 (Berti, 2022) overseen by a

monitoring program to ensure consistency in its service delivery, such as accredited ISO:9001 Quality Management and ISO:45001 Safety Management System and or ISO:31000 Risk Management System.

To ensure the future safety of Ukrainian seafarer crews, further follow up research is required to monitor the implementation of IMO Convention on Standard of Training, Certification and Watchkeeping (STCW-78), as amended by the Ukrainian Inspectorate for Training and Certification of Seafarers. The current Russian/Ukraine war is stretching Ukraine's already strained resources with Ukrainian ports and seafarers strained and under considerable pressure from the war. Support must be provided to Ukraine to assist it support its seafarers, their ongoing training and future involvement within international best practice governance. Ukraine is a country which is working very hard to better itself, and with the support of the international community we can work together as one to help the Ukraine maritime industry become a strong, well trained, safety leaders within the international maritime community.

Additionally, to improve port safety and the transport of dangerous maritime goods both at sea and ashore, further research is required to conduct a comprehensive shipping dangerous goods analysis review which should include all forms of packaged and bulk form dry, liquid and chemical substances to provide a gap analysis on the currently available research data. This body of research should include the interface between sea and land and how IMO dangerous goods standards can be appropriately interfaced with the port environment. Currently the only document which details the role of port facilities and dangerous goods is Circular 1216, Revised Recommendations on the Safe Transport of Dangerous Cargoes and Related Activities in Port Areas 2007 (Berti, 2022). This document is non-binding, not currently enforceable and requires review as part of the wider global dangerous goods management framework. Furthermore, the IMO in collaboration with the United Nations and flag states need to create a formal framework for the mandatory adoption, implementation, and monitoring of dangerous good standards globally. Until standards are compulsory and loopholes in their interpretation are closed to ensure a clear understanding of their requirements incidents will continue to occur.

Regardless of country, ownership, or registration, seafarers and the general public have the right to demand better regulation and consistency in maritime safety leadership for those at sea and within the port interface to prevent a repeat of this disaster in the future.

Finally, systemic failures will only change if identified risk factors are addressed across the wider industry. This includes the implementation of standardised safety leadership and safety behaviour awareness training in combination with maritime safety management systems and their monitoring. With ongoing training to all levels of the rank structure and robust international collaboration towards flag of convenience reform to create an even playing field where the safety of seafarers becomes a primary concern within the supply chain not just profits. Only then could we see a reduction in maritime incidents and loss of life.

4.3 CASE STUDY TWO - JOURNAL ARTICLE ONE RESULTS AND DISCUSSION

MV Sewol Ferry Disaster South Korea (2014)

A Stamp-Based Casual Analysis of The Korean Sewol Ferry Accident

4.3.1 Background

The MV SEWOL disaster occurred on the morning of 16 April 2014 while the ship was in transit between Incheon and the largest island off the South Korean Peninsula, Jeju Island (Safety4Sea, 2019). A formal investigation revealed that the ship capsized after a sharp alteration of course (Zhang & Wang, 2015) led to water ingress into the ship and the eventual sinking over two and a half hours. Contributing factors impacting the sinking included modifications to the ship's upper superstructure and an overload of cargo (Lee et al., 2016), some of which had not been safely secured to the deck before departure from Incheon (Zhang & Wang, 2015). When the cargo shifted suddenly during the alteration, of course, combined with the ship's higher centre of gravity due to the modifications to accommodate more passengers, the ship passed the point of return. This deadly combination sealed the ship's fate. The terrible high loss of life in this disaster was largely due to the Captain's orders to confine the passengers in their cabins during the obvious sinking of the ship despite knowing that the ship was slowly flooding, she could not be stabalised with the constant ingress of water as the ship continued to heel over and the crew did not have either the skills or ability to effect the course of the situation. Additionally, Chonghaejin Marine failed to provide appropriate training and ensure the vessels safety management system was fit for purpose and the crew inducted in its use (Zhang & Wang, 2015).

On the day of the incident, the ship was carrying 476 passengers, of which a contingent of 325 high-school students on a day trip (Kee et al., 2017), with only 172 passengers and crew rescued (Kwon et al., 2017; Lee et al., 2016).

In the swam of investigations conducted in the aftermath of the disaster by the Korea Maritime Safety Tribunal (KMST) and the Board of Audit and Inspection of Korea (BAIK) resulted in 399 people being charged with various crimes with 154 later criminally convicted and jailed (Kwon, 2017).

This journal article examines the application of Dr. Nacy Leveson Systems-Theoretic Accident Model Process (STAMP) and Casual Analysis based on Systems Theory analysis (CAST). Dr. Nancy Leveson created both systems theories (Leveson, 2017) for application to the marine incident environment, precisely, the MV SEWOL disaster.

Figure 16: MV SEWOL at sea October 2013.

Source: Alamy (2013)

4.3.2 The MV Sewol

The MV SEWOL started life as the ferry Naminoue in 1994 when the Hayashikane Dockyard in Japan built her. She operated without incident for 18 years in Japan before being sold to Chonghaejin Marine Company in Korea (Kwon et al., 2017).

After the purchase, the vessel was renamed MV SEWOL and underwent significant modifications to increase its passenger carrying capacity by an additional 117 passengers. This involved increasing the number of cabins to the ship's third, fourth and fifth decks, the highest decks from sea level (Kwon et al., 2017). This conversely increased the ship's weight by 239 tons, moved her centre of gravity higher, and reduced the cargo she could carry while increasing the amount of ballast water she required to maintain stability (1,703 tons). Notably, the resulting new requirement of additional ballast water to maintain stability was four times the original requirement of ballast water before the modifications (Kwon et al., 2017).

After modification, the Korean Register of Shipping (KR) spent five months putting the ship through a testing and evaluation period before approving the modifications and issuing the ship owner (Chonghaejin Marine) an inspection certificate of seaworthiness (Kwon et al., 2017).

In 2013, Chunghaejin Marine allocated a small portion of its revenue towards safety training sessions, specifically 0.001 %. This minor cost allocation could indicates that the company may have been cutting costs regarding safety measures and employee training. It is evident the company did not prioritise its crew members' well-being and financial security. Three of the five crew members on the MV Sewol, including the Captain, were temporary workers. As is commonly seen in flag of convenience matters, crew receive fewer benefits and job security compared to permanent employees in such situations. Furthermore, the crews salaries were (20 to 30 % less) than other coastal shipping companies crew. This further suggests that Chunghaejin Marine was trying to save costs by employing lower-wage temporary workers (Kee et al., 2017)

Prior to the disaster, it seems the crew of MV Sewol misrepresented records concerning the quantity of cargo and the number of vehicles onboard the ship (Kee et al., 2017). Instead of accurately reporting 2,142 tons of cargo and 185 cars, they reported much lower numbers, including 657 tons of cargo and 150 cars. This inaccurate misreporting of the ship's cargo information, which is crucial for the safe operation of a vessel (Kee et al., 2017), is inexcusable.

Figure 17: MV SEWOL sinking listing to port, 16 April 2014.

Source: What went wrong, the Sewol Ferry Disaster (2019)

The ship's ballast water tanks, used for stabilising the vessel at sea, did not contain the correct amount of ballast in accordance with the ship's stability manual (Kwon et al., 2016). Legally the MV Sewol was required to carry 1,565 tons of ballast water in her ballast tanks. However, on the day of the disaster, the ship only carried 761 tons in her ballast tanks. It is the job of the Chief Officer to ensure the ship is ready in all respects for sea including the cargo is stored and secure and the ship is ballasted correctly to ensure her stability while at sea. This was a serious safety breach by the company and an obvious example of poor safety leadership and safety culture within Chunghaejin Marine (Kwon et al., 2016).

Additionally, it was revealed that crew of the MV Sewol's had allegedly bribed three officers of the Coast Guard to prevent documents being submitted (Kwon et al., 2016). Bribing regulatory officials violates the law and undermines the integrity of maritime safety laws and oversight (Kwon et al., 2016).

To obtain approval for the reconstruction of the MV Sewol from the Korean Register of Shipping, Chunghaejin Marine misrepresented the vessel's actual situation. This included underreporting the “ship's weight as 100 tons lower” (Kwon et al., 2016) than what it actually was while overstating its capacity to carry vehicles. Such blatant misrepresentations can and did have regulatory and safety implications, as accurate ship data reporting is essential for ensuring the safe and competent operation of vessels at sea. These actions demonstrate unethical and illegal behaviour by the MV Sewol and Chunghaejin Marine crew. Such practices can lead to severe consequences, including tragic incidents like the MV Sewol disaster. Regulatory authorities and law enforcement agencies would typically investigate and take legal actions against those involved in such activities to uphold safety standards and the rule of law in the maritime industry (Kwon et al., 2016)

Reporting false information about a ship's weight and capacity for carrying cargo to obtain approval from the Korean Register of Shipping violates regulatory standards and maritime safety protocols. Such misrepresentations can have significant consequences, compromising the vessel's safety and those on board.

It is essential that ship's crew accurately record and report their ship's specifications and capabilities. Incorrect reporting to company or regulatory authorities violates legal and ethical standards while potentially endangering life as did occur in the MV Sewol disaster (Kwon et al., 2016).

4.3.3 Timeline of events - 15 April 2014

Table 9: Timeline of Events 15 April 2014

	Timeline of Events - 15 April 2014
Time	**Comments**
18:30	The SEWOL departure was delayed two and a half hours due to thick fog
20:45	Late vehicles arrived at the dock; the crew still loaded the vehicles.
	KSA approved the ship's departure without physically inspecting c
	stability book. Only the load line was usually inspected. The
	board, departed Incheon for Jeju Island. Three hundre
	Danwon High School students on a field trip. T
21:00	less than half the required 1,703 tons. Th
	cargo, two times the approved leg
	Seok commanded the SEW
	did not sound a safety
	ship in the even
21:30	The SEW th
21	

Source: Quoted from Kwon et al., (2017)

4.3.4 Timeline of events - 16 April 2014

Table 10: Timeline of Events 16 April 2014

Time	Timeline of Events - 16 April 2014 Comments
7:00	The SEWOL passed near Jindo-Island, located on the southern coast of South Korea. Winds were from a south-westerly direction at 2 to 3 knots. Seas ranged from 1 to 2 feet. Visibility was to 20 nautical miles.
7:00	The third mate, Park, Han-Gyeol, Helmsman, Cho, and Joon-Ki, began their scheduled 4-hour morning watch on the bridge.
8:40	While travelling at 18 knots, the SEWOL entered the Maenggol Channel, notorious for its strong underwater currents, located 11 miles away from Jindo Island.
8:47	Helmsman Cho was steering course 135 degrees.
8:48	The third mate gave two orders to the helmsman to alter course, first to 140 degrees and then to 145 degrees. The helmsman heard the mate's orders and made the first turn of five degrees to starboard. Once the ferry heading was 140 degrees, the helmsman again altered the remaining 5 degrees to the ordered course of 145 degrees. However, the ferry was listing to port. Due to the list to port, investigators looked further into how the helmsman made the second turn given the cargo shift.

Source: Source: Quoted from Kwon et al., (2017)

Several potential outcomes could be considered:

1) The helmsman attempted the second alteration to course 145 degrees, but he turned the ferry to 155 degrees from 140 degrees when he was flustered and perceived the turn as inadequate.

2) The helmsman stated at the Gwangju District Court on 11 October 2014 that he turned the ferry to the other direction after hearing the mate's order to restore balance, "turn in the opposite direction." After reviewing this situation carefully, it can be reasonably concluded that he turned to starboard when the helmsman heard "the opposite direction" while turning to port.

08:49: The ferry listed 20 degrees towards the water line, causing unlashed cargo to the deck to shift towards the port (left) side of the ferry. The ship turned 45 degrees to starboard and then rotated 22 degrees for around 20 seconds. The cargo shifting to the port side caused the ship to lose its restoring force, a dynamic element of ship handling. The listing to port and gradual entry of sea water into the hull through the bow and stern doors created further instability.

08:50: The ferry listed 30 degrees to port. The Chief Engineer, Park Ki-Ho, stopped the ship's engines. The Captain who at that time was in his cabin, immediately went to the bridge and ordered the second mate to turn on the anti-heeling pumps to assist the ship to re-right to an upright position. However, the pumps were not working. Why they were not working is unknown.

Table 11: Details the sinking of the MV SEWOL

	Timeline of Events During Event
Time	**Comments**
9:16	The ferry listed 45 degrees to port.
9:34	The ferry listed 53 degrees to port.
9:44	The ferry listed 57 degrees to port.
9:50	The third deck exit was submerged.
9:54	The ferry listed 64 degrees to port. The fourth deck exit was submerged.
10:07	The ferry listed 69 degrees to port.
10:10	The ferry listed 77 degrees to port, and the fifth deck exit was submerged.
10:12	All port side exits of the ferry were submerged.
10:17	The ferry listed 108 degrees to port.
10:31	The bow of the ferry was submerged.
12:57	The SEWOL finally sank completely after water ingress had overcome the ship's ability to remain afloat.

Source: Quoted from Kwon et al., (2017)

4.3.5 Understanding of STAMP and CAST theories

Systems-Theoretic Accident Model and Processes (STAMP)

The history of accident causation models has existed for over 100 years (Wu et al., 2023). Notable world recognised subject matter expert James Reason's Swiss Cheese and Human Error concepts introduced in 1990, along with Henrich's Domino model that dates back to 1931 (Kwon et al., 2017). Their widespread acceptance and popular use is due to their easy comprehension and seamless applicability across different workplace environments. These theoretical models focus on the analysis of failure event timelines leading to the incident or event. However, in the MV SEWOL disaster incident analysis, a more detailed model was needed to conduct a detailed investigation of the social and technical factors along with the multifaceted contributing factors of the disaster.

Living and working within the maritime environment onboard a ship within its dynamic high-risk operations and complex structures Bielic and Čulin (2017) is stressful. A ship can be viewed as a highly complex social and technical system, appropriate given the ship's organisational rank structure. Yang et al. (2017) further stated that aircraft and nuclear power mishaps were mainly due to emergent properties of socio-technical systems. This same theory can be applied in maritime, given the recognised understanding within the safety profession that safety is an emergent property (Kwon et al., 2017), ever-evolving, with no single system component in isolation. It is, therefore, vital to ensure we view the ship environment system as one with a management hierarchy or rank structure. This hierarchy or levels of management ensures that the systems enforced by the higher levels of management controls or constraints (Kwon et al., 2017) or the lack of such constraints can impact lower levels and their outcomes on the lower levels of the system.

In her book Engineering a Safer World: Systems Thinking Applied to Safety, Dr Leveson (2017) discusses the concepts of systems theory and cognitive models. Additionally, she discusses how traditional approaches and models are not adequately able to manage the complexity of the socio-technical system analysis required in a maritime incident investigation (Leveson, 2017).

In the maritime incident environment, it is almost unavoidable to have one or more human factor elements in the causation chain. With the MV SEWOL incident, both socio-technical and human factors were prominently featured in the subsequent investigations.

Leveson (2017), In Systems-Theoretic Accident Model and Processes (STAMP) discussed several vital elements of incident causation. Leveson (2017) further discussed STAMP as beneficial to prevent future failures while reinforcing positive behavioural safety. This methodology was applied to the maritime investigation in the MV SEWOL incident with the following benefits.

(a) Consideration of factors external to human factors and individual components.

(b) Evaluation of system design failures and ineffective system interactions.

(c) Analysis of human behaviour factor elements including how human behaviours, impact decision making.

(d) Ensuring investigation outcomes are focused on understanding contributing factors with the goal of preventing further reoccurrence.

Leveson (2017) identified three main STAMP concepts applicable to the maritime environment: safety constraints, hierarchical control structures and process models (Kwon et al., 2017). These concepts intersect with safety being a property that emerges. The properties of emergence, hierarchy, communication and control (Kwon et al., 2017) were identified by Leveson (2017) as core pilars of STAMP.

4.3.6 Casual analysis based on systems theory

Using casual analysis based on systems theory can provide a structured model for investigators or researchers to approach an incident. This approach helps to identify the most prevalent human factors and other additional elements involved in the incident or event. The primary benefit of using the CAST approach is it removes the bias of blame (Kwon et al., 2017) while reinforcing focus on elements responsible or contributing to why the incident or event occurred in a holistic, ingetrative, systematic approach. The CAST system uses a nine step process to evaluate the incident or event in question (Leveson, 2017). Additionally, Leveson, (2017) further identified the following nine steps:

(a) Identify the contributing system hazards.

(b) Identify any system safety constraints or requirements.

(c) Document a detailed risk management to identify hazards.

(d) Identify the chain of events leading to the event.

(e) Analyse the event and determine why controls were ineffective.

(f) Determine how and why the safety control structure contributed to the event, including human behavioural decisions and their motivations.

(g) Communications and coordination of the event.

(h) Safety control system dynamics and any decrease in the effectiveness of such.

(i) Develop recommendations for improvement.

4.3.7 Summary of the MV Sewol disaster

The official Korean Government investigations and subsequent academic literature have well documented the following information.

On the 16th of April 2014, the ship MV SEWOL capsized and sank during a regular passenger voyage between Incheon and Ji Ju Island, overloaded with cargo (Kim et al., 2016). The sinking and loss of the ship led to a significant loss of life, most of whom were young high-school students (Kee et al., 2017; Kim et al., 2021; Kwon et al., 2017). When the incident occurred, the ship was under the command of an inexperienced third officer on the bridge. The Captain was not located on the bridge to supervise the third officer as the vessel entered the dangerous Maenggol Channel (Kim et al., 2016) travelling at 18.9 knots (Kim et al., 2016).

Chonghaejin Marine, the ship owner encouraged the crew of the SEWOL to load additional cargo indicating a poor organisational safety culture onboard the ship. Subsequently, there was not have enough safety equipment to lash the cargo down to the deck properly. The following safety inspection by the Korea Shipping Association was not completed in accordance with approved guidelines, resulting in the ship being overloaded and the unsafe storage of cargo in the hold and on deck not being identified (Kwon et al., 2017) prior to the ship sailing. Additionally, it was identified that the crew responsible for supervising the loading and stowage of cargo onboard had not completed training in this vitally important task (Kwon et al., 2017).

The ships ballast water requirements designed to ensure the vessel's stability, were neither adhered to nor verified by the Chief Officer prior to departure. Incident investigators established that officers from the Korea Shipping Association only visually checked the load line on the ships exterior hull. The ship's ballast log located on the bridge was not inspected (Kwon et al., 2017).

At the waypoint position where the ship was required to alter course, the third officer issued orders to alter course to starboard from 135 degrees to 145 degrees. In contrast, this alteration of 10 degrees does not sound significant. The third officer did not have the situational awareness or experience when making this course alteration to consider the important factors of the ship's speed, engineering and structural configuration, overloaded and unsecure cargo, and reduced ballast, combined with the strong and, at times, fast underwater currents (Kwon et al., 2016) present in that area. Subsequently he did not know he was putting the vessel in an unsafe situation.

The contributing factors of speed (18.9 knots), underwater currents and large rudder angle inputs by the helmsman resulted in a dangerous heeling of the ship (15 to 20 degrees) (Kwon et al., 2016; Kim et al., 2016) to port. This sudden movement caused the unlashed cargo to shift causing the ship's centre of gravity to shift. This resulted in water ingress through the ship's starboard side hatch and the stern cargo door at the stern (Kwon et al., 2016; Kim et al., 2016).

With the creasing water ingress, the ship continued to list to port, increasingly unable to right herself. Attempts by the Captain to counter the ship's list and pump water from the vessel failed. Progressive water ingress continued unabated causing the ships superstructure to slowly take on more water.

During this time, the Captain continued to inform passengers that they needed to remain in their cabins. This was a consistent deviation from basic emergency management and the ships evacuation procedures. The delay to launch the ships 44 lifeboats and evacuate as many passengers as possible contributed to the significant loss of life. The Captain took no further action to evacuate the passengers other than ordering them to place personal floatation devices on (PFDs) (Kwon et al., 2017). Sadly, this order from the Captain would not have helped them as their cabins began to flood the seawater would have forced the passengers to the top bulkhead (roof) of their cabins until they slowly drowned, unable to breath or escape.

Distress calls from the ship's crew on the bridge and distressed passengers onboard were inappropriately managed vessel traffic operators and the Korean Coast Guard who failed to dispatch a vessel upon hearing of the tragedy. Once the Coast Guard did arrive on scene, they failed to take immediate action to enforce command and control over the rescue and attempt to rescue trapped passenger. More was done by fishermen who responded to calls for help than the Coast Guard in the initial chaotic stages of the Coast Guard response (Kwon et al., 2017. The Korean Maritime Safety Tribunal concluded that a significant deficiency in the implementation of training Coast Guard crews in search and rescue and the monitoring of training standards was responsible (Kwon et al., 2017).

Table 12: Unsafe Antecedents contributing to sinking of MV Sewol.

Source: Quoted from Zhang and Wang (2015)

Table 13: Captain's role in the incident causation of the MV SEWOL sinking.

Source: Adapted from Kwon et al., (2016)

Communications between ship and shore were not consistent, nor did they relay important situational emergency information critical to the response of relevant agencies. Upon detailed investigation (Kwon et al., 2017; Kim et al., 2016), it was determined that:

1) Korea Shipping Association certified the MV SEWOL with fictitious documents supplied by the ship owner, Chonghaejin Marine.

2) The Korea Shipping Association approved the modifications to the ship without physical review and inspection of the vehicle lashing plans. A total of 58 of the 66 vehicles could not be lashed to the deck.

3) Korea Shipping Association officers should have correctly inspected the vessel before departure. The inspection officer needed the skills to determine if the ship was overloaded.

4) the Korea Shipping Association officer completed the required vessel departure approval paperwork after the ship's departure, which was incorrect. This documentation should be completed prior to departure only if it is safe.

5) The crew should have shared the vessel's actual cargo load data with the Korea Shipping Association officers.

6) Officers had yet to be assigned to check the condition of the cargo. For example, was the cargo secured to the deck in accordance with company procedures?

7) An officer had not been assigned the task of checking that the bow and stern doors were secure and watertight before departure in accordance with company procedures.

8) An officer had not been assigned to submit the Ferry safety inspection chart before departure to the nominated Korea Shipping Association officer for inspection and sign-off before departure.

9) The Captain was not on the bridge at the time of the incident. This officer was also different from the ship's regular Captain, who was on leave during the disaster.

10) The third mate did not have the experience and training to take command of the ship. His orders to change course at speed while overloaded were significant contributing factors.

1) The crew of the MV SEWOL were deficient in emergency training, which was identified as a loophole in Korean Maritime Law and exploited as a cost-saving by the ship owner. Over the past five years, 33 of 489 vessel Captains and senior officers undertook safety training because of this loophole.

12) The Captain evacuated himself and crew members over the passengers.

13) The ship owner should have included two essential elements of the ship's operational requirements of ballast water and total load in its operational regulation standing orders.

4.3.8 Limiting Factors

Significant limiting factors in the development of this journal article review were the inability of the author to obtain a full copy of the official investigation report developed by the Korea Ministry Safety Tribunal (KMST) and the Board of Audit and Inspection of Korea (BAI) into the sinking of the MV SEWOL. Unfortunately, despite repeated attempts to verify the research mentioned in various documents completed by the Korean Government, the details within the official report remain elusive, with copies of the report no longer available. The author used multiple documents to verify statements claimed within referenced material from the official report where possible.

4.3.9 Conclusion

The in-depth analysis of the MV SEWOL disaster using a STAMP-based casual analysis demonstrated that the detailed accident analysis model of STAMP did improve investigation outcomes regarding the social and technical factors given the complexity of the MV SEWOL disaster.

Within the maritime environment and shipboard operations, a unique and dynamic workplace exists with many varying components within its complex structure, Bielic and Čulin (2017) . The STAMP systems-theoretic approach to this highly complex technical system of shipboard operations was appropriate. It produced a comprehensive investigation result, which this paper supports the ongoing use of within the maritime environment.

Additionally, regardless of the International Maritime Organisation (IMO) and individual port state control requirements, accountability starts with the ship owner to provide the governance and safety management systems to support safe shipboard operations. Chunghaejin Marine demonstrated a blatant disregard for regulatory compliance and maritime safety standards in pursuit of increased profit. The company operated outside of regulatory oversight with corrupt involvement from the very institutions in place to prevent illegal, unsafe operations.

Direct and indirect contributing factors, including but not limited to company executives, ship management team and government officials, compromised the safety of the ship, its passengers and crew.

In final analysis, the Korean Register of Shipping and Chunghaejin Marine executives were all legally responsible for the MV SEWOL disaster.

The MV SEWOL, overloaded with cargo and with inadequate extensive modifications, capsized due to a sharp alteration of course, whereby unsecured cargo shifted causing the ship's center of gravity to move, leading to a tragic loss of life. The STAMP analysis highlights how systemic failures, including poor cargo management, inadequate training, and a lack of safety protocols contributed significantly to the disaster. It emphasizes that both the design and operational aspects of the system, along with human decision-making, need to be considered to ensure safety. The case underscores the importance of behavioural-based safety leadership, illustrating that the actions and decisions of individuals at every level of management critically impact overall safety in the high-risk maritime environment. This tragedy serves as a stark reminder of the necessity for rigorous safety standards and proactive safety leadership from the top down in preventing similar incidents in the future.

4.4 CASE STUDY THREE - JOURNAL ARTICLE TWO RESULTS AND DISCUSSION

Holistic Case Study on the Explosion of Ammonium Nitrate in Tianjin Port (2015)

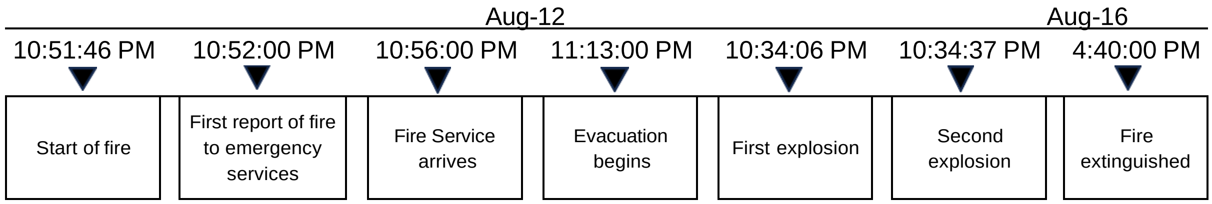
4.4.1 Background

The Tianjin port explosion of 12 August 2015 at the Ruihai International Logistics Co., Ltd (Fu et al., 2016) was a catastrophic disaster that had far-reaching consequences, causing significant loss of life, a multi-casualty nightmare for pre-hospital medical teams and a complicated multifront fire for firefighters with extensive financial and structural damage in the immediate area (Vera-Ruiz, 2020) of the explosion which caused delays to the loading and unloading of cargo ships in the surrounding Tianjin Port (Neame et al., 2015). The resulting flow on effects to supply chains and the maritime industry were significant (Neame et al., 2015). This journal article review will provide an overview of the disaster, its causes, its similarity to the Beirut explosion disaster and the effect organisational safety had on behavioural factors influencing the disaster.

4.4.2 Incident overview

On 12 August 2015, at 22:51:46, a significant explosion occurred at the Northern Chinese Port of Tianjin in Tianjin City, China. The blast happened at a warehouse owned by Ruihai International Logistics Co., Ltd., a large hazardous chemicals storage facility. The initial explosion caused a fire, rapidly spreading throughout the storage area due to the thermal radiation released. The blast resulted in an estimated death toll of 173 people, with injuries to around 798 individuals (Yu et al., 2022). Shockingly, the death toll included 104 firefighters (Guardian News and Media, 2015; Zhang et al., 2015) who rushed to the scene to fight the fire. The financial losses were estimated to be around 6 billion Chinese Yuan (Fu et al., 2016), making it one of the most expensive chemical incidents in Chinese history.

Figure 18: Incident timeline.



Source: Fu et al. (2016)

4.4.3 Causes

The primary cause of the initial explosion was attributed to the autocatalytic decomposition of the chemical nitrocellulose which led to the first fire (Fu & Wang, 2016). Additionally, the second catastrophic explosion resulted from the detonation of a substantial amount of TNT, (Fu et al., 2016). An estimated 430 tons of TNT was involved in the second explosion (Fu et al., 2016).

Interestingly, the blast in Tianjin in 2015 (800 tons) was less than a quarter of the Beirut explosion (2750 tons) in 2020 (Wang et al., 2023). However, the largest recorded explosion involving ammonium nitrate was aboard the Norwegian-flagged cargo ship Ocean Liberty in Brest, France, in 1947 (Cedre France, 2009). It is notable that three of the four most significant disasters involving ammonium nitrate took place on board vessels.

Table 14: Statistics of five major ammonium nitrate disasters, four occurring on vessels.

Date	Location	Quantity (Tons)	Explosion on Vessel
Friday, 4 October 1918	Morgan, New Jersey, USA	1000	No
Wednesday, 16 April 1947	Texas City, Texas, USA	2300	Yes
Tuesday, 4 August 2020	Beirut Port, Lebanon	2750	Yes
Monday, 28 July 1947	Brest France	3000	Yes
Wednesday, 12 August 2015	Tianjin Port, China	800	No

Source: Adapted from Yu et al. (2022)

4.4.4 Explosion analysis

The aftermath of both explosions left a significant impact on the surrounding area. The second explosion resulted in the formation of a crater 97 meters in diameter (Yu et al., 2022), illustrating the blast's immense force and destructive power. Investigators determined that two successive sympathetic detonations led to a devastating fire (Yu et al., 2022). Evidence corroborates that the initial fire and explosion triggered a chain reaction leading to a more substantial secondary blast around 30 seconds after the first (Fu and Wang, 2016), disastrously impacting the immediate surrounding infrastructure and the built environment (Yu et al, 2022; Fu et al., 2016). It is estimated that up to 111 different substances were stored in the facility at the time of the explosion (Fu et al., 2016)

4.4.5 Safety implications

The incident highlighted the importance of implementing proven safety management systems and ensuring those systems are fit for purpose and implemented effectively. Furthermore, international regulations for the handling and storing of hazardous chemicals (HAZCHEM) were noticeably absent from the storage facility (Fu et al., 2016). It is a constant reminder of the risks associated with storing and transporting HAZCHEM materials. Safety measures and regulations are only effective if they are implemented and monitored by competent people . As was detailed in the Beirut case study, the ammonium nitrate was also incorrectly stored with other chemicals (Forensic-Architecture, 2020). When the initial fire started the heat from the fire set off a chain reaction which ultimately led to the devastating explosion. This highlights the importance of effective dangerous goods management and supporting safety regulations and inspections to monitor storage facilities. Additionally, in this tragic incident, the government-appointed regulator and the facility operator were largely negligent in their duty of care (Fu et al., 2016). Significant work will need to be undertaken by the Chinese government to retore confidence and ensure safety standards are implemented across the hazardous chemical industry in China (Neame et al., 2015).

4.4.6 Human and economic impact

The incident resulted in significant human casualties, with 165 reported deaths, 8 missing individuals, 7533 destroyed containers, and 798 hospitalised injuries (Fu et al., 2016).

The estimated economic impact was around 6 billion Chinese Yuan (Wang, 2015), destroying 304 buildings in the process (Fu et al., 2016).

The paper emphasised the importance of learning lessons from historical explosions caused by ammonium nitrate to prevent such incidents in the future. The question remains: are companies and regulators learning from past events? Indeed, the answer is NO. The Beirut disaster, five years after Tianjin, caused unimaginable suffering and loss. The most disappointing thing is the consistency in both incidents in regulation implementation and oversight by both Governments.

4.4.7 Thermal hazards and flammable properties of nitrocellulose

Nitrocellulose (NC) is a “thermally unstable compound” (Yu et al., 2022) characterised by -NO2 groups, which can significantly impact its storage ability (Yu et al., 2022; Wang, 2015). The nitro groups can make nitrocellulose highly flammable and sensitive to heat and friction (Yu et al., 2022; Fu et al., 2016; Wang et al., 2023) and therefore must remain wet. Nitrocellulose is a flammable material that requires moisture for chemical stability and safe handling, usually kept damp with water or ethanol. However, dry nitrocellulose can ignite spontaneously with the right environmental conditions. At Tianjin, it was stored in plastic bags with a moistening agent but not sealed thermoplastically (McGarry et al., 2018). The warehouse workers, lacking proper safety induction and chemical handling training, appear to have damaged the packaging. This caused the moistening agent to evaporate and some nitrocellulose to spill (McGarry et al., 2018). With the ambient temperature on the 12th of August around 36 degrees celsius and with the added temperature of the warehouse at 65 degrees celsius the remaining wetting agent then dried. This caused the dry nitrocellulose to then ignite (McGarry et al., 2018). When combined with ammonium nitrate, which is relatively stable at ambient temperatures (Wang et al., 2023), it can become a complicated hazard if exposed to high temperatures (Yu et al., 2022). These two chemicals together can be a dangerous explosive disaster, as we have seen.

To reduce the explosive sensitivity properties, commercial nitrocellulose is typically wetted with ethanol/alcohol or water (Wang et al., 2023). In the Tianjin explosion, the official report determined that the ignition of nitrocellulose was caused by autocatalytic decomposition (Yu et al., 2022) from a sustained temperature of 65 degrees celsius (McGarry et al., 2018). The incorrect storage combined with high temperatures within Tianjin at the time contributed to the explosion.

4.4.8 Fire and explosion hazards of ammonium nitrate (AN)

Ammonium nitrate is an oxidiser with an oxygen balance of approximately 20%, making it conducive to combustion (Yu et al. 2022). There are two commercial grades of AN: fertiliser grade and technical grade, commonly used to produce explosives (Yu et al., 2022).

The classification of ammonium nitrate as an oxidiser with an instability rating of three indicates its potential for detonation when confined within an area subject to extreme heat, such as shipping containers in Tianjin Port (McGarry et al., 2018) or in warehouses in Beirut Port (Forensic-Architecture, 2020).

Figure 19: Comparison between Tianjin and Beirut Ammonium Nitrate Explosion blast craters.

Source: Lloyd et al. (2017)

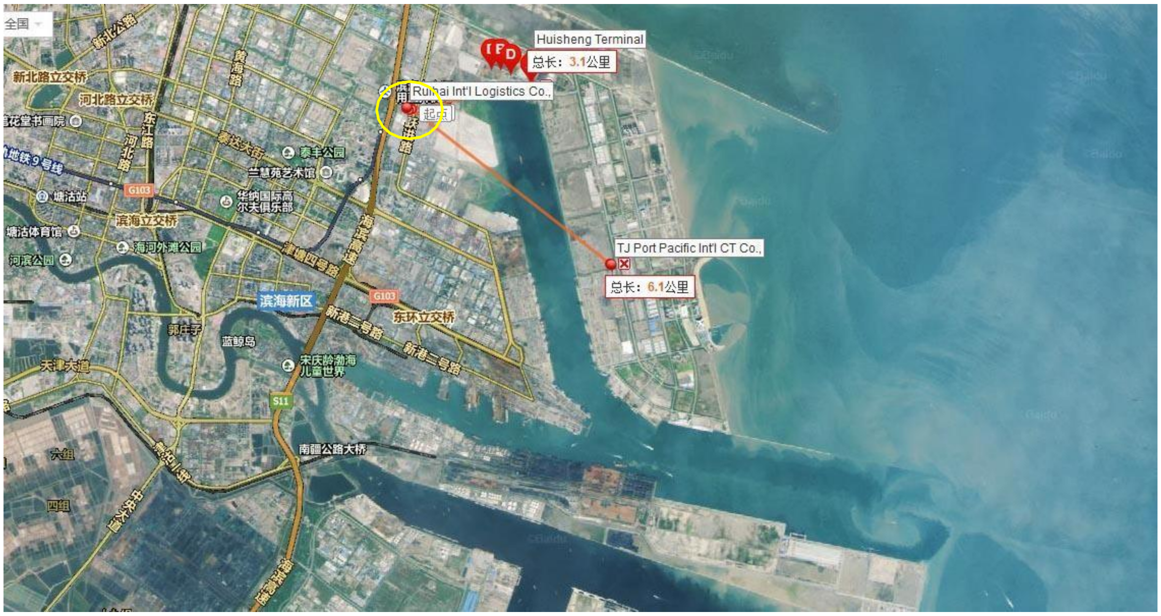
4.4.9 Explosion hazards and susceptibility to detonation of ammonium nitrate

The authors discussed the history of ammonium nitrate, its uses in manufacturing explosives and fertilisers for agriculture (Wang et al., 2023) since 1910, and the various accidents and disasters related to ammonium nitrate explosions worldwide. It is undeniable that ammonium Nitrate is a hazardous chemical. However, it is equally undeniable that Ammonium Nitrate is ingrained within our society. It is used by the agriculture industry as a high-nitrogen fertilizer (Rao, 2014) and feeds millions of people globally, and it is used in explosives for mining, construction, and quarrying with the military. It is also used in instant cold packs, pyro techniques, herbicides, insecticides, yeast, and antibiotics (Rao, 2014; Speight, 2017).

As ammonium nitrate is an oxidiser, it can produce oxygen, which supports increased fire combustion independent of atmospheric oxygen. Because of the exothermic ability of ammonium nitrate, its ability to release oxygen can accelerate combustion, leading to severe fire and the risk of further explosions as other chemical properties are affected. This was shockingly evident in the Beirut explosions, as discussed in case study one (Beirut), and this Tianjin case study, where in James Reasons (1990), Human Error, Swiss Cheese model of latent failures at management levels, psychological precursors, and unsafe acts perfectly aligned to create an incident (Larouzee & Le Coze, 2020; McGarry et al., 2018).

The concept of sympathetic detonation, whereby an explosion in one location can trigger a detonation in another area within proximity, (Yu et al., 2022) was introduced. Research into the blast radiuses of both the Beirut and Tianjin explosions has shown that blast safety distances that should have been taken into consideration during the planning phase of the storage facilities were not considered, exacerbating the devastation from both explosions (Ide & Huang, 2015). This fact raises essential concerns for future storage facility locations and the governmental frameworks and approvals, which should ensure that such facilities are not within populated areas and comply with local and international hazardous chemical storage regulations.

Figure 20: Aerial photograph of Tianjin Port and location of explosion impact area in yellow.



Source: Guard Alert (2014)

The Tianjin explosion also highlights the importance of emergency first responders' local knowledge of hazardous chemical facilities, their layout, chemicals stored, chemical storage locations (Jacobs et al., 2015), and operational area access to conduct emergency response training. Firefighters unknowingly responded to the chemical reaction well underway by adding water to chemicals that react with water. The increasing intensity of the burning fires also increased the flash point of other chemicals at the facility, contributing to an already dangerous situation that continued to escalate with devastating effects (Iyengar, 2015).

4.4.10 Unsafe organisational behavioural safety factors

4.4.10.1 Lessons learned

The Tianjin Port explosion provides valuable insights and lessons from the incident analysis. These lessons are critical for various important stakeholders globally, including government, the public, port and chemical industry bodies and regulatory agencies. Tianjin has been described as the most severe explosion involving ammonium nitrate since 1947 until the Beirut Port explosion in 2020 (McGarry et al., 2018).

Firefighters suffered significantly in the Tianjin explosion (McGarry et al., 2018), as with the Beirut explosion. Firefighters did what they were trained to do. Fight the fire, but in order for them to do their job safely, they require information about what chemical they are dealing with, which could have been significantly improved in this incident.

Firefighters were not equipped for the fire, which worsened the disaster, leading to loss of life. One firefighter stated that his department had conducted a risk assessment of the Port with the most dangerous sites. The Rui Hai International Logistics company was not one of the sites listed (Jacobs et al., 2015). This is yet one more layer of the failed Chinese safety regulator. James Reason (1990) Human Error, Swiss Cheese model of latent failures at management levels, psychological precursors and unsafe acts shows clearly how one thing led to another, creating an environment for disaster. It was a matter of if, but when something disastrous was going to happen, resulting in significant loss of life.

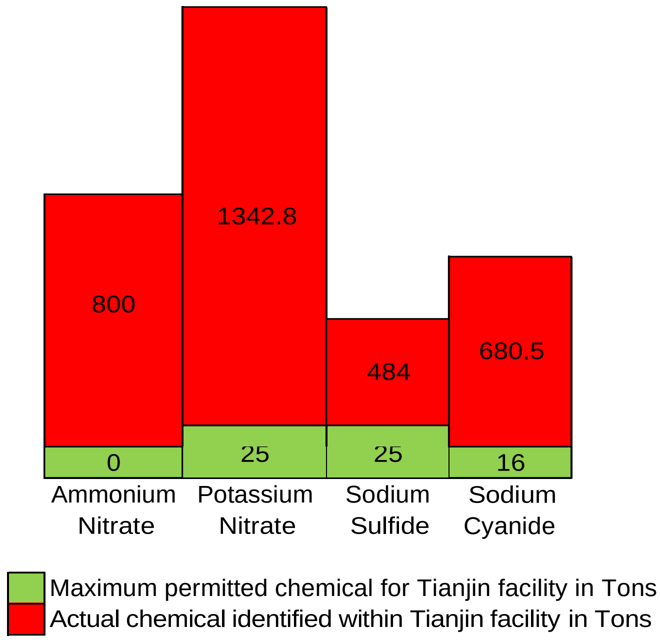
A quick and immediate response to a large industrial fire is essential. However, due to the facility not being operated as per Chinese regulations, not to mention International best practices along with the additional dangers omni present at the facility on the day of the Tianjin explosion, the firefighters in both situations walked blindingly into a death trap (Berger & Karklis, 2020). First responders had yet to learn of the significance of the emergency they were responding to or the immediate threat in which they were about to place themselves. This highlights the absolute need for regulated, implemented, and monitored chemical storage facilities, safety plans with training guidelines for firefighting in the response and tactical management of industrial facilities storing ammonium nitrate and other hazardous chemicals to prevent the further significant loss of emergency responder lives.

Table 15: Recorded losses from the Tianjin Explosion.

Source: Adapted from Lloyd et al. (2017)

The final report revealed Ruihai International company was found to have illegally stored excessive quantities of ammonium nitrate, nitrocellulose and other dangerous chemicals (Jacobs et al., 2015; McGarry et al., 2018;), emphasising the importance of adherence to necessary hazardous chemical safety regulations and duty of care by employers to their workers to ensure they are trained and competent to work in high-risk environments. Chemicals were reportedly stacked without regard for type or reactive ability with other substances (McGarry et al., 2018), like nitrocellulose and ammonium nitrate, which, as we have seen, created significant dangers for the local workers who had no idea of what they were transporting in the storage yard notwithstanding the imminent dangers to firefighters responding to a fire where a chemical chain reaction had started that they did not know about nor could not stop (Iyengar, 2015; McGarry et al., 2018).

Figure 21: Main hazardous chemicals located at Ruihai International Logistics, Tianjin.



Source: Adapted from Fu et al., (2016)

The study confirmed autocatalytic decomposition can ignite nitrocellulose in containers due to poor heat removal (Yu et al., 2022; Wang et al., 2023). Autocatalytic decomposition of nitrocellulose was found to be more hazardous in closed containers than in open (Yu et al., 2022). The paper further determined that nitrocellulose can ignite after approximately nine days of "autocatalytic decomposition in a container sustained at 60°C" (Wang et al., 2023). For tropical storage environments, this is a significant finding. Additionally, when stored in a confined container, ammonium nitrates with increasing temperature and added ignition sources, such as the fire in Tianjin, can lead to its breakdown and flash point, exploding violently (Yu et el., 2017; Wang et al., 2023, McGarry et al., 2018).

4.4.11 Conclusion

In conclusion, the Tianjin port explosion of 2015 was a tragic event with significant loss of life and property damage (Jacobs et al., 2015). The incident's causes, sequence of events, and impact on supply chains and human life underscore the importance of stringent international safety measures and regulatory oversight in handling hazardous materials.

The catastrophic explosions had a profound impact on safety practices in the chemical and logistics industries, prompting a re-evaluation of safety standards within China to prevent a repeat disaster in the future (McGarry et al., 2018).

However, despite the significant global focus on the Tianjin disaster, the international community and individual governments failed to take adequate measures to avert a similar occurrence, resulting in the Beirut disaster five years later with striking similarities.

While China and Beirut are geographically far apart, the similarities in how these incidents occurred cannot be ignored. Corruption, ineffective training, lack of regulatory compliance and oversight and negligent chemical storage with a complete disregard for a fundamental duty of care to workers and the public are blindingly prevalent in both situations. Furthermore, both disasters were 100 % preventable, with human error being the primary contributing root cause for both incidents.

The article highlighted the importance of strengthening international regulation, foster collaboration, and ensure compliance, as well as to heighten risk awareness to reduce the storage and quantity of ammonium nitrate in chemical storage facilities near urban infrastructure.

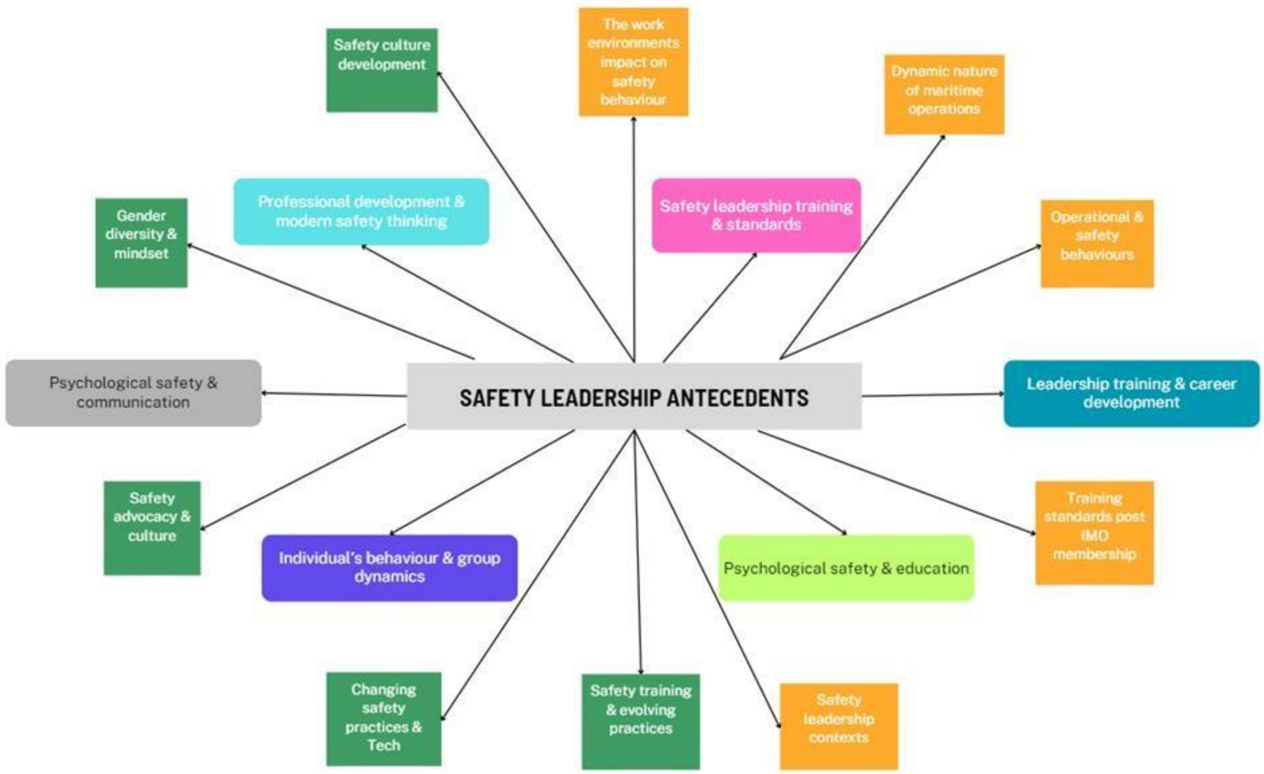
It would be remiss not to acknowledge the sacrifice of the emergency responders who lost their lives both at Tianjin and Beirut. People who are selflessly dedicated to helping others in need, who unknowingly walked into certain death on the day of the explosions. In 2014, the International Labor Organisation estimated that 186 people die in China every day due to occupational work-related accidents (ILO, 2015). This is a shocking statistic, even for a country with a population of over 1.3 billion (Whiteman, 2015). However, the statistics demonstrate a declining number of occupational-related deaths from 1.328 for every 100,000 workers in 2014 down to 12.9% in the previous year (Whiteman, 2015). For China to evolve from a developing safety culture to at least a performing safety culture maturity as per Matsimbe et al., (2020), State and local governments in China must collaborate closely to harmonize safety and regulatory systems, ensuring monitoring and compliance with international best practice in hazardous chemicals management for the future.

4.5 PHASE ONE RESEARCH FINDINGS

4.5 Findings

The research identified several antecedents that can affect organisational or individual safety leadership. These included organisational culture, leadership styles, resource availability, and the importance placed on 'safety' relative to operational needs.

Figure 22: Identified 16 antecedents that impact safety leadership.



Source: Author's data

Continuing research conducted by Kim et al. (2021) who developed a safety leadership self-efficacy scale adapted to the maritime context (self-evaluation). The study by Kim et al. (2021) specifically focused on the STCW leadership requirements for shipboard officers at the management and operational levels. The study also considered safety leadership behaviours identified in two previous empirical studies (Kim & Gausdal, 2017; Kim and Sydnes, 2020). This study used the same base survey context but added an additional eight specific behavioural safety questions to create a modified SLSES.

Table 16: Additional eight specific behavioural safety questions.

Number	Safety Behaviour Question
1	I understand what behavioural safety is?
2	I believe the maritime environment (a vessel which operates in a range of maritime settings including but not limited to: in harbour, inland waterways or in the open ocean) can be hazardous?
3	I understand how behavioural safety can influence positive safety outcomes in my workplace/vessel?
4	I have had safety leadership training as part of my workplace health and safety training?
5	I have had behavioural safety training as part of my workplace health and safety training?
6	I believe that a good organisational safety culture starts with good safety leadership displayed by senior company management and this promotes good safety behaviour by myself and the crew?
7	Can you provide an example of what good behavioural safety leadership means to you?
8	I believe that if I had access to behaivoural safety training it would help reduce incidents and injury within the workplace?

Source: Author's data

These questions were added to expand on the proposed model by Kim and Sydnes, (2020) to adapt the survey model further to establish a best practice safety leadership behaviours model.

Table 17: Participant Role and Type of Service.

Source: Author's data

Table 18: Participant Years of Experience.

Source: Author's data

Table 19: Modified Safety Leadership Self-Efficacy Scale Survey (MSLSES) scoring key.

0=Not at all	1=Slightly Agree	2=Moderatly Agree	3=Agree
Low	Moderate-Low		

Source: Author's data.

Table 20: Interpretation of Modified Safety Leadership Self-Efficacy Scale Survey (MSLSES).

Source: Author's data.

Table 21: Answers to question: Please give an example of what behavioural safety is to you?

Eight responses were provided by survey participants.

Number	Please give an example of what behavioural safety is to you?
1	Working safely, following the rules
2	Lead by example
3	Being the example of good safety onboard
4	Walk the walk
5	Leading by example
6	Leading by example to be the example of high standards on board
7	Demonstrating the right safety personally to my crew
8	Wanting to work safely

Source: Author's data.

Table 22: Modified Safety Leadership Self-Efficacy Scale Survey (MSLSES) results.

SMotivation	Q3	rating average	4
	Q4	rating average	3
	Q5	rating average	3
	Q6	rating average	3
	Q7	rating average	3
	Q8	rating average	3
	Q9	rating average	3
	Q10	rating average	3
	Q11	rating average	4
	Q12	rating average	3
	Q13	rating average	3
SMan	Q14	rating average	3
	Q15	rating average	3
	Q16	rating average	3
	Q17	rating average	3
	Q18	rating average	4
	Q19	rating average	3
	Q20	rating average	2
SInitiatives	Q21	rating average	3
	Q22	rating average	3
	Q23	rating average	3
	Q24	rating average	3
	Q25	rating average	3
Sbehaviour	Q26	rating average	3
	Q27	rating average	3
	Q28	rating average	Working safely, following the rules Lead by example Being the example of good safety onboard
	Q29	rating average	4
	Q30	rating average	3
Snr Man	Q31	rating average	4
	Q32	rating average	0
			I have had behavoural safety training as part of my workplace health and safety training
	Q33	rating average	4
	Q34	rating average	3
	Q35	rating average	3
	Q36	rating average	3
	Q37	rating average	3
	Q38	rating average	3
	Q39	rating average	3

Source: Author's data.

Table 22: Modified Safety Leadership Self-Efficacy Scale Survey (MSLSES) results.

Safety Professionals	Q40	rating average	3
	Q41	rating average	3
	Q42	rating average	3
	Q43	rating average	3
	Q44	rating average	3
	Q45	rating average	3
	Q46	rating average	3
Frontline Supervision	Q47	rating average	3
	Q48	rating average	3
	Q49	rating average	3
	Q50	rating average	3
	Q51	rating average	3
	Q52	rating average	3
Frontline Workers	Q53	rating average	3
	Q54	rating average	3
	Q55	rating average	3
	Q56	rating average	3
	Q57	rating average	3
	Q58	rating average	3
Safety Compliance	Q59	rating average	3
	Q60	rating average	3
	Q61	rating average	3
	Q62	rating average	3
	Q63	rating average	3
Safety Participation	Q64	rating average	4
	Q65	rating average	3
	Q66	rating average	3
	Q67	rating average	2
			I receive an adequate level of training in safety behaivour
	Q68	rating average	3
	Q69	rating average	3
	Q70	rating average	3
	Q71	rating average	3
	Q72	rating average	1
			I am not interested in participating in additional safey measures in my workplace

Source: Author's data.

4.5.1 Modified safety leadership self-efficacy scale findings:

A Safety Leadership Self-Efficacy Scale for maritime officers can enhance safety and overall performance in the shipboard environment. Self-efficacy is the belief one holds in their capability the ability to execute a specific task or attain a certain goal (Kim et al., 2021; Nykänen et al., 2019). When applied to safety leadership in a maritime context, this scale can have the following advantages:

a) Improved Safety Performance: By assessing and enhancing safety leadership self-efficacy among officers, in combination with the following points, it is reasonable to expect an improvement in safety-related behaviours and decisions. Officers with higher self-efficacy are likelier to take positive steps to prevent incidents and respond when things go wrong (Bandura, 1997; Kim and Gausdal, 2017; Kim et al., 2021; Neal and Griffin, 2006).

b) Reduction in Accidents and Incidents: A stronger belief in one's ability to lead safety initiatives can reduce accidents and incidents on board ships. Effective safety leadership can help prevent incidents and mitigate their impact when they do occur (Neal & Griffin, 2006).

c) Enhanced Crew Morale: Maritime officers who exhibit confidence and competence in safety leadership can positively influence crew morale and outcomes. When crew members see their leaders taking safety seriously and confidently handling safety-related challenges, they are more likely to feel motivated and engaged (Bandura, 1997; Kim et al., 2021).

d) Enhanced Risk Awareness: Self-aware officers are more likely to identify and mitigate risks early. This can lead to a reduction in near misses and possible prevention of potentially catastrophic accidents, protecting both the crew, vessel and cargo (Bandura, 1997).

e) Policy and Procedure Compliance: Maritime regulations and safety standards are strict and require continuous adherence. Officers with a strong sense of self-efficacy in safety leadership are more likely to ensure compliance with these regulations, reducing the risk of legal and financial consequences (Neal et al., 2000).

f) Increased Shipboard Organisational Culture: Fostering a positive safety culture is essential in the high-risk maritime environment. A Safety Leadership Self-Efficacy Scale can help identify areas where officers need improvement, thereby promoting a more positive and safety-focused organisational culture (Neal et al., 2000).

g) Training and Professional Development: The scale can identify areas where officers may need additional training and development to enhance their safety leadership skills. This targeted approach to training can lead to more effective safety leadership and improved organisational safety (Bandura, 1997; Neal et al., 2006).

h) Positive Self-Accountability: Officers with higher safety leadership self-efficacy are likelier to hold themselves and their team members accountable for safety-related actions and decisions, leading to a more responsible and safety-conscious crew (Bandura, 1997; Neal et al., 2006).

i) Ongoing Continuous Improvement: Regularly assessing safety leadership self-efficacy can help maritime organisations track progress and improve safety leadership practices through targeted training (Neal et al., 2006).

j) Emergency Preparedness and Crisis Response: In high-risk maritime situations, having confident officers who believe in their ability to lead effectively during emergencies is invaluable. A higher safety leadership self-efficacy can lead to better emergency management at sea and port. (Bandura, 2006; Neal and Griffin, 2006)

Reviewing the above results aligns with previous research conducted by Kim et al. (2021); Kim and Gausdal, (2017) Kim and Sydnes (2020), whereby a high score in the current research has indicated a positive correlation to safety leadership in the maritime environment. It can therefore be firmly determined that given the consistent upper range of the scores obtained in this research, a high degree of safety leadership is observed within the officers and senior ratings who participated in the study.

Additionally, while participants indicated that they had yet to receive formal training in behavioural safety, a broad understanding of the concept is observed in the findings. This finding is an opportunity for further research within the maritime sphere, and supports research question three’s statement to update the International Maritime Organisation (IMO) mandated safety leadership training framework to support changes to the STCW Table A-11/2 (Masters and chief officers), Table A-III/2 (Chief engineering offices and second engineers), Table A-II/1 (Officers in charge of a navigational watch), (EDU Maritime, 2010).

PHASE TWO RESEARCH FINDINGS

4.6 Findings

Part 2 interview questions

a) In general, what does safety behaviour mean to you?

b) Tell me about your experience of safety behaviour in your current organisation?

c) Tell me what you know about the Beirut Blast and MV Rhosus, the ship which carried the ammonium nitrate into Beirut that exploded in August 2020?

And or,

d) Tell me what you know about the explosions in the Northern Chinese port of Tianjin in 2015 or

e) Tell me what you know about the MV Sewol Ferry capsize disaster in South Korea in 2014?

f) Having completed this survey and safety leadership training previously. Do you think the current IMO regulated safety leadership training is satisfactory? Please explain your answer.

4.6.1 Face-to-face interview results / interview analysis

Interview 1 – Naval officer

At the time of the interview the officer was in the process of posting ashore from a senior department head position onboard a large capital warship. He stressed the importance of safety in the Navy and how safety culture has progressed over the past 25 years, noting that regular safety meetings were held on his last ship where he was a department head. Everyone was kept informed about potential risks and operations onboard the ship. This process was driven by the Captain, who as the senior naval officer aboard supported and encouraged safety collaboration within the ship's company at all ranks. The officer also mentioned the balance between safety and taking necessary operational risks in the Navy. The officer gives examples of training for combat situations and the need to adapt to new non-operational (peace) and war-like threats. While he did express some uncertainty surrounding the effectiveness of safety in high-risk situations given the inherent danger warships operate within along with the time sensitive nature of operational decision making. The officer recognised the differences between merchant shipping and naval operational fleet risks and emphasised the importance of safety leadership in the naval setting. The officer acknowledged the significance of the Beirut and SEWOL incidents; however, he was unaware of the specific hazards and implications regarding safety behaviours and their impact on these disasters due to them not impacting his specific area of operational work. The officer was able to provide a detailed overview of naval safety leadership from the mid 1990’s to today and how the Navy’s safety culture has matured over this time citing several examples of how safety behaviours have changed.

Interview 2 – Merchant naval officer

At the time of the interview the officer was at sea in the North Sea. Before leaving the Royal Navy for the Merchant Navy and oil and gas industry, the officer with over 35 years of experience at sea discussed the concept of safety behaviour in the maritime industry in detail. It highlighted the importance of an individual's behaviour in ensuring safety, especially when no one is watching. This is a true indicator of a sound organisational safety culture and of an individual with a high-safety behavioural understanding. The officer emphasised the influence of psychological factors, human factors, leadership, and group dynamics on safety behaviour outcomes. The officer also discussed the link between safety culture and behaviour, emphasising top leadership's role in promoting a positive safety culture. The officer shared his experience on his current ship and highlighted the importance of psychological safety and open communication in promoting safe behaviour in the dynamic maritime environment. The officer was aware of the Beirut and SEWOL ferry disasters and fully understood the hazards, risks and safety behaviour elements involved, highlighting the systemic issues and human factors that contributed to those incidents.

4.6.2 Conclusion

Research by Kim et al. (2021); Kim and Sydnes 2020; Nykanen et al., 2019) has revealed that safety leadership self-efficacy is a multidimensional construct, reflecting a leader's confidence in their ability to enact safety leadership to self and others in the chain of command. In general terms, an officer's ability to use a range of platforms and skills, including social skills, to influence, motivate, and build relationships with fellow crew members to foster a positive organisational safety culture for success is fundamental onboard any ship operating within the high-risk maritime environment. This statement applies to both military and merchant fleets.

The Safety Leadership Self-Efficacy Scale for maritime officers can contribute significantly to safer international shipping operations and improved seafarers' organisational safety culture performance. Furthermore, it can help shipping lines identify areas of improvement in safety leadership, ultimately leading to safer vessel management for crews at sea, improved organisational safety culture and more efficient/cost-effective shipping operations with reduced incident causation.

A maritime leader's ongoing competence for safety management at sea includes identifying, managing, and leading positive risk management behaviours, often in hazardous situations in complex environments. The positive influence IOSH (UK) identified with supervisors were found to have in the construction settings is similarly reflected in this research within the maritime space. In this case, with the maritime officer substituted for the construction supervisor.

This paper supports the introduction of a modified SLSES survey on a widespread scale to improve shipboard organisational safety culture, safety leadership and positive safety behaviour outcomes. The defining factor in determining this result was the consistently moderate to high and high scores observed in the survey results of 32 individuals.

The importance of how leadership and self-efficacy can benefit maritime officers must be further considered. Research by Hannah et al., (2008) determined that an individual's ability to lead was associated with improved leadership engagement across various challenges. Officers with high leadership self-efficacy are likelier to take on leadership roles and responsibilities; they believe in their ability to handle challenges and lead others. In the high-risk maritime environment, these traits are critical to ongoing safety at sea.

CHAPTER V:

DISCUSSION

5.1 Discussion of results

This chapter will discuss the results obtained during the research and the interpretation of such.

5.2 Discussion of research question one

Research Question: To identify antecedents which affect organisational and or individual safety behaviours and human factors that affect safety leadership behaviours in the high-risk maritime environment.

5.2.1 Findings

The research survey questions were designed around Behavioral Based Safety Leadership's impact on organisational safety culture and incident causation in the maritime environment. The survey contained multiple choice and written answer questions related to safety motivation, management initiatives, behaviour, and a safety leadership self-efficacy scale adapted for the maritime setting. Participants include various roles within the maritime industry, covering topics such as safety behaviour understanding, experience with safety in organisations, training satisfaction, and safety leadership aspects. The survey aimed to gather insights on how human factors and behaviour-based safety leadership can influence safety culture in the high-risk maritime environment.

Research by Lützhöft et al. (2011) identified that safety culture is and remains a critical risk in the maritime industry. Additionally, it revealed that while most incidents are caused by human error, these elements or interactions can be linked to the organisation's safety culture. The antecedents leading to unsafe behaviours, which can lead to an unsafe act or incident, can be elusive. However, this research has shown that the organisational safety culture of an organisation can and does have a significant impact on the safety behaviours of its workers.

The research identified several antecedents that can affect organisational or individual safety leadership. These included organisational culture, leadership styles, resource availability, and the importance of 'safety' relative to operational needs. It also discussed the impact of individual behaviours, training, and experience in shaping safety behaviour outcomes. The influence of external factors, including regulations, standards, and the differences in safety perspectives between military and civilian maritime operations, were also discussed.

These factors collectively shape safety leadership behaviours in high-risk maritime environments.

Table 23: Sixteen antecedents were identified that have impacted safety leadership #1

Number	Question	Result	Comments
1	To identify antecedents which affect organisational and or individual unconscious behaviours and human factors that affect safety leadership behaviours in the high-risk maritime environment.	The following **sixteen** antecedents were identified that have impacted safety leadership	
1.1		An Individual's Behaviour and Group Dynamics	Safety behaviour is a function of individual actions and considerations about safety, especially when unsupervised. Group dynamics, leadership, peer pressure, and biases can affect this behaviour.
1.2		Psychological Safety and Education	The importance of psychological safety and education in understanding the safety environment and the need for strategic oversight at all levels of management, not just among middle and work-front leaders.
1.3		Leadership Training and Career Development	The gap in leadership training, especially for senior roles, and the need for early career education on safety leadership are key antecedents which should be further explored.
1.4		Safety Leadership Training and Standards	The research showed that the lack of retraining in safety leadership practices highlighted gaps in safety leadership and behavioural safety understanding.
1.5		Professional Development and Modern Safety Thinking	The inadequacy of current IMO-regulated safety behaviour leadership training and the need for ongoing professional development in modern safety practices.
1.6		Psychological Safety and Communication	The challenge of breaking down barriers in psychological safety encourages open communication between crew members and all levels of management while adapting to technological changes and ever-crowded shipping lanes.
1.7		Operational and Safety Balance	Balancing safety with operational needs, such as in military operational environments where missions inherently involve various risks.
1.8		Gender Diversity and Mindset	The impact of limited gender diversity in the merchant navy and its effect on safety behaviours and mindsets.
1.9		Safety Training and Evolving Practices	The evolution of safety practices and training in the Navy over the years reflected a shift towards more stringent safety behaviours within the Naval Service.
1.10		The Work Environment's Impact on an Individual's Safety Behaviour	How the working environment influences individual behaviours, especially within group settings.
1.11		Safety Culture Development	The role of senior leadership in building and sustaining a positive organisational safety culture ashore and onboard ships is a long-term process.
1.12		Safety Advocacy and Culture	All management leadership levels advocate for a positive safety culture and balance it with mission objectives.

Source: Author's data

Table 23: Sixteen antecedents were identified that have impacted safety leadership #2

Number	Question	Result	Comments
1.13		Changing Safety Practices and Technology's Role	The influence of evolving technology on safety practices and the need for continuous learning to adapt to new safety standards technologies.
1.14		Dynamic Nature of Maritime Operations	The dynamic and ever-changing maritime environment requires constant risk assessment and adaptability in safety practices.
1.15		Training Standards Post-IMO Membership	The significant change in maritime training standards within Ukraine after joining the IMO highlighted the shift in safety leadership training, practices and behavioural outcomes.
1.16		Different Safety Leadership Contexts	The distinction between safety leadership in other maritime sectors and the need to adapt accordingly to maintain a high level of safety.

Source: Author's data

These antecedents reflect a combination of individual, organisational, and external factors that influence safety leadership in the high-risk maritime environment.

5.3 Discussion of research question two

Research Question: Assess and compare the relative contributions of these factors in shaping safety leadership behaviours and their outcomes in the workplace.

5.3.1 Findings

The following table details each contributing factor by discussing how each influences behaviour and decision-making in the safety-critical high-risk maritime environment.

Table 24: Contributing factors and how each influences behaviour and decision-making.

Number	Question	Result	Comments
2	Assess and compare the relative contributions of these factors in shaping safety leadership behaviours and their outcomes in the workplace.	The below details each contribution factor by discussing how each influences behaviour and decision-making in the safety-critical high-risk maritime environment.	
2.1		Individual Behaviour and Group Dynamics	This factor strongly influences the individual level. Personal ethics, integrity, and how individuals behave when unsupervised are crucial. However, this can be significantly affected by group dynamics, peer pressure, and leadership styles. Its impact can vary greatly depending on the organisational culture and the individual's traits.
2.2		Psychological Safety and Education	Psychological safety enables individuals to speak up and address safety concerns without fear of negative consequences. Proper education about safety practices is critical for fostering an environment where safety is prioritised. It is a foundational element that influences all levels of an organisation.
2.3		Leadership Training and Career Development	The need for continuous and updated training, especially for senior roles, can result in outdated safety practices. Leadership training is vital for setting the tone and expectations for organisational safety behaviour, making its contribution significant.
3.4		Safety Leadership Training and Standards	Standards and retraining programs are crucial in maintaining and updating safety practices. Organisations adhering to high standards will likely have better safety outcomes, as these standards often encapsulate best practices and lessons learned from past incidents.
2.5		Professional Development and Modern Safety Thinking	This factor is increasingly important due to the evolving nature of maritime operations. Organisations prioritising ongoing professional development are more likely to adapt to changes and incorporate modern safety thinking, leading to more effective safety leadership.
2.6		Psychological Safety and Communication	Open communication and challenging unsafe practices without fear are critical for real-time safety management. This factor is essential for day-to-day operations and influences safety outcomes directly.
2.7		Operational and Safety Balance	In high-risk environments like the maritime industry, balancing operational needs and safety is delicate. This factor is crucial as it directly affects decision-making in critical situations.
2.8		Gender Diversity and Mindset	While indirectly influencing safety, diversity in thought and perspective can lead to more comprehensive safety strategies. This factor is more subtle but can contribute to a more holistic approach to safety.
2.9		Safety Training and Evolving Practices	The effectiveness of safety training and its adaptation to current practices significantly impact safety behaviour, especially at the operational level. Well-trained personnel are better equipped to handle safety-related challenges.
2.10		Environment's Impact on Individual Behavior	The immediate working environment influences individual behaviour substantially. It shapes daily safety practices and can reinforce or undermine formal safety training and protocols.

Source: Author's data

Table 24: Contributing factors and how each influences behaviour and decision-making #2

Source: Author's data

While all these factors shape safety leadership behaviours, their relative impact can vary depending on leadership training, previous operational experience, the individual's values system, organisational safety culture development, psychological safety, and the delicate balance between operational needs and safety management. Operational needs can be the most influential for both military and civilian shipping because they are intrinsically linked to financial inputs and outputs and can have a cascading effect on other aspects of safety leadership and behaviours.

5.4 Discussion of research question three

Research Question: To outline a conceptual framework for the introduction of Safety Leadership Self-Efficacy Scale (SLSES) with behavioural safety elements included to increase awareness of unconscious safety behaviours to implement realistic, measurable processes to improve safety leadership behaviours and safety performance within the high-risk maritime environment.

5.4.1 Findings

Introducing a Modified Safety Leadership Self-Efficacy Scale (SLSES) with behavioural safety elements within the high-risk maritime environment could benefit the maritime industry as a tool for improving safety leadership behaviours and overall safety performance. The maritime industry or, more specifically, the IMO could improve the international standard of maritime safety leadership by considering the findings within this research and developing a suitable training packages for example; "Behavoural-based safety leadership and organisational safety culture" and its implementation within the Convention for Standards of Training, Certification, and Watchkeeping (STCW) framework. This could then be proposed as an amendment to the STCW framework which must then be adopted by two-thirds of the IMO Genaral Assembly. Once accepted by two-thirds of the Member States the amendment enters force 12 months later (IMO, 2023).

In conclusion, introducing a modified SLSES focusing on behavioural safety elements can enhance safety leadership in the high-risk maritime environment. It could also increase awareness, targeted training, and continuous improvement in safety behaviours, ultimately contributing to better individual and organisational safety performance. However, such success would depend on its thoughtful design, proper implementation, and consistent use within the organisational framework of each organisation, company and fleet with the demonstrated support of senior management ashore and at sea.

Table 25: Introducing a Modified Safety Leadership Self-Efficacy Scale (MSLSES)

Number	Question	Result	Comments
3	To outline a conceptual framework for the introduction of Safety Leadership Self-Efficacy Scale (SLSES) with behavioural safety elements included to increase awareness of unconscious safety behaviours to implement realistic, measurable processes to improve safety leadership behaviours and safety performance within the high-risk maritime environment.	Introducing a Modified Safety Leadership Self-Efficacy Scale (SLSES) with behavioural safety elements within the high-risk maritime environment could benefit the maritime industry as a tool for improving safety leadership behaviours and overall safety performance It is recommended that IMO review model courses: 1.39 Leadership and Teamwork and 1.40 Use of Leadership and Managerial Skills to address identified areas for improvement with the view to include the following eight elements.	
3.1		Increased Self-Awareness	A vital aspect of the modified SLSES would be to help individuals, especially those in leadership roles, become more self-aware of their safety behaviours, conscious and unconscious. By quantifying and reflecting on their safety leadership, leaders can identify areas for improvement and reinforce positive behaviours.
3.2		Focus on Behavioural Elements	Including behavioural elements in the scale would emphasise the importance of individual actions and decision-making processes in safety outcomes. This focus can help identify specific behaviours that must be changed or encouraged within the maritime environment.
3.3		Realistic and Measurable Goals	A well-designed SLSES can provide clear and measurable objectives for safety leadership improvement. This measurability is crucial for setting realistic goals and tracking progress over time.
3.4		Enhancing Training and Development	The scale could be used as a training tool, helping to identify specific areas where leaders need further development. It can also be integrated into ongoing professional development programs to ensure that safety leadership skills are continuously improved.
3.5		Promoting a Safety positive Culture	By emphasising safety leadership, the scale can contribute to cultivating a more robust positive safety culture within the organisation. Leaders who are more competent and confident in their safety leadership abilities will likely influence their teams positively, leading to a more safety-conscious workforce.
3.6		Addressing the Dynamic Nature of Maritime Operations	Given the ever-changing and challenging nature of the maritime environment, a tool that helps leaders assess and adapt their safety behaviours is precious. It can help in making quick yet informed decisions in dynamic situations.
3.7		Benchmarking and Continuous Improvement	The SLSES can be a benchmarking tool, allowing organisations to compare their safety leadership levels against industry standards or past performance. This benchmarking can drive continuous improvement in safety practices.
3.8		Adaptability to Individual and Organisational Needs	Scalability to reflect the unique challenges and needs of different maritime industry roles makes it a versatile tool for a wide range of personnel.

Source: Author's data

CHAPTER VI:

SUMMARY, IMPLICATIONS, AND RECOMMENDATIONS

6.1 Summary

Of the 32 participants who completed the initial part one survey, one was excluded for not meeting the study criteria, as the same person submitted a second survey response. In part two interviews, one participant was excluded due to a significant amount of data being compromised in the recording, which the author was unaware of when he checked the initial recording immediately after. This may have occurred due to the interruption of the WI-FI satellite access while the ship was at sea as the vessel proceeded further offshore. A second participant in part two was further excluded due to his not responding to follow-up communications while he was at sea. His interview was not complete. This was again due to the long periods at sea and unreliable access to private WI-FI services onboard the ship.

6.2 Implications

This new research, further developed from Kim et al. (2021), Kim et al. (2017) is positive. The implications of this research, particularly regarding introducing a modified Safety Leadership Self-Efficacy Scale (SLSES) with behavioural safety elements in the high-risk maritime environment, have been multifaceted, with the below following antecedents identified along with 16 benefits identified. A SLSES can broadly impact both individual and organisational elements moving forward.

The following antecedents were identified that have impacted safety leadership:

Table 26: Summary of antecedents Identified

Number	Antecedent
1	An Individual's Behaviour and Group Dynamics
2	Psychological Safety and Education
3	Leadership Training and Career Development
4	Safety Leadership Training and Standards
5	Professional Development and Modern Safety Thinking
6	Psychological Safety and Communication
7	Operational and Safety Balance
8	Gender Diversity and Mindset
9	Safety Training and Evolving Practices
10	The Work Environment's Impact on an Individual's Safety Behaviour
11	Safety Culture Development
12	Safety Advocacy and Culture
13	Changing Safety Practices and Technology's Role
14	Dynamic Nature of Maritime Operations
15	Training Standards Post-IMO Membership
16	Different Safety Leadership Contexts

Source: Author's data

Table 27: Benefits Identified #1

Number	Benefit Identified	Comments
1	Enhanced Safety Leadership	The research underscores the importance of safety leadership in high-risk environments. By focusing on self-efficacy in safety leadership, maritime organisations can develop more capable and confident leaders in managing safety, leading to more effective safety practices.
2	Cultural Shift towards Safety	Implementing such a scale can contribute to organisational culture shifting, emphasising safety as a core value. This shift can lead to a more proactive approach to safety, where preventing incidents becomes as important as responding to them.
3	Improved Risk Management	With better-trained leaders and a more robust safety culture, organisations can expect to see improvements in risk management. Leaders more aware of their safety behaviours and their impact on the team can make more informed decisions to mitigate risks.
4	Data-Driven Safety Initiatives	The SLSES provides a tool for quantifiable measurement of safety leadership behaviours. This data-driven approach allows organisations to identify areas of weakness and target their training and development efforts more effectively.
5	Increased Regulatory Compliance	By enhancing safety leadership and culture, maritime organisations may find it easier to comply with national and international safety regulations, reducing the risk of non-compliance penalties.
6	Better Incident Response and Reduced Accidents	Improved safety leadership should lead to a more competent response to safety incidents and potentially reduce the number and severity of accidents.
7	Enhanced Reputation and Competitiveness	Organisations known for strong safety leadership and a robust safety culture can enhance their reputation in the industry. This reputation can lead to increased competitiveness and potentially more business opportunities.
8	Employee Well-being and Retention	A strong focus on safety can improve employee morale and well-being, as staff feel safer and more valued. This can lead to increased employee retention and attractiveness to potential new hires.
9	Financial Implications	Improved safety often saves costs by reducing accident-related expenses and downtime. Insurance premiums may also be positively impacted.
10	Adaptation and Continuous Learning	Implementing the SLSES can encourage continuous learning and adaptation within the organisation, ensuring that safety practices evolve to meet changing conditions and challenges in the maritime environment.

Source: Author's data

Table 27: Benefits Identified #2 continued

Source: Author's data

In summary, this research suggests that integrating a modified Safety Leadership Self-Efficacy Scale (SLSES) into IMO maritime safety management practices can improve safety leadership, risk management, regulatory compliance, and organisational culture. These improvements could create a safer, more efficient, and resilient global maritime industry.

6.3 Recommendations for future research

While this research has been positive, with informative data able to provide clear benefits to the maritime industry, additional opportunities to conduct further research to expand the sample sizes to a larger group of shipping professionals is needed to enhance ongoing research and improvement into safety leadership, unconscious safety behaviours and organisational safety culture.

While implementing a modified SLSES survey widely within the maritime industry should occur, for such to be implemented by the IMO, further research into a larger sample size across the international shipping community is needed.

Unconscious safety behaviours are a relatively new area of social science with little academic research into its various elements, especially within the shipping and maritime context. Due to this, research questions still need to be answered to identify antecedents that affect organisational and individual unconscious behaviours and human factors that affect safety leadership behaviours in the high-risk maritime environment.

The research has been able to identify 16 antecedents which can affect organisational and individual unconscious behaviours and human factors that affect safety leadership behaviours in the high-risk maritime environment. This research requires further investigation and supportive evidence to hold more weight with the IMO.

Additionally, a greater understanding of unconscious safety behaviours as an independent research body of work would be beneficial in helping further this current dissertation.

More research needs to be conducted into the cognitive antecedents of specific unconscious behavioural safety for this research to draw definitive conclusions regarding the entire understanding of the complete antecedents of unconscious safety behaviours.

While existing research does discuss leadership models, active safety leadership and safety behaviours in detail, it fails to explain why some behaviours are more active in some than others (Dóci et al., 2020). If a clearer understanding of the cognitive functions and interrelations with unconscious behavioural outcomes is explored, this research could provide a far more significant impact and recommendations for change to the IMO and, by association, the global high-risk maritime industry.

6.4 Conclusion

In conclusion, this dissertation used qualitative and quantitative approaches to explore the impact of behavioural-based safety leadership on organisational safety culture in high-risk maritime environments.

The operationalisation of theoretical constructs involves adopting three paradigms—humanistic, positivist, and interpretive. The study incorporates meta-theoretical concepts like behaviour-based safety, occupational health and safety, personality, emotional intelligence, and leadership. This led to the formation of research hypotheses, aiming to reduce adverse incidents and prevent loss of life through behavioural safety leadership while advocating for changes in safety leadership training requirements.

The research methodology involved a comprehensive literature review, empirical case studies, surveys and face-to-face interviews with various military and civilian maritime professionals worldwide.

The population and research sample included senior officers, senior ratings, ships officers, and shipping management ashore.

The research purpose and questions focused on identifying antecedents affecting safety leadership behaviours, comparing their contributions, and outlining a conceptual framework for a Safety Leadership Self-Efficacy Scale (SLSES). The latter includes behavioural safety elements to enhance awareness of unconscious safety behaviours to improve safety leadership and performance.

This research study has confirmed previous research by (Kim et al., 2017; Kim et al., 2021) that leadership behaviours at the top level can impact safety from the top down as was demonstrated in the survey data obtained. Furthermore, the implementation of a modified Safety Leadership Self-Efficacy Scale (SLSES) has shown that a high level of safety leadership from management was present in the surveyed participants. Interestingly, over 90% of respondents had yet to receive any official behavioural safety training. Yet, a high level of safety behavioural awareness was present due to the positive safety culture indicated within the research results. Given this critical fact, one can imagine the effect formal mandated behavioural safety leadership training would have on a positive organisational safety culture both at sea and ashore in the high-risk maritime environment.

Therefore, this research can confirm there is evidence to support changes to the International Maritime Organisation's (IMO) STCW Table A-11/2 (Masters and chief officers), Table A-III/2 (Chief engineering offices and second engineers), Table A-II/1 (Officers in charge of a navigational watch), (EDU Maritime, 2010) to integrate behavioural safety leadership training.

The research attempted to address the overarching problem of understanding unconscious safety behaviours, highlighting the importance of identifying antecedents that influence cognitive responses to hazards while bridging gaps in knowledge regarding the correlation between hazards, antecedents, and cognitive responses in the high-risk maritime sector. While 16 antecedents were identified in the research, the clear linking of these antecedents to cognitive behaviour patterns could not be established.

In summary, this dissertation provided a foundation for understanding and improving safety leadership, unconscious safety behaviours, and organisational safety culture, acknowledging the need for ongoing research and advancements in this critical field to improve safety outcomes for shipping professionals at sea in the high-risk maritime environment.

When safety performance is only measured by incident and injury rates, responses are reactive rather than proactive (Ocon &a McFarlane, 2007). It is, therefore, essential that proactive behavioural-safety leadership training strategies be developed by the IMO and implemented within the formalised training of the STCW system for seafarers to create an additional *IMO Model Course for example Behavioural-based Safety Leadership & Organisational Safety Culture* and add this to the currently mandated IMO Model Courses 1.39 Leadership and Teamwork and 1.40 Use of Leadership and Managerial Skills to address identified areas for improvement.

Table 28: Recommended new IMO Mandated Course

Number	Course Title
1	Behavioural-based Safety Leadership & Organisational Safety Culture

Source: Author's data

APPENDIX A

PHASE 1 SURVEY COVER LETTER

&

PHASE 2 RESEARCH INFORMATION SHEET

PHASE 1 SURVEY COVER LETTER

Behavioural Based Safety Leaderships impact on organisational safety culture and incident causation in the high-risk maritime environment.

Hello,
Thank you for taking the time to contribute to my research into how human factors and behaviour-based safety leadership can positively impact organisational safety culture and incident causation in the high-risk maritime environment. My research is being conducted in two separate studies, detailed below.

Research Study 1.

Study 1 is an anonymous two-part survey (Questionnaire) of 71 multiple choices and 2 written answer questions expected to take up to 15 min to complete.

Part 1 has a series of 38 questions, each linked to a specific area of safety motivation, management, initiatives and behaviour.

Part 2 includes a series of 34 questions linked to a safety leadership self-efficacy scale (SLSES) adapted to the maritime environment.

You are only completing research study 1 today. If you would like to be involved in the interviews for research study 2, please answer YES on the survey's last question.

Research Study 2:

Participants take part in an up to a 30-minute interview with audio or visual aids used to record the interview for transcription purposes. The supervising Professor, Jaka Vadnjal (SSBM), will monitor the interview outcomes but will not be a part of the interview process.

Privacy of Information:

You will be assigned a participant number ONLY for your privacy. No name will be associated with the data analysis process. You will not be identified in the data. You will be required to submit your nominated email address to enable interview correspondence and, once a time and day are agreed upon, a zoom meeting link to conduct the interview. Your interview transcript can be provided to you upon request. Your data will not be on-sold to any third party.

The information obtained during this research study is for Swiss School of Business Management (SSBM) student CJ Manjarres-Wahlberg to conduct research towards his Executive Doctoral of Business Management (EDBA) degree thesis. Your data will ONLY be used for this purpose and will remain confidential.

Typical questions in the Part 2 interview may include:

- In general, what does safety behaviour mean to you?
- Tell me about your experience of safety behaviour in your current organisation?
- Tell me what you know about the Beirut Blast and MV Rhosus, the ship which carried the ammonium nitrate into Beirut that exploded in August 2020? or
- Tell me what you know about the explosions in the Northern Chinese port of Tianjin in 2015 or
- Tell me what you know about the MV Sewol Ferry capsize disaster in South Korea in 2014?
- Having completed this survey and safety leadership training previously. Do you think the current IMO regulated safety leadership training is satisfactory? Please explain your answer.

Kind Regards,

CJ Manjarres-Wahlberg

EDBA Student - SSBM Geneva 2023

Research Phase 2 Information Sheet

Hello,

Thank you for taking the time to contribute to my phase 2 research.

Research Study 2:

This phase of research consists of one up to a 60-minute interview with audio/visual aids used to record the interview for transcription purposes. The supervising Professor, Jaka Vadnjal (SSBM), will monitor the interview outcomes but will not be a part of the interview process.

The information obtained during this research study is for the Swiss School of Business Management (SSBM) Executive Doctor of Business Administration (EDBA) degree thesis. Your data will ONLY be used for this purpose and will remain confidential. Your name will not appear in the thesis at any time and your privacy will be protected at all times, unless you agreed to be quoted directly in the interview consent form you signed.

Questions that will be asked include:

1. In general, what does safety behaviour mean to you?
2. Tell me about your experience of safety behaviour in your current organisation?
3. Tell me what you know about the Beirut Blast and MV Rhosus, the ship which carried the ammonium nitrate into Beirut that exploded in August 2020?
4. Tell me what you know about the MV Sewol Ferry capsize disaster in South Korea in 2014?
5. Having completed this survey and safety leadership training previously. Do you think the current IMO regulated safety leadership training is satisfactory? Please explain your answer.

Thank you for your time.

Regards,

CJ Manjarres W

CJ Manjarres-Wahlberg
EDBA Candidate - SSBM Geneva 2023

APPENDIX B

INFORMED CONSENT

Informed consent: Merchant naval officer

SSBM GENEVA

Interview Consent Form

Research project title: Behavioural Based Safety Leaderships impact on organisational safety culture and incident causation in the high-risk maritime environment.

Research investigator: CJ Manjarres-Wahlberg

Research Participants name:

The interview will take between 45 to 60min. We don't anticipate that there are any risks associated with your participation, but you have the right to stop the interview or withdraw from the research at any time.

Thank you for agreeing to be interviewed as part of the above research project. Ethical procedures for academic research require that interviewees explicitly agree to being interviewed and how the information contained in their interview will be used. This consent form is necessary for us to ensure that you understand the purpose of your involvement and that you agree to the conditions of your participation. Would you therefore read the accompanying information sheet and then sign this form to certify that you approve the following:

- the interview will be recorded, and a transcript will be produced.
- you will be sent the transcript and given the opportunity to correct any factual errors if you wish.
- the transcript of the interview will be analysed by CJ Manjarres-Wahlberg (DBA Candidate) research investigator.
- access to the interview transcript will be limited to CJ Manjarres-Wahlberg and academic colleagues (Professor Jaka Vadnjal supervising professor) and researchers with whom he might collaborate as part of the research process.
- any summary interview content, or direct quotations from the interview, that are made available through academic publication or other academic outlets will be anonymized so that you cannot be identified, and care will be taken to ensure that other information in the interview that could identify yourself is not revealed.
- the recording will only be kept for the duration of the research. On completion of the degree process with SSBM the interview will be deleted.

- any variation of the conditions above will only occur with your further explicit approval in writing.

Quotation Agreement

I also understand that my words may be quoted directly. With regards to being quoted, please initial next to any of the statements that you agree with:

✔	I agree to be quoted directly.
	I agree to be quoted directly if my name is not published and a made-up name (pseudonym) is used.

All or part of the content of your interview may be used;

- In academic papers, policy papers or news articles
- On our website and in other media that we may produce such as spoken presentations
- On other feedback events
- In an archive of the project as noted above

By signing this form I agree that;

1. I am voluntarily taking part in this project. I understand that I don't have to take part, and I can stop the interview at any time;
2. The transcribed interview or extracts from it may be used as described above;
3. I have read the Information sheet;
4. I don't expect to receive any benefit or payment for my participation;
5. I can request a copy of the transcript of my interview and may make edits I feel necessary to ensure the effectiveness of any agreement made about confidentiality;
6. I have been able to ask any questions I might have, and I understand that I am free to contact the researcher with any questions I may have in the future.

[redacted]

Printed Name

[redacted]

Participants Signature

08/06/2023

Date

Researchers Signature

08 June 2023

Date

Contact Information

This research has been reviewed and approved by the Edinburgh University Research Ethics Board. If you have any further questions or concerns about this study, please contact:

Name of researcher:

CJ Manjarres-Wahlberg
Tel: +61 418 824 105
E-mail: cj@hemint.org

You can also contact CJ Manjarres-Wahlberg's supervisor:
- Professor Jaka Vadnjal
- E-mail: jaka@ssbm.ch

What if I have concerns about this research?
If you are worried about this research, or if you are concerned about how it is being conducted, you can contact SSBM by email at contact@ssbm.ch.

This research is not being funded by any third-party individuals or organisations.

Informed consent: Naval officer

SSBM GENEVA

Interview Consent Form

Research project title: Behavioural Based Safety Leaderships impact on organisational safety culture and incident causation in the high-risk maritime environment.

Research investigator: CJ Manjarres-Wahlberg

Research Participants name:

The interview will take between 45 to 60min. We don't anticipate that there are any risks associated with your participation, but you have the right to stop the interview or withdraw from the research at any time.

Thank you for agreeing to be interviewed as part of the above research project. Ethical procedures for academic research require that interviewees explicitly agree to being interviewed and how the information contained in their interview will be used. This consent form is necessary for us to ensure that you understand the purpose of your involvement and that you agree to the conditions of your participation. Would you therefore read the accompanying **information sheet** and then sign this form to certify that you approve the following:

- the interview will be recorded, and a transcript will be produced.
- you will be sent the transcript and given the opportunity to correct any factual errors if you wish.
- the transcript of the interview will be analysed by CJ Manjarres-Wahlberg (DBA Candidate) research investigator.
- access to the interview transcript will be limited to CJ Manjarres-Wahlberg and academic colleagues (Professor Jaka Vadnjal supervising professor) and researchers with whom he might collaborate as part of the research process.
- any summary interview content, or direct quotations from the interview, that are made available through academic publication or other academic outlets will be anonymized so that you cannot be identified, and care will be taken to ensure that other information in the interview that could identify yourself is not revealed.
- the recording will only be kept for the duration of the research. On completion of the degree process with SSBM the interview will be deleted.

- any variation of the conditions above will only occur with your further explicit approval in writing.

Quotation Agreement

I also understand that my words may be quoted directly. With regards to being quoted, please initial next to any of the statements that you agree with:

✓	I agree to be quoted directly.
	I agree to be quoted directly if my name is not published and a made-up name (pseudonym) is used.

All or part of the content of your interview may be used;

- In academic papers, policy papers or news articles
- On our website and in other media that we may produce such as spoken presentations
- On other feedback events
- In an archive of the project as noted above

By signing this form I agree that;

1. I am voluntarily taking part in this project. I understand that I don't have to take part, and I can stop the interview at any time;
2. The transcribed interview or extracts from it may be used as described above;
3. I have read the Information sheet;
4. I don't expect to receive any benefit or payment for my participation;
5. I can request a copy of the transcript of my interview and may make edits I feel necessary to ensure the effectiveness of any agreement made about confidentiality;
6. I have been able to ask any questions I might have, and I understand that I am free to contact the researcher with any questions I may have in the future.

[redacted]

Printed Name

[redacted]

22 June 2023

Participants Signature

Date

22 June 2023

Researchers Signature

Date

Contact Information

This research has been reviewed and approved by the Edinburgh University Research Ethics Board. If you have any further questions or concerns about this study, please contact:

Name of researcher:

CJ Manjarres-Wahlberg
Tel: +61 418 824 105
E-mail: cj@hemint.org

You can also contact CJ Manjarres-Wahlberg's supervisor:
- Professor Jaka Vadnjal
- E-mail: jaka@ssbm.ch

What if I have concerns about this research?
If you are worried about this research, or if you are concerned about how it is being conducted, you can contact SSBM by email at contact@ssbm.ch.

This research is not being funded by any third-party individuals or organisations.

APPENDIX C

INTERVIEW GUIDE

Interview guideline

General

The point of conducting an interview is to allow the interviewee to tell their story in their own words. Interviewing can be a difficult task. It is therefore important that some ground rules are established to help both the interviewer and interviewee to stay on course during the interview process.

The interview is not the same as a survey. You need to stay on course and use this guide to pull the conversation back into line if it starts to go down a rabbit hole.

If possible, trial your questions on a friend or colleague to judge the time and gain feedback for using it operationally.

Interview points

1. Begin the interview with a "warm-up" question that may not be related to the topic to help you both relax.
2. Be ethically sensitive to the interviewee, so that they understand what the research is about and its purpose and that their answers will remain confidential unless they have agreed to statements being used in the dissertation directly.
3. Do not ask more than one question at a time.
4. Structure the interview so it has purpose and meaning.
5. Be clear, ask questions with no jargon.
6. Let the interviewee think and find time to finish their answer.
7. Listen attentively and actively to what is being said and how they say it, empathy can be beneficial in an interview to help the interviewee relax.

8. Be aware of inconsistencies in interviewee replies and challenge if needed to keep your data relevant.
9. Ask clarifying questions if needed to ensure clarity for your data without imposing bias.
10. The social skills of empathy, warmth, attentiveness and humor can assist a good interview.
11. Do not judge the interviewee for any of their responses, remain neutral.
12. Never answer a question for the interviewee.
13. Silence can be a beneficial tool to help an interviewee reflect and amplify a response.
14. Try not to concentrate on the interview time alone. Relax into the interview and let it take its course as much as possible without being disrespectful to the interviewee’s constraints.
15. Adjust the language of the interview to suit the interviewee.
16. Take care to word questions so that interviewees are motivated to response honestly and completely to the question.

APPENDIX D

JOURNAL ARTICLE:

A Stamp-Based Casual Analysis of The Korean Sewol Ferry Accident

A STAMP-based causal analysis of the Korean Sewol ferry accident

Article *in* Safety Science · March 2016

DOI: 10.1016/j.ssci.2015.11.014

3 authors:

Tae-eun Kim
Univeristy of Tromsø (UiT) The Arctic University of Norway

Salman Nazir
University of South-Eastern Norway

Kjell Ivar Øvergård
University of South-Eastern Norway

Safety Science 83 (2016) 93–101

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/ssci

A STAMP-based causal analysis of the Korean Sewol ferry accident

Tae-eun Kim *, Salman Nazir, Kjell Ivar Øvergård

Training and Assessment Research Group, Department of Maritime Technology and Innovation, Buskerud and Vestfold University College, Postboks 4, 3199 Borre, Norway

ARTICLE INFO

Article history:
Received 27 July 2015
Received in revised form 18 October 2015
Accepted 14 November 2015
Available online 30 November 2015

Keywords:
Sewol ferry
Socio-technical systems
STAMP
Maritime safety
Accident analysis
Safety engineering

ABSTRACT

The increased complexity of socio-technical systems has revealed the limited contributions of existing event-based accident analysis methods on sustainable safety improvements. Systems-Theoretic Accident Model and Processes (STAMP) – constructed upon Systems Theory – deploys a holistic approach to safety and provides broad insights into accident causality via the integration of the analysis from both direct and indirect factors involved. A dedicated STAMP-based analysis is conducted in this paper by taking the recent Sewol ferry tragedy as an example, to illustrate the utility of applying the STAMP-Model to the maritime transportation domain and to stimulate a broader view of accident mechanisms that expands casual analysis beyond immediate physical failures to a systemic view. Some recommendations are developed for continuous improvements and corrective actions to prevent such catastrophic accident from future occurrences.

1. Introduction

The implementation of numbers of safety-related regulations (IMO, 2015) and advances in technology and automation systems (*e.g.*, Hetherington et al., 2006) have steadily evolved the safety level of marine transportation (Allianz Global Corporate and Speciality, 2015). Yet despite the continuous improvement, the recent foundering of Costa Concordia (Schröder-Hinrichs et al., 2012), Norman Atlantic (Vairo et al., 2015) and Sewol – with the losses of innocent lives – have demonstrated unforeseen and sadly cataclysmic vulnerabilities, further underscored long-standing concerns over the safety of passenger ships.

Maritime transportation has been referred as an 'error-inducing system' (Perrow, 1999; Rijpma, 2003). It has been considered as a profit-oriented, authoritarian, poorly organized, and weakly unionized industry (Linstone et al., 1994; Burke et al., 2011), in which multiple errors might bring out unexpected interaction that can defeat a safety system (Perrow, 1999). In such a system, operator error is prominently given as an explanation for an accident as failures and consequences of actions appear immediately at the level of proximate personnel. This argument has put pressure on the identification and elimination of human errors, which has long been considered activities of critical importance for maritime accident investigation. This traditional view of safety has been criticized by many researchers (*e.g.*, Woods et al., 1994; Amalberti, 2001; Leveson, 2004; Dekker, 2006; Hollnagel, 2008), as it confuses safety with reliability (Besnard and Hollnagel, 2014). The growing complexity of socio-technical systems, in which humans and their habits are integrated parts of the technical system (Qureshi, 2007), indicates that safety analysis needs to consider not just individual reliability but also how the combination of system components as a whole interact with each other in such way to promote errors and accidents (Leveson, 2004; Salmon et al., 2015). Thus, focusing on eliminating individual errors and revealing so-called 'root causes' without improving the system design and constructing an effective safety control system to prevent those unsafe interactions, new accidents arising from other 'root causes' will continue to occur.

Several authors (*e.g.*, Reason, 1997; Rasmussen, 1997), in discussing the "safety space", have argued that socio-technical systems tend to drift toward states of higher risk. The performance of the actors within a socio-technical system is always constrained by the surroundings, *e.g.*, administrative, competitiveness, economic benefits and safety related constraints, which creates a small space of freedom for designers, operators, and managers to perform their work tasks with little considerations given to the feasibility and consequences (Rasmussen, 1997). Thus, accident analysis should incorporates the circumstances that induce variation in behaviors as well as the dysfunctional interactions among correctly operating components.

Several accident analysis models *e.g.*, Functional Resonance Analysis Method (FRAM) (Hollnagel, 2012), AcciMap (Rasmussen, 1997), have been developed on the basis of systems approach (Underwood and Waterson, 2013). The current study uses Leveson's Systems-Theoretic Accident Model and Processes (STAMP) Model as (1) it encompasses both engineering development and operational

* Corresponding author. Tel.: +47 48659634.
E-mail address: taiqi@me.com (T. Kim).

http://dx.doi.org/10.1016/j.ssci.2015.11.014
0925-7535/

aspect of the system, thus gives a broader representation of the factors influencing behavior and safety; (2) STAMP assists in understanding the entire accident process and further promotes generating complete recommendations for improving the overall system safety; (3) it provides formal basis and a more structured approach that can be suitably applied to maritime domain.

As of today, most studies in the field of Systems Theory together with STAMP have been applied to aerospace systems (Leveson, 2004), railway transportation (Ouyang et al., 2010; Underwood and Waterson, 2014), water contamination accident (Leveson et al., 2003), U.S. Army friendly fire shootings (Leveson et al., 2002), biodefense (Laracy, 2006) and aircraft accidents (Nelson, 2008). However, to the authors' knowledge no single study exists which covers in particular the marine transportation industry within the subject of passenger ship.

To fill this knowledge gap, a dedicated STAMP-based accident analysis is conducted by taking the case of the capsizing Sewol – the Korean Ro-Ro passenger ship – as an example to illustrate the appropriateness of STAMP application to the analysis of maritime accidents, with the aim to emphasize on why the accident occurred and how to prevent similar losses in the future.

2. STAMP methodology

The STAMP is, as an accident analysis model, constructed upon basic Systems Theory (Leveson, 2011) and focuses on inadequate control or enforcement of safety-related constraints on the system design, development and operation (Leveson, 2011). It provides a systemic view of causality, and examine non-linear, indirect, and feedback relationships between events (Ouyang et al., 2010). STAMP views systems as hierarchical structures with multiple control levels. Each level in the hierarchy imposes constraints on the activity of the level beneath it, the events leading to losses only occur when safety constraints were not successfully enforced or the constraints have been violated (Leveson, 2011). The potential for unsafe control may exist in the original design of the safety control structure and the controls may degrade over time, allowing the system to move to states of increasing risk.

In contrast, many traditional accident analysis techniques such as Event Tree Analysis (ETA), Failure Modes and Effects Analysis (FMEA), Fault Tree Analysis (FTA), Cause-Consequence Analysis rely on a chain-of-event paradigm of causation (Qureshi, 2007), and deal with systems and the environment as a static design and unchanging structure (Leveson et al., 2003). Thus, arguably inappropriate for the study of modern engineering systems, especially complex software-intensive systems, complex human–machine interactions, and systems-of-systems with distributed decision-making that encompass both physical and organizational aspects (*e.g.*, Dulac, 2007; Leveson, 2011).

STAMP considers the dynamic nature of systems, identifying missing or inappropriate features (those which fail to maintain the constraints). It proceeds through analyzing feedback and control operations, which replaces the traditional chain-of-events model. Causal Analysis based on STAMP (CAST) (see Table 1) is one of the dedicated techniques and processes for accident analysis (Leveson, 2011) that was constructed by using STAMP as theoretical foundation.

CAST provides a framework to examine the entire accident process involved in the accident, identify the most important systemic causal factors involved (Leveson, 2011), with a focus on why the accident occurred and thereby succeeding in preventing future occurrences. The sequence of the analysis steps performed in this work has been slightly changed with the proximate event being presented before the start of the main analysis of the accident. Information about the Sewol accident and the control structure constructed in this work was obtained from the original investigation reports of Korean governmental agencies (*e.g.*, MOF, 2014; KMST, 2014) and available literature (*e.g.*, Cho and Yoon, 2015; Hwang, 2015; Zhang and Wang, 2015) detailing the events.

Table 1
Causal Analysis based on STAMP (CAST) process (adapted from Leveson (2011)).

Step No.	Description of steps
1	Identify the system(s) and hazard(s) involved in the accident
2	Identify the system safety constraints and system requirements associated with that hazard(s)
3	Document the safety control structure in place to control the hazard and enforce the safety constraints
4	Determine the proximate events leading to the accident
5	Analyze the accident at the physical system level
6	Moving up the levels of the safety control structure, determine how and why each successive higher level contributed to the inadequate control at the lower level
7	Analyze overall communications and coordination contributors to the accident
8	Determine if there were any changes to the system hierarchical safety control structure over time that migrated the system to a less safe position and contributed to the accident
9	Develop recommendations

3. CAST analysis of the capsize of Sewol accident

3.1. The proximate events

The following facts can be established as far as the official investigation reports stated:

On the 16th April 2014, the 20-year-old Korean flag Ro-Ro passenger vessel – Sewol (6825 tons) capsized during a frequent domestic voyage from Incheon to Jeju island leaving from port with more than 2 times overload condition (2142.7 tons of cargo loaded, compare with authorized limit 987 tons) (MOF, 2014). The capsizing led to the loss of 295 lives (excluding missing passengers), most of whom were high school students.

The ship traveled at about 18.9 knots under manual control by a third mate and helmsman. The Captain was absent from the steering room at the moment of the accident when the ferry entered the Maenggol Channel (KMST, 2014) – an area that was notorious for its strong and fast underwater currents. The third mate was monitoring the radar and gave two orders to the helmsman to turn starboard from 135 degrees to 145 degrees true course (KMST, 2014). According to the official report, these two 5-degree commands were inferred to be enacted with unnecessarily large rudder angle based on simulations. The changes in combination with the high speed resulted in a noticeable outward heel (15–20 degree) that caused it to lean sharply to port, which shifted the improperly stowed and secured cargo to the port side and further increased list. This allowed water to pour into the ship through the side door and the cargo access door located at the stern, and quickly developed a 60-degree list to port (MOF, 2014). Additionally, the ship did not carry sufficient amount of ballast (761.2 tons compare with required 1703 tons when fully loaded) although this was recommended by classification society at the time of approval (KMST, 2014). Progressive flooding within the superstructure exacerbated the situation, and in conjunction with the added effect of the fast underwater current, the vessel´s list gradually increased until it capsized. A mayday call was transmitted via a working radio channel – Very High Frequency (VHF) 12 to contact the coastguard for rescue assistance. However, master and crew failed to provide timely evacuation instructions on board and the 44 available life rafts were not properly launched. Also, passengers were repeatedly told to stay where they were, thus prevented an early plausible evacuation and trapping the passengers inside the vessel.

3.2. Hazard identification, control structure

Leveson (2011) defines a hazard as "a system state or set of conditions that, together with a particular set of worst-case environmental conditions, will lead to an accident" (p.184). The system hazard related to the accident is the vulnerable stability of the vessel that causes fatalities, injuries or property damage during sailing. Accordingly, the hazard entails the following system safety constraint: (1) the vessel itself must have sufficient intact stability and steering ability for safe operation. The safety control structure must prescribe criteria for approving ship designs, accepting new buildings/conversions at the system development stage; (2) during operations, the safety control structure must ensure a satisfactory stability of the vessel to be allowed to sail out of port, and control any potential risks (*e.g.*, overloading, inappropriate cargo stowage and securing, improper maneuvering) that might allow the vessel to exceed the safety stability constraints; (3) moreover, appropriate emergency preparedness and response must be ensured, rapid rescue operations must be initiated after the loss of stability by the master and crew on board in coordination with other emergency responders (*e.g.*, coast guard, vessels in the vicinity).

Fig. 1 shows the hierarchical control structure that ensures safe development and operation of passenger ships in South Korea. The hierarchal control structure starts with the government who has the authority and responsibility for establishing guidelines and legislations to enforce regulations over vessels registered under its flag, while complying with the conventions from the International Maritime Organization (IMO) that are ratified by the state for domestic voyage.

As shown in Fig. 1, guidelines are provided to the Ministry of Oceans and Fisheries (MOF) who then give regulations, policies and certificates to the Korean coastal passenger transportation industry down to the captain and crew involved in the ship operation must comply with. MOF sub-delegated authority to a classification society – Korean Register of Shipping (KR) – for issues related to approvals of designs, surveys and classification matters, particularly in relation to ship design, structure, load lines, machinery and equipment requirements. The Korea Coast Guard (KCG), as an external branch of MOF, has primary responsibility for approving operation planning reporting provided by shipping companies, and further supervises and directs inspection practices conducted by the Korean Shipping Association (KSO) (MOF, 2014).

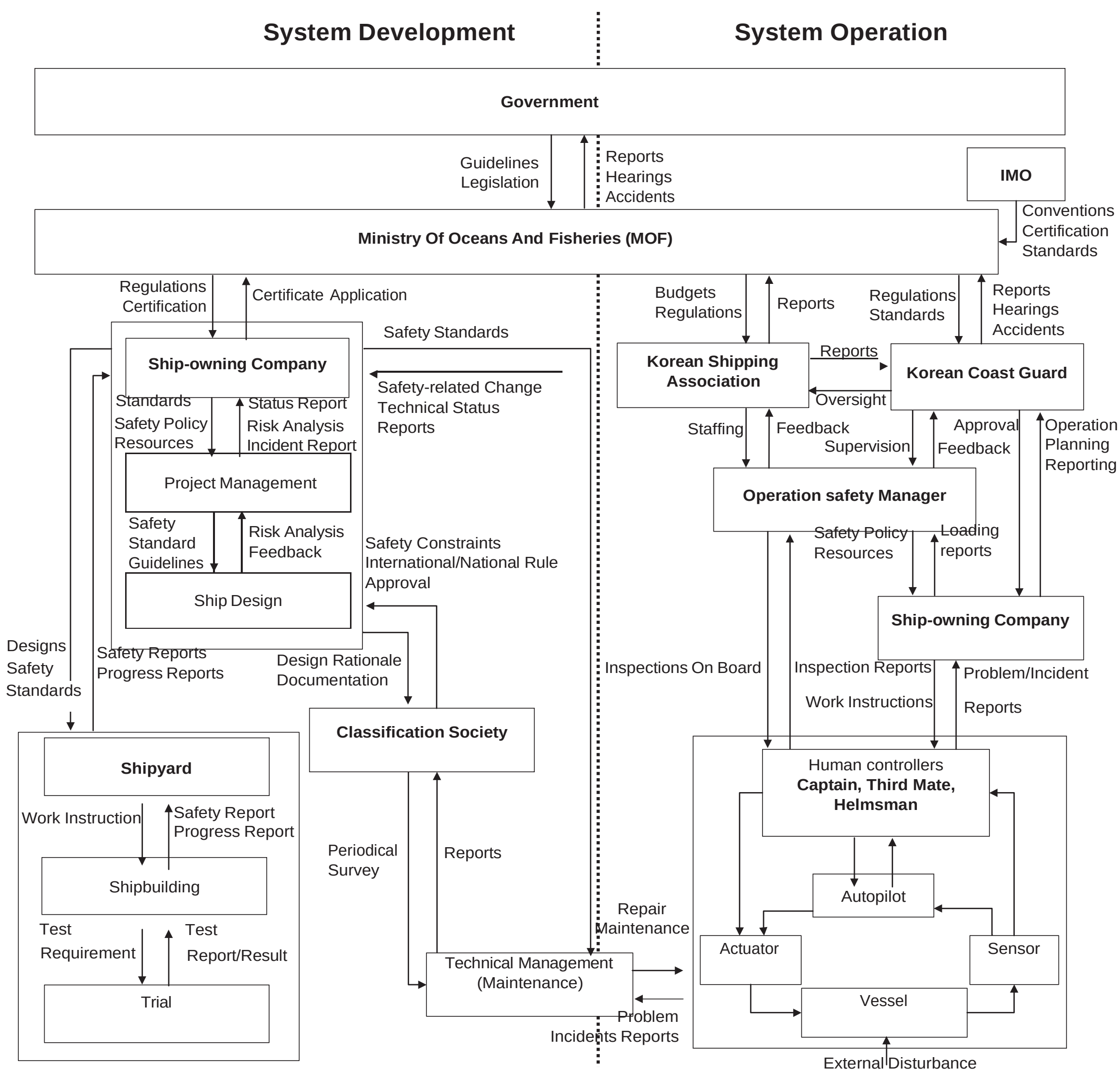


Fig. 1. The hierarchical control structure that ensures safe development and operation of passenger ships in Korea.

Ship-owning company has responsibility for enforcing policies and regulations that apply to the operation of the vessel, ensuring ships are operated in a sufficient condition that ensures safety of the crew and passengers. They further have the responsibility for continuing training requirements for crew to maintain competence as knowledge about safety, for appropriately maneuver the vessel, for correctly take out emergency actions and so on (KMST, 2014).

Together, the safety constraints enforced by all of these controllers must be adequate to enforce the overall safety constraints. It should be noted that the model of safety control structure shows in Fig. 1 incorporate the development stage of the vessel (on the left) and those involving the physical control in the operational part of the system (on the right), as safety during operation not only depends on the design and construction of the vessel, but also on effective control during operations. Each controller designed within the hierarchy of the passenger ship safety control system – has its own responsibilities for enforcing safety constraints appropriate for that component. These responsibilities and authorities taken together must enforce the safety constraints through the vessel design, operation, maintenance and management.

3.3. Constructing accident causation

The above mechanisms (see Fig. 1) would theoretically ensure ships and shipping activities are fully compliant with all applicable requirements throughout the ship's life. However, this is known not to be the case in reality as operators or organizations strive to deal with economic and efficiency pressures oblige to continue to jeopardize life, property and the environment. Following Sections 3.1 and 3.2, the causation of the capsizing of Sewol is constructed in this Section by gathering information about how the hazards could happen, and inspecting the control loop for each hazardous control action to specify its impact on the accident. The key components from the control structure were selected for further analysis – crew, ship-owning company, classification society, relevant government regulatory agencies and industry association. The violated safety constraints, mental model flaws, as well as inadequate enforcement of control actions or missing feedback were determined and analyzed.

3.3.1. Analysis of the physical system

The physical process of the vessel system is shown in Fig. 2. The physical process being controlled is the operation of the Ro-Ro passenger vessel to ensure a safe and efficient navigation through coastal waters. The Sewol is controlled in two main modes: either manually where navigators manipulate actuators (*e.g.*, rudder, propellers), or automatically where the vessel is controlled by the autopilot that manipulates the actuators to follow a pre-programmed route. Despite the Sewol being under automatic control, crew still need to monitor the autopilot and the vessel´s course and speed, and they must regain manual control if the need to do so arises.

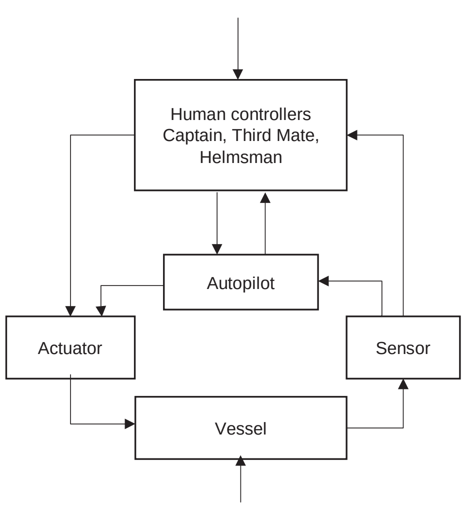


Fig. 2. Vessel Operating Process.

Before entering the Maenggol Channel the third mate turned off the autopilot. This was the first time the third mate steered toward Jeju Island (KMST, 2014). As the crew of Sewol was the real controller prior to and during the accident, the contextual and behavior-shaping mechanisms will be analyzed and discussed in detail to reveal how they contributed toward accident causality (see next Section 3.3.2).

The limitation of the physical system design is that ships of this type (RO-RO passenger) have un-subdivided deck, and a very large superstructure compared with other types. Such vessels often suffer from extremely high lever arm alterations, shorter rolling periods, and consequently are critically endangered by high transverse acceleration forces (IMO, 2006). Given the large free surfaces in the ship, sudden movements of the vessel can cause the cargo on the vehicle deck to break loose from their lashings and pile up on the low side of a listing deck that can result in insufficient upright metacentric height (GM) force.

Sewol was originally constructed and operated in Japan from 1994 and it was bought by Chonghaejin at 2012 and modified in a Korean yard to boost capacity. Modifications included adding extra passenger cabins and raising the cargo capacity that would have compromised her intact stability and evacuation performance to some extent (Hwang, 2015; KMST, 2014).

At the time Sewol departed from Incheon port, the ship was overloaded significantly (2142.7 tons of cargo loaded, compare with authorized limit of 987 tons) with improperly secured cargos and insufficient ballast. The partially filled ballast tanks had potential to create a large free surface effect and which, combined with cargo shifting and overloading, resulted in a negative GM and caused the vessel to capsize, as described in the investigation report. All risk factors of the system and the environmental context bring the vessel into an unacceptable high-risk state for the proximate operators, *i.e.*, master and crew, to trigger the undesirable interactions and defeat the system.

3.3.2. Crew level analysis

The CAST framework is a bottom up approach, starting at the lowest level. The personnel with the closest proximity to the actual process controlled, *e.g.*, the crew onboard the ship, that was involved in the loss at the physical system level, will be addressed first.

Fig. 3 shows the results of a STAMP-based causal analysis of the Sewol ferry operators. The crew is responsible operating in compliance with ship-owner and flag state's rules and instructions to perform safe and efficient ship operation. Master and crew are required to know the (physical) limitations of vessel, being aware of the ship loading condition, ballast condition and potential hazards. Navigation, transmission of information, cargo securing and stowage, and other activities must be ensured that are conducted within the safety constraints in accordance with Korean Seaman's Acts (Kim, 2011). The seafarers employed on passenger ship are required to provide proper evacuation plans and instructions in case of emergency situations, as per their instruction manuals (Kim, 2011).

Evidence from the accident investigation report (KMST, 2014) ascertained that master and crew of Sewol failed to conduct adequate inspection to prevent cargo movement through proper securing and stowage, and failed to perform cautious maneuvering

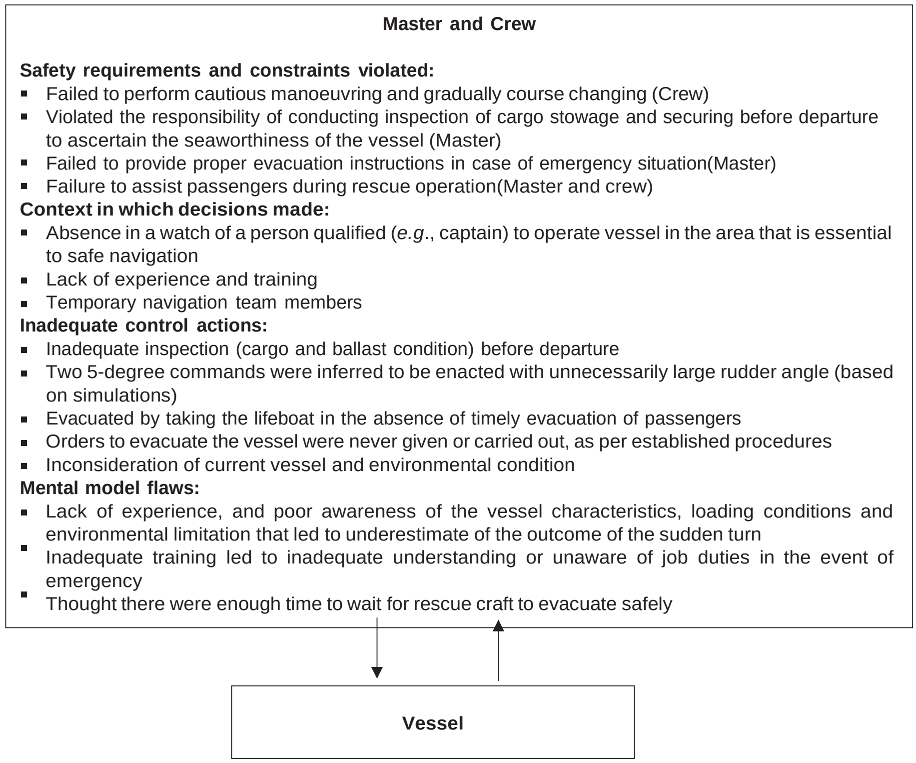


Fig. 3. The analysis at the ship master and crew level.

and gradually course changing. The context in which the third mate continuous course changing order was made affected her performance, namely the absence of the captain or first mate whose presence on the bridge when the ship was operating in the challenging area could be considered essential to safe navigation. Following the two continuous commands issued by the third mate, the rudder angle carried out by the helmsman was inferred to be unnecessarily large that cannot be accepted under current state of the vessel. However, the analysis of the explanation of the actual rudder angle is complicated by the fact that it might be a technical flaw of the rudder which resulted in the rudder performance not being consistent with the order, or it may has been an oversteering made by the helmsman or could be caused by other unidentified facts.

In either case, the large rudder angle – regardless of originating from a human control flaw or from a technical error, when combined with the significant overload condition, cargo shifts and the insufficient amount of ballast water, give a plausible technical explanation to the sudden heeling motion of the ship. Strong underwater current where the capsizing occurred may have interacted with the unfortunate physical conditions described of cargo, rudders and ballast to increase the magnitude of the heeling motion. Flaws in both of the navigators (*i.e.*, third mate and helmsman) mental models include their inaccurate assessment of risk with poor awareness of the overloading conditions, vessel characteristics and limitation imposed by the external environment. The inconsistency between their mental maps and state of the system led to an underestimation of the effect of issuing and executing the control commands.

As the Sewol sank, the life rafts that had not been launched by the crew did not automatically deploy, nor were they required to do so (KMST, 2014). The captain executed inappropriate decisions and actions by giving repeated orders to passengers to stay in their cabins, rather than issue and provide appropriate evacuation instructions on how to proceed over the public address system. He thought the cold and fast ocean waters were unsafe without rescue boats present and assumed there were enough time to wait for rescue craft to evacuate safely. Another factor that might have influenced behavior, according to the investigation, was that among the 15 crew members in charge of navigation, most were temporary contract seafarers. A relatively low degree of engagement and cooperativeness may be inferred that contributed to the poor performance under emergency situation, which can also be observed from the improper actions taken by captain, first mate and chief engineer who abandoned the ship leaving no evacuation instructions to the passengers. Inadequate emergency response during the chaotic moments reveals the incompetency of the crew to enforce established safety constraints, due to an apparent poor state of preparedness, improper training, and inadequate understanding or lack of awareness of their duties as defined by their roles.

Accordingly, inappropriate issue and execution of vessel command, poor awareness of hazards, failure to provide evacuation instructions on time, and failure to assist passengers by master and crew during rescue operation are considered the flawed control actions identified in CAST that trigger the accident to take place at the sharp-end level.

3.3.3. Ship-owning company level analysis

Fig. 4 summarizes the role of the ship-owning company in the accident. Many of the flawed decisions and control actions taken by the master and crew onboard of Sewol can be explained and understood by examining this level. The ship-owning company of Sewol ferry, performed all forms of ship management services: technical, crew, and commercial management that involve vessel operation, maintenance, fleet management, crew recruiting and training, etc. For the operational aspect (see Fig. 1), the owning company violated the safety constraints that stipulate that it is responsible for ensuring all seafarers in its employ are suitably

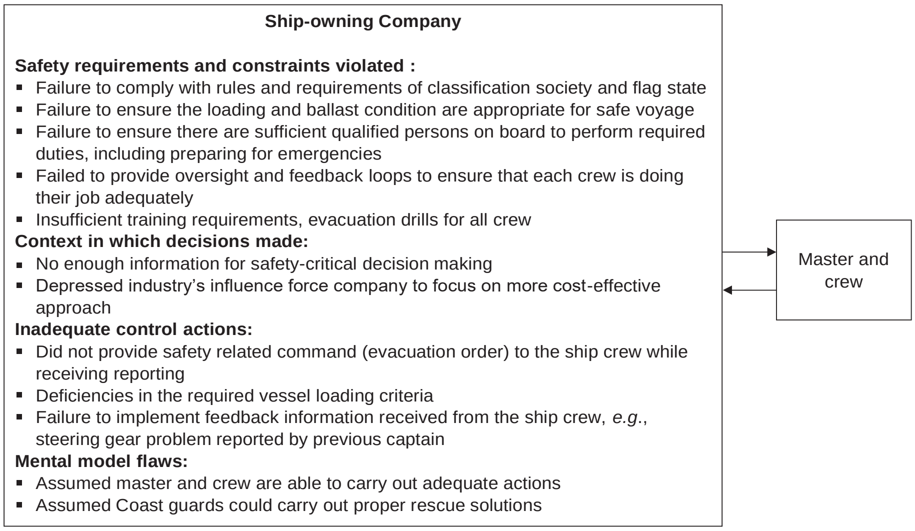


Fig. 4. Ship-owning company level analysis.

instructed in the hazards connected with their work and the shipboard environment to avoid accidents and injuries (KMST, 2014).

The conversion of the Sewol ferry was verified by classification society and given the class, nevertheless, several operational recommendations that were laid down on the ballast and loaded cargo condition of the ship. The main stipulation was that it should operate with an additional 1333 tons of ballast with less cargo than the limits before modification (KMST, 2014). The ship-owning company violated the constraints placed by the classification society illegally overloading the vessel with cargos, and release certain amount of ballast in order to prevent the displacement of the vessel exceeding required load line that can be observed by the supervisory authorities at port. Furthermore, the plan of stowage and securing of cargo units and vehicles approved by classification was not enforced explicitly by the person in charge within the owning company. The use of ISO standard 8 feet containers results in inefficiency in lashing, as the container loading area of Sewol imported from Japan are designed for standard 10 feet containers (Korea Maritime Institute, 2014; KMST, 2014). The safe operation was compromised with a vessel that had inadequate stability characteristics allowed to be in service.

In this occurrence, the owner failed to provide sufficiently qualified personnel on board to perform required duties or provide enhanced awareness of their safe practices during normal and emergency operations. The negligent training results in crew that are unaware of the stability characteristics of their vessel and the general principles involved that may unknowingly place themselves and their vessel at undue risk. At the time of accident, the ship-owning company received the reporting from the captain but did not provide adequate orders regarding to evacuation and assumed that the crew would take care of the problems. Owner also neglected the feedback information received from the ship, *e.g.*, a steering gear problem was reported by a previous captain (KMST, 2014), which reflects the ineffectiveness of the problem-reporting channel. At this point, it appears that its communication channels and safety management system had not been adequately established by the ship-owning company for operators to express the concerns when a hazardous condition is detected onboard, several recommendations can be generated from this part of analysis (see Section 3.4).

3.3.4. Classification society

The flag state's responsibilities of technical inspection and survey are delegated to a classification society – Korean Register of Shipping (KR) (MOF, 2014), the interaction among the primary high level controllers involves in operation and development of the vessel are showed in Fig. 5. Thus, KR verifies the ship, the construction and condition of which that satisfy the applicable rules and requirements, and register it with the corresponding class and class notations.

The most significant role of KR in relation to this accident is the relative inspections and calculations regarding the issuance of modification design of Sewol. KR approved the modifications (as all safety margin calculations meet with the required standards) only as long as certain operational conditions were met, involving the loading and ballast condition of the ship as previously mentioned. The actions of KR were consistent with their process model of normal vessel inspection and survey. However, for some reasons, information feedback between the classification society and the flag state authorities is missing (see Fig. 5) – the certain loading limits of vessel that have been recommended by classification society were only given to the company but not recognized by other authorities, resulting in the instructions becoming ineffective.

Inadequately communicated feedback about the safety constraints enforcements implied by the Classification indicates weaknesses of the safety control structure that need to be revised or redesigned to ensure the effectiveness of measuring channels.

3.3.5. Government regulatory authorities and industry association

The flag state authority should provide appropriate inspection services to enforce or administer the application of the provisions of national laws and regulations. Where the safety of the ship, crew and passengers are endangered, the authority should, in accordance with national laws and regulations, take effective measures to ensure that the ship is prohibited from leaving port until such deficiencies have been remedied and compliance with the relevant laws and regulations assured (KMST, 2014).

In this case, the mission of technical inspection and survey is delegated to classification society – KR as previously mentioned, the operational capability inspection is delegated to Korean Coast Guard (KCG) and further to the Korea Shipping Association (KSA) (MOF, 2014). KSA – as a private industry association that represents the interests of shipping companies engaged in coastal shipping, undertake the responsibility of monitoring and inspecting the departing condition of the ship at port on behalf of KCG. Thus, this reallocation of regulatory responsibility has moved the passenger ship safety control to a decentralized industry self-regulation process, but whether such industry self-regulation raise the problem

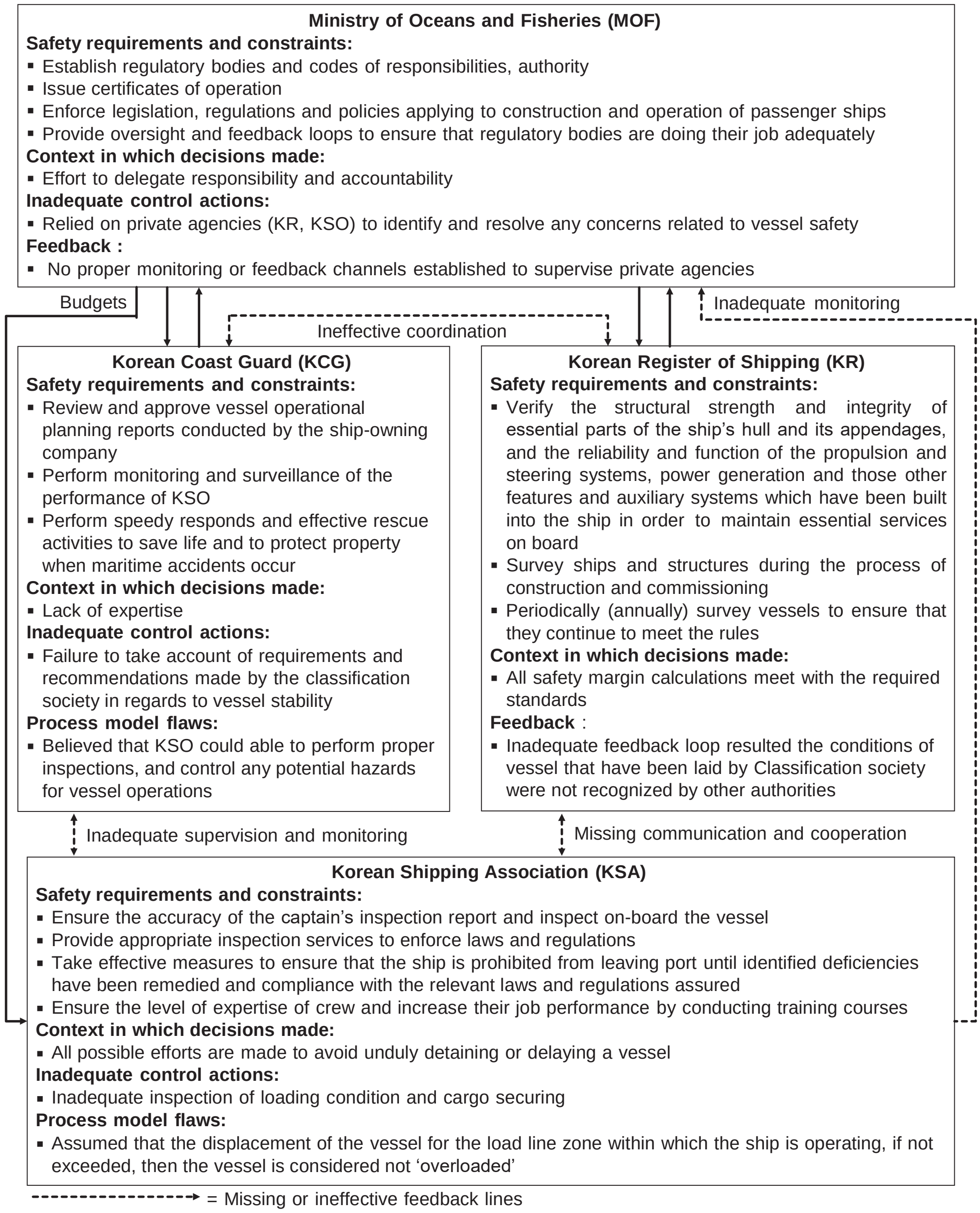


Fig. 5. Analysis of classification society, industry association and government regulatory authorities.

of opportunistic behavior among members, however, did not mention in the official report, thus will not be considered further in this analysis.

KSA simply observed the displacement of the vessel for the load line zone within which the ship is operating. If not exceeded, then the vessel is considered not 'overloaded'. KSA obviously violates the formal procedures (KMST, 2014) to ensure the accuracy of the captain's inspection report regarding the loading condition of the vessel, or inspect the safety equipment on-board, or take any effective measures to ensure that the ship is prohibited from leaving port until identified deficiencies have been remedied in compliance with the relevant laws and regulations assured.

The negligent inspection practice may have resulted from inadequate routines or possible efforts that were made to avoid unduly detaining or delaying the vessel further as Sewol had already been delayed due to fog. The context within which their decisions and control actions take place was that KSA were unaware of the loading limits that were recommended by the classification, necessary information thus being incomplete for KSA decision makers. Failure to exchange such essential information and poor cooperation among governmental agencies and the industry association have vital influence on the attainment of an accurate and acceptable level of vessel safety control.

3.4. Recommendations

To prevent reoccurrence of similar accidents in the future and as a result of the analysis of the accident involving the Sewol Ro-Ro passenger ship, an effective safety assurance and control structure should be redesigned and constructed from the integration of all layers, rather than simply attempt to fix the apparent 'symptoms' (*e.g.*, either the crew failings, the KCG or the KSA in isolation).

The problem detected during the CAST analysis of this study generates the following safety recommendations for preventing similar losses in the future:

(1) Thorough improvement should be carried out on the entire safety control structure, proper measuring channel, such as feedback that reflects the effectiveness of safety constraints need to be designed for continuous improvements and corrective actions.
(2) Establish integrated and corporate safety information system to maintain accurate process (mental) models of all system controllers to assist in their decision making.
(3) The safety limits of the vessel should be based on the shipyard's original design and the level of upgrading with respect to increased requirements or limits. A thorough risk assessment should routinely be carried out to ensure safe working practices. Continuous monitoring of risk and identifying potential areas of concern before they develop into hazards should be given priority. Constrain hazards before they lead to accidents.
(4) The ship's command should desist from taking risks and give absolute priority to the safety of the vessel and passenger, which also includes the securing of cargo and provision of a sufficiently intact lashing system in accordance with requirements to maintain ship stability.
(5) Crew of Ro-Ro passenger ships should be properly trained for accurate and immediate actions during emergency, and should have clear instructions on maximizing their vessels' chances of survival in cases of water ingress to the car deck. The training should address day-to-day shipboard operations, risk assessment procedures as well as contingency planning and emergency preparedness.

4. Discussion

The analysis of the tragic capsizing of the Sewol Ro-Ro passenger ship was approached from a systemic perspective by examining weaknesses in the safety control structure. The model of STAMP-based casual analysis has served the two main aims of the paper:

- Posed questions on systemic issues of Sewol accident and uncovered the rationale behind the decisions that were made leading up to this huge death toll.
- Illustrate the utility of applying the STAMP-Model to the maritime transportation domain to stimulate a broader view of accident mechanisms that expands the analysis beyond immediate physical failures to a systemic view. This insight in turn ensures that a systems approach can be taken to the design of robust safety systems.

As Leveson (2011) pointed out, if the purpose of accident analyses is to find the "root cause" or someone to blame, we might lose the sight to seek potential opportunities to maximize what can be learned from the accident.

The rudder command – regardless of whether it was a flawed human decision or a technical error, should not be addressed as a primary explanation for Sewol accident. The financial incentives and cost-cutting efforts to ship-owners moved the vessel to an unacceptable high risk state in which accidents are inevitable. Government regulatory agencies and industry associations failing to enforce proper constraints or establish effective feedback channel to ensure safety–critical information and activities are being carried out correctly and that adaptions at lower levels have not moved operations beyond safe limits. Thus, the improperly designed vessel safety control structure with unbalanced responsibility created an unacceptable hazardous condition. Those making decisions regarding vessel conversion design, approvals, cargo arrangement, crew management, vessel operation and inspections were ignored or unaware the negative impact of their decisions on other parts in the safety systems.

Some of the components were indeed operated 'reliably' in terms of making decisions (*e.g.*, KR) based on their context and information they had, however, poor coordination and communication, dysfunctional interactions among the components of the total safety system played a critical role in leading to the hazards involved and escalating to an accident. Obviously, many of these systemic casual factors are only indirectly related to the immediate events and conditions. The STAMP-based analysis of Sewol tragedy conducted in this work has demonstrated both of the direct and indirect casual factors associated with the accident that were not identified by those conducted under traditional analysis methods (*i.e.*, Zhang and Wang, 2015).

Whilst no burden can be lifted from those whose lives have been so radically changed, the Sewol tragedy provides an important lesson for the passenger transport industry. It highlights the needs for taking a systems approach to the detection and prevention of breaches of safety constraints and calls for corrective actions at both national and international level. Only then can we supersede the quick fixes of symptoms provided by individual components of the system and get to the true cure.

5. Conclusion

Despite the endeavor of international organizations, flag and port administrations and classification societies in terms of promulgating regulations and requirements that make the maritime industry safer overall, the responsibility for ensuring the safety of ships, crew and passengers must initiate from the owners themselves. The reality calls for a cost-effective safety management approach that balance safety with economic, efficiency, performance constraints, which do not cause the degradation in safety efforts over time.

The STAMP-based casual analysis method has assisted in exploring and constructing accident causation via a holistic and systematic approach, and uncovered the rationale behind the decisions that were made leading up to this huge death toll. Nevertheless, limitations associated with the application of STAMP on maritime domain are also recognized: (1) a thorough and in-depth CAST analysis requires extensive data associated with the overall system that may difficult to be fully obtained from available resources; (2) the recommendations generated in the analysis may also face difficulties to be substantially and timely carried out.

The case of the capsizing of the Sewol ferry surely still has a lot of unsolved questions, and whilst this study provided some new insights to encourage further discussion and research into the establishment of effective measures for national and international maritime safety control and management.

References

Allianz Global Corporate and Speciality, 2015. Safety and Shipping Review 2014. <http://www.agcs.allianz.com/assets/PDFs/Reports/Shipping-Review-2015.pdf> (retrieved June 9, 2015).

Amalberti, R., 2001. The paradoxes of almost totally safe transportation systems. Saf. Sci. 37, 109–126.

Besnard, D., Hollnagel, E., 2014. I want to believe: some myths about the management of industrial safety. Cogn. Technol. Work 16 (1), 13–23. http://dx.doi.org/10.1007/s10 111-012-0237-4.

Burke, R.J., Cooper, C.L., Clarke, S., 2011. Occupational Health and Safety. Gower, Burlington, VT.

Cho, J.K., Yoon, S., 2015. A note on the marine policy of the ferry Sewol-ho disaster in Korea. Am. J. Appl. Sci. 12 (3), 229.

Dekker, S., 2006. The Field Guide to Understanding Human Error. Ashgate, Aldershot.

Dulac, N., 2007. A framework for dynamic safety and risk management modeling in complex engineering systems. Ph.D. dissertation, Engineering Systems Division, MIT February 2007.

Hetherington, C., Flin, R., Mearns, K., 2006. Safety in shipping: the human element. J. Saf. Res. 37 (4), 401–411.

Hollnagel, E., 2008. Risk + barriers = safety? Saf. Sci. 46, 221–229.

Hollnagel, E., 2012. FRAM: The Functional Resonance Analysis Method. Ashgate, Aldershot, UK.

Hwang, Kwang il, 2015. Comparative study on predictions of passengers' evacuation performances before and after the remodeling of MV Sewol. J. Korean Soc. Mar. Eng. 39 (1), 105–114.

IMO sub-committee on stability and load lines and on fishing vessels safety, 2006. Benchmarking for a proposal of a probabilistic intact stability criterion. <http://www.imo.org> (retrieved June 9, 2015).

IMO, 2015. Safety regulations. <http://www.imo.org/> (accessed 27.07.2015).

Kim, In Hyeon, 2011. Transport Law in South Korea (IEL). Kluwer Law International, ISBN 9041138374, 9789041138378.

KMST, 2014. Safety Investigation Report. Korean Maritime Safety Tribunal (in Korean).

Korea Maritime Institute, 2014. The KMI Newsletter Ocean and Future. ISSN 2093-3584.

Laracy, J.R., 2006. A systems theoretic accident model applied to biodefense. Defence Security Anal. 22 (3), 301–310.

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

Leveson, N.G., 2004. A new accident model for engineering safer systems. Saf. Sci. 42 (4), 237–270.

Leveson, N., Daouk, M., Dulac, N., & Marais, K., 2003. In: Applying STAMP in Accident Analysis NASA Conference, pp. 177–198. <http://esd.mit.edu/WPS/esd-wp-2003-02.pdf> (retrieved June 9, 2015).

Leveson, N.G., Allen, P., Storey, M.-A., 2002. The analysis of a friendly fire accident using a systems model of accidents. In: International Conference of the System Safety Society, Denver.

Linstone, H.A., Mitroff, I.I., Hoos, I.R., 1994. The Challenge of the 21st Century: Managing Technology and Ourselves in a Shrinking World. State University of New York Press, Albany.

MOF, 2014. Progress on and Follow-up Measures for Sewol-ho Accident Recovery. Korea Ministry of Oceans and Fisheries (in Korean).

Nelson, P.S., 2008. A STAMP Analysis of the LEX Comair 5191 Accident. Control 0 (June), p. 38.

Ouyang, M., Hong, L., Yu, M., Fei, Q., 2010. STAMP-based analysis on the railway accident and accident spreading: taking the China–Jiaoji railway accident for example. Saf. Sci. 48 (5), 544–555. http://dx.doi.org/10.1016/j.ssci.2010.01.002.

Perrow, C., 1999. Normal Accidents: Living with High-risk Technologies. Princeton University Press, Princeton, New Jersey.

Qureshi, Z.H., 2007. A review of accident modelling approaches for complex socio-technical systems. In: Proceedings of the Twelfth Australian Workshop on Safety Critical Systems and Software and Safety-related Programmable Systems, vol. 86, Mawson Lakes, South Australia, pp. 47–59.

Rasmussen, Jens, 1997. Risk management in a dynamic society: a modeling problem. Saf. Sci. 27 (2/3), 183–213.

Reason, J., 1997. Managing the Risks of Organizational Accidents. Ashgate, Aldershot, UK.

Rijpma, J.A., 2003. From deadlock to dead end: the normal accidents-high reliability debate revisited. J. Contingencies Crisis Manage. 11, 37–45. http://dx.doi.org/10.1111/1468-5973.1101007.

Salmon, P.M., Walker, G.H., Stanton, N.A., 2015. Broken components versus broken systems: why it is systems not people that lose situation awareness. Cogn. Technol. Work 17 (2), 179–183.

Schröder-Hinrichs, J.U., Hollnagel, E., Baldauf, M., 2012. From Titanic to Costa Concordia—a century of lessons not learned. WMU J. Maritime Affairs 11 (2), 151–167.

Underwood, P., Waterson, P., 2013. Systemic accident analysis: examining the gap between research and practice. Accid. Anal. Prev. 55, 154–164.

Underwood, P., Waterson, P., 2014. Systems thinking, the Swiss Cheese Model and accident analysis: a comparative systemic analysis of the Grayrigg train derailment using the ATSB, AcciMap and STAMP models. Accid. Anal. Prev. 68, 75–94.

Vairo, T., Pastorino, R., Rehman, A., Fabiano, B., 2015. An approach to risk evaluation in connection with fire scenarios from a cruise ship. Chem. Eng. Trans. 43, 1939–1944. http://dx.doi.org/10.3303/CET1543324.

Woods, D.D., Johannesen, L.J., Cook, R.I., Sarter, N.B., 1994. Behind Human Error: Cognitive Systems, Computers and Hindsight. CSERIAC, Columbus, Ohio.

Zhang, S., Wang, J., 2015. Analysis of South Korea Sewol sunken ferry accident based on behavioral safety. J. Coastal Res., 611–613 http://dx.doi.org/10.2112/SI73-106.1.

APPENDIX E

JOURNAL ARTICLE:

Development and validation of a safety leadership self-efficacy scale (SLSES) in maritime context

Safety Science 134 (2021) 105031

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/safety

Development and validation of a safety leadership Self-Efficacy Scale (SLSES) in maritime context

Tae-eun Kim [a,*], Are Kristoffer Sydnes [b], Bjørn-Morten Batalden [b]

[a] Department of Maritime Operations, Faculty of Technology, Natural Sciences and Maritime Sciences, University of South-Eastern Norway (USN), Norway
[b] Department of Engineering Science and Safety, Faculty of Science and Technology, UiT-The Arctic University of Norway, Norway

ARTICLE INFO

Keywords:
Safety management
Leadership
SEM
Maritime industry
SLSES

ABSTRACT

Extensive studies have highlighted the importance of leadership on safety in the maritime industry. However, current research lacks empirically tested theoretical models with valid and reliable scales for describing and measuring safety leadership in ship operations. This study reports the development and validation process of the first *Safety Leadership Self-Efficacy Scale* (SLSES) for assessing shipboard officer's efficacy in exercising leadership for safety in merchant shipping. The research has been divided into three stages, including a content validation study (20 subject matter experts), an Exploratory Factor Analysis (EFA) ($n = 150$) and a Confirmatory Factor Analysis (CFA) ($n = 396$). The results have supported a higher order factor structure with three subscales – motivation facilitation, safety management and safety initiative – contributing to the measurement of safety leadership self-efficacy. The resulting scale has revealed adequate measurement properties with good explanatory power, construct validity and high internal reliability (Cronbach's $\alpha = 0.971$). SLSES can provide maritime researchers, practitioners and shipping organizations with a tool to assess and enhance safety leadership potentials of current and future shipboard officers. The theoretical, methodological and practical implications of SLSES were discussed.

1. Introduction

Although the maritime industry has gone to great lengths to enhance safety by promulgating safety rules, regulations and standards, unanticipated – and sometimes catastrophic – accidents still occur (Schröder-Hinrichs et al., 2012; Batalden and Sydnes, 2014; Kim et al., 2016). Lessons learned from accidents (e.g., Costa Concordia, Sanchi, Sewol ferry, Bow Mariner) have consistently observed the important role of human element, especially leadership and management practice for safety (Grech et al., 2008; Kim et al., 2016). A well-functioning Safety Management System (SMS), good accident prevention activities and active safety communications cannot be envisioned without the existence of strong leadership and management support (O'Dea and Flin, 2001; Kim and Gausdal, 2017). As Leveson (2011) put it, "Safety starts with management leadership and commitment. Without these, the efforts of others in the organization are almost doomed to failure" (p. 177).

Across various high-risk industrial contexts, extensive research has shown the important impact of leadership on safety culture (Yang et al., 2009; Ross, 2011), on safety climate, subordinates' safety compliance and participation behaviours (Clarke, 2013; Pilbeam et al., 2016; Kim and Gausdal, 2020) as well as safety outcomes (e.g., accidents and injury rate) (Mullen and Kelloway, 2009). It has been considered as an important differentiating factor between high and low accident companies (Kjellen, 1982; Bentley and Haslam, 2001; Mattson et al., 2019) and an even more important predictor for safety performance compare to hazard reduction systems (de Koster et al., 2011).

By acknowledging the importance of leadership issues for safety in ship operations, the International Maritime Organization (IMO) has raised the minimum standards of competence for seafarers by including leadership training as a mandatory competence requirement for shipboard officers at both management and operational level (IMO, 2017; Wahl and Kongsvik, 2018; Kim and Mallam, 2020), as specified under the International Convention on Standards of Training, Certification and Watchkeeping (STCW 1978 as amended) (IMO, 2017). However, research into maritime safety leadership (e.g., its determinants, behaviours and process) is very scarce, and it also lacks empirically tested theoretical models – with a validated and reliable scale – for describing and assessing safety leadership in ship operations (Kim and Gausdal, 2017; Besikçi, 2019). This knowledge gap has consequently undermined

* Corresponding author.
E-mail address: tk@usn.no (T.-e. Kim).

https://doi.org/10.1016/j.ssci.2020.105031
Received 9 December 2019; Received in revised form 31 August 2020; Accepted 1 October 2020

our theoretical understanding and training practice of safety leadership in the maritime context. Current leadership training objectives and materials were largely based on generic leadership knowledge and the Crew Recourse Management (CRM) training adapted from the aviation industry with little sector-specific adjustments and scientific adaptation to the maritime context (Barnett et al., 2003; Oltedal and Lützhöft, 2018). The unique nature of shipping, such as the remote working condition, closed social milieu, exposure to hazardous substances, dynamic situation at sea, as well as the transient and multinational crew composition, has made the ship operational context differ from any other industries (Håvold, 2005; Slišković and Penezić, 2015; Besikçi, 2019). These inherent sector specific characteristics render the effectiveness of transferring leadership knowledge from other industries to the maritime setting (O'Connor, 2011; Oltedal and Lützhöft, 2018; Besikçi, 2019).

In this light, the purpose of this research is to give particular focus to maritime safety leadership, and to design a Safety Leadership Self-Efficacy Scale (SLSES) for describing and assessing shipboard officer's safety leadership self-efficacy in the context of merchant shipping. The research drew upon the insights of safety leadership literature and Bandura's self-efficacy theory, while engaged in a three-stage process to systematically explore and examine the validity and reliability of the measurement scale.

2. Theoretical background

2.1. Safety leadership

Safety leadership has been defined as a process of interaction between leaders and followers to achieve organizational safety goals (Wu, 2005). Leaders' behaviours and the way they interact with their subordinates have been consistently recognized that have significant effect on safety performance (Clarke, 2013) and are important predictors of safety records in many hazardous industrial contexts (Hofmann and Morgeson, 1999; Zohar, 2002). Majority of safety leadership studies have predominantly concerned with investigating and identifying the form of leadership style for safety in formal roles, with reference to a well-established leadership theory (e.g., transformational and transactional leadership theory (Bass, 1985), Leader-Member Exchange (LMX) theory (Graen and Uhl-Bien, 1995), authentic leadership theory (Cooper et al., 2005), situational leadership theory (Graeff, 1983)). Each of these theories view the complex and continuing leadership phenomenon from different angles and emphasize different means for influencing followers. Among which transformational and transactional leadership theory have received the most attention (Clarke, 2013).

Transformational leadership is relationship-oriented, whereas transactional leadership has a stronger task-orientation (Bass and Avolio, 1997). Research based on transformational leadership views leadership as leaders' ability to exert influence to their followers through inspiration, engagement and empathy to achieve "performance beyond expectations" (Zohar, 2003). Transactional leaders focus on maintaining routines, minimizing variations, increasing reliability and predictability from their followers to ensure "expected performance" are in place (Zohar, 2003). A series of studies have shown that a combined use of both transformational and transactional leadership are most beneficial for safety (Clarke, 2013; Kim and Gausdal, 2020). These leadership research are in line with safety theories arguing that to effectively manage safety of today's complex socio-technical systems, it is important to not only avoid that things would go wrong to achieve performance reliability, but also need to increase the system capability to adapt to and succeed under varying conditions and unexpected disruptions to deliver sustainable safety performance (Hollnagel, 2014).

Among limited empirical studies which focused specifically on the study of safety leadership in the shipping industry, an attempt were made by Kim and Gausdal (2017) to synthesize the behaviours and actions manifested by effective leaders in shipping organizations. The study argued that achieving, maintaining and sustaining safety performance in ship operations demands effective safety leadership to be instilled at all organizational levels. Kim and Gausdal (2017) identified eleven key behaviours enabling good safety performance in ship operations, which includes lower-level managers' communicating, caring and supporting, participative involvement; middle-level managers' empowering, monitoring, informing and coordinating; and top managers' enabling, safety concern, inspiring and facilitating behaviours. Organizational leadership for safety significantly influence the learning outcomes from the minor, moderate and major near-misses, which are valuable inputs for the organization to update the safety management practices and generate corrective/preventive actions (Ginsburg et al., 2010). A positive association between the participant's perception of their manager's leadership skills and frequency of incident reporting is also noted by Oltedal and McArthur (2011) in merchant shipping.

Existing literature investigating leadership impact on safety outcomes have provided several important implications: Firstly, it indicated that the variations in individuals and teams' safety practices are causally related to managerial leadership styles and behaviours, and susceptible to influence. Secondly, leaders should excel both task and relationship-oriented leadership in order to effectively influence safety behaviours and outcomes. Thirdly and most importantly, it highlighted the tremendous need for safety leadership assessment and development in order to recognize the current level of performance and identify room for improvement.

2.2. Leadership self-efficacy

Self-efficacy is a critical construct within Bandura's social cognitive theory (Bandura and Walters, 1977), he defined it as: "people's judgments of their capabilities to organize and execute courses of action required to attain designated types of performance" (Bandura, 1986, p. 391). It influences on "what challenges to undertake, how much effort to expend in the endeavour, and how long to persevere in the face of difficulties" (Bandura, 1986, p. 29).

Wood and Bandura (1989) has first linked self-efficacy construct to management. Leadership self-efficacy is a key variable regulating leader's functioning in a dynamic environment (McCormick, 2001). It determines not only initiation, intensity and persistence of leadership behaviours (Paglis, 2010), but also fosters the level of motivation, organizational commitment and efficient analytic thinking ability (Wood and Bandura, 1989), with meta-analysis reported a significant correlation G(r = 0.38) between self-efficacy and performance (Stajkovic and Luthans, 1998). Credible evidence supports the statement that possessing strong leadership self-efficacy could impact not only on leadership effectiveness (Anderson et al., 2008; Hannah et al., 2008) but also the work-related performance (Stajkovic and Luthans, 1998; McCormick, 2001). Anderson et al. (2008) identified 18 dimensions as key components of leadership self-efficacy i.e., change, drive, solve, build, act, involve, self-control, relate, oversee, project credibility, challenge, guide, communicate, mentor, motivate, serve, convince, and know. Leaders with higher self-efficacy are more likely to initiate and engage in leadership attempts (Paglis and Green, 2002), use leadership skills and have better effectiveness compare to those with lower self-efficacy (Anderson et al., 2008). Research also observed that frontline leaders' self-efficacy have direct and positive effects on safety behaviours (Chen and Chen, 2014). Furthermore, self-efficacy, work engagement and human error are significantly correlated, in which self-efficacy significantly predicts probability of human errors in aviation (Li et al., 2018).

In this study, we define *safety leadership self-efficacy* as the extent to which leaders perceive their capabilities to exemplify and execute courses of action required to attain a good safety performance on-board ship. It refers to, for instance, the extent to which shipboard officers perceive their self-efficacy in relation to the development, implementation, and oversight of standard operating procedures (STCW code

Table A-II/2, KUP 6), how they perceive their knowledge and ability to apply decision-making techniques (STCW code Table A-II/2, KUP 5), how they facilitate effective communication (STCW code Table A-II/2, KUP 4), etc (IMO, 2017; Kim and Mallam, 2020). We reason that leadership self-efficacy is particularly important in this safety-critical working environment, where a greater level of confidence and self-belief is needed in order to manage and lead a high-risk activity that has massive risk and uncertainty built-in. Wherein proficient technical competence, a greater level of decisiveness, assertiveness and adaptive skills need to be orchestrated in order to lead effectively, make critical decisions and achieve good performance under the dynamic situations. Thus, measuring leadership self-efficacy is of importance to indicate the current level and recognize room for improvement.

3. Methodology

To reliably and accurately assess a theoretical construct, the measurement tool should be developed following a systematic and rigorous process of development and validation (DeVellis, 2016; Farooq, 2016). The scale development process, as discussed by Carpenter (2018), is both theoretically and methodologically demanding. In this study, the scale development process was divided into three stages, including a content validity study with Subject Matter Experts (SMEs) who are familiar with this topic, an Exploratory Factor Analysis and a Confirmatory Factor Analysis using Structural Equation Modelling, with the goal to examine the content validity through SMEs, and to explore and confirm the underlying factor structure of the scale with shipboard officers. The overall flow of the research is illustrated in Fig. 1, which consists of several key steps taken in this research on the development and estimation of the measurement properties of the safety leadership self-efficacy scale.

3.1. Item generation

One cannot adequately measure self-efficacy without taking into account the specific domain and the actual tasks and responsibilities (Bandura, 2006). The initial item pool was developed by the authors based on the findings from safety-specific leadership research, general leadership self-efficacy research, STCW leadership requirement as well as the inputs of three maritime researchers to adapt general items to maritime context.

Firstly, as described in the theory Section 2.1, several studies have investigated or summarized what constitute effective leadership and highlighted the behaviours or styles that associated with improved safety culture, safety compliance and participation behaviours and other safety-related outcomes in maritime context. In addition to this, we have also considered the general Leadership Self-Efficacy (LSE) taxonomy developed by Anderson et al. (2008), which included 18 dimensions as key components of leadership self-efficacy. These dimensions also have causal relationships with leadership effectiveness, which can be used as a reasonable inventory for understanding different leadership self-efficacy dimensions. Thus, by taking into account these two groups of research, STCW leadership requirements, as well as the knowledge and maritime experience of the investigators, initial 65 items were generated for measuring safety leadership (see Section 4, Table 3). These items are linked not only with leader's personal accountability such as safety commitment, knowledge, confidence and consciousness, but also his/her behaviours and actions that promote safety. Each of these items can be considered as an important behaviour that leaders should exhibit at the frontline level of ship operations, and it is also associated with one dimension of LSE taxonomy (Anderson et al., 2008). For the dimensions that was included in LSE taxonomy, but the causal relationship to safety was not specifically studied in the field of safety leadership research (e.g., self-control), we have still included them in the item pool. An expert panel will be established to review, judge and determine the extent to

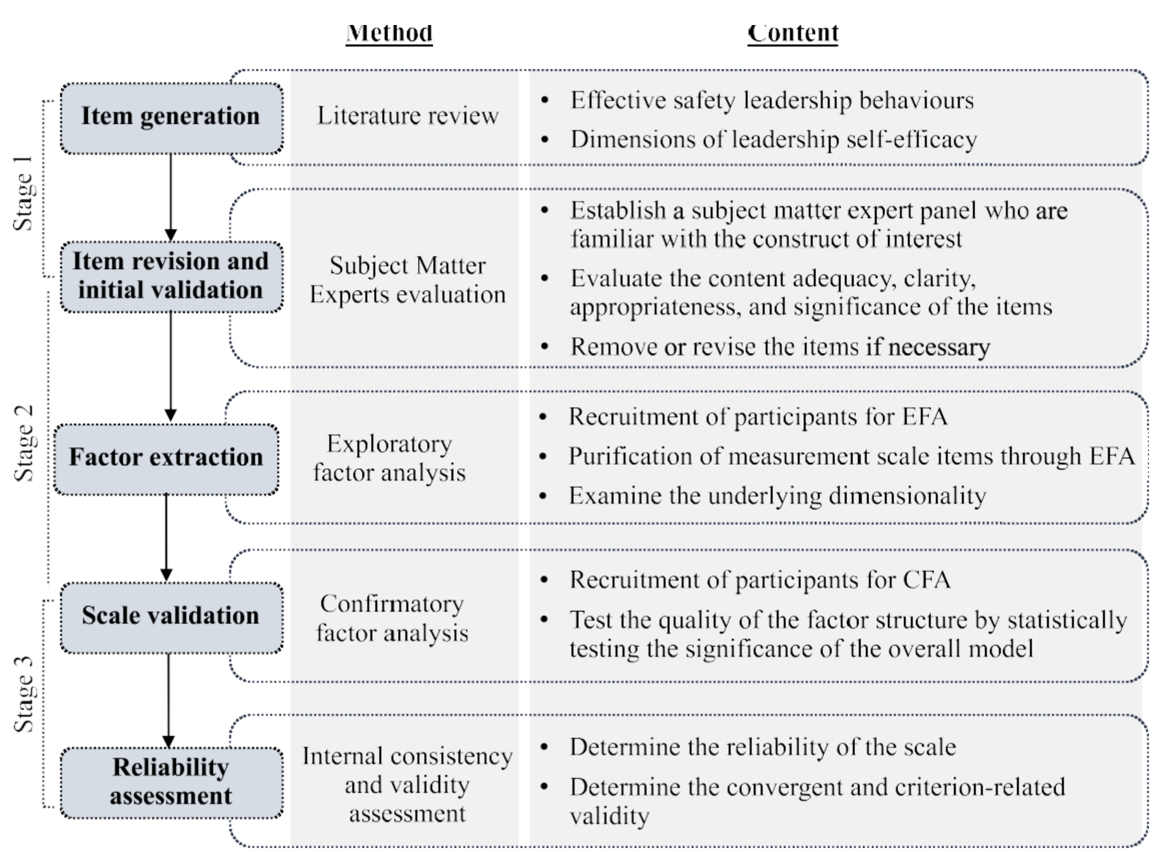


Fig. 1. Safety Leadership Self-Efficacy Scale (SLSES) development process.

which the item could be considered as an important variable to measure.

3.2. Overall scale development process

Stage 1: Content validity assessment process

The first stage has fundamental importance to the instrument development process, as it enables the researchers to validate the representativeness, content validity and clarity of the items through synthesizing the evaluations from subject matter experts. The established item pool was reviewed and evaluated by a team of experts (N = 20) to examine the content validity, clarity, appropriateness of each item for measuring safety leadership self-efficacy of shipboard officers. These experts are invited to review the items and rate their viewpoints on the appropriateness of each item on a 9-point Likert scale questionnaire. The experts were also asked to offer their suggestions for adding new items. Demographic profiles of the expert participated in item validation is summarized in the following Table 1.

Total 20 SMEs participated, among which 40% of them work within merchant shipping industry, 60% are university professors, lecturers, researchers in maritime subjects, constituting a strong expert panel to provide reasonable judgement of the items. Based on the SMEs' evaluation, content validity is examined to reflect the degree to which this measurement scale and its items are appropriate for the construct being measured. Content Validity Index (CVI) is the most widely reported approach in scale development studies (Shi et al., 2012; Zamanzadeh et al., 2015). It includes obtaining the validity index for both individual item (I-CVI) and the scale itself (S-CVI). I-CVI can be computed by taking the number of experts who gave a high rating on each item and divided by total number of experts (Zamanzadeh et al., 2015). In addition to CVI, statisticians (e.g., Wynd et al., 2003) have recommended to include a consensus index – Cohen's coefficient kappa (K) – in content validity studies to supplement the CVI, as the CVI does not consider the possibility of inflated values due to chance agreement. Kappa statistics was calculated using the equations below:

$$P_C = [N!/A!(N-A)!]^* .5^N$$

In which P_c refers to the chance agreement, and A refers to the number of panellists indicating a specific item can appropriately measure the safety leadership self-efficacy of shipboard leaders. N denotes the total number of experts who participated in the panel. After obtaining the results of CVI, Kappa (K) was calculated with the following equation:

$$K = (\text{I-CVI} - P_C)/(1 - P_C)$$

The K value above 0.74 is considered excellent, between 0.60 and 0.74 is good, between 0.40 and 0.59 is fair, below 0.40 is poor (Cicchetti and Sparrow, 1981). The probability of chance agreement will reduce with increasing number of experts and the value of I-CVI and kappa should converge (Zamanzadeh et al., 2015).

Table 1
Demographic characteristics of Subject Matter Experts (SME).

Criteria of classification	Statistics
Sectors	Merchant shipping: 40% Maritime research and education: 60%
Years of EXperience in shipping	≥ 20: 15% 16–20: 25% 10–15: 10% 6–10: 35% ≤5: 15%
EXperienced maritime accidents	Yes: 75% No: 25%
Level of education	High school or equivalent: 15% Bachelor's degree: 20% Master's degree (including MBA): 35% PhD: 30%
Total No. of experts participated	20

Stage 2: Exploratory Factor Analysis (EFA)

Evaluating the performance of the items through factor analysis to assess whether they adequately constitute the scale are considered to be one of the most critical steps in determining the viability of the developed scale. Both EFA and CFA were used in this study to examine the underlying dimensionality of the items, and to test the quality of the factor structure by statistically testing the significance of the overall model.

In stage 2, EFA is performed to determine the number of latent variables based on commonalities within the data and to examine the loading of individual items. Several methods exist for factor extraction in the EFA process, in this study we used Maximum likelihood for extraction as it offers more reliable estimation for scale development research (Worthington and Whittaker, 2006a, 2006b). Oblique rotation (i.e., Promax) method was selected instead of commonly used orthogonal rotation, as it is unreasonable to assume the items to be completely uncorrelated to each other (Fabrigar et al., 1999). Sampling adequacy for EFA was assessed using Kaiser-Meyer-Olkin (KMO) Test, with the criteria to be greater than 0.70 and p-value to be less than 0.01. To ensure rigor of this process, items with factor loading lower than 0.5 and high cross loading (>0.4) (Hatcher, 1994) will be removed at this stage. The Cronbach's alpha of the extracted factors should be >0.70 (Nunnally, 1994).

Stage 3: Confirmatory Factor Analysis (CFA)

After the EFA, we used Structural Equation Modelling (SEM) to examine the relationship between the factors and measured variables, and to test and confirm the factor structure by using a new data set. SEM is a term for a large set of techniques based on the general linear model (Ullman, 2006), in which CFA technique is one type of SEM (Ullman, 2006). The factor structure derived from stage 2 was then incorporated as the measurement model in CFA. This process plays an important role in validating the hypothesized model and finding the reliability of the measurement. Subject samples for factor analyses have included ship masters and officers etc. working on the global merchant shipping industry. The demographical distribution was summarized in Table 2.

In total the data used in stage 2 and 3 was collected from 396 participants from global merchant shipping industry. The diversity of the participants has also been heightened as the questionnaire was distributed in both Europe and Asia to allow for better generalizability. Majority of participants were from the main shipping sectors i.e., tankers, roll-on/roll-off vessels or bulker carriers, who hold leadership positions such as ship captains, chief engineers, deck and engineering department officers. The questionnaires were developed and administered using Qualtrics™ with anonynous link, in which the participants were asked to put their answers on a 9-point Likert-type scale under each

Table 2
Demographic profiles of 396 participants.

Criteria of classification	Range	*N*	Percent (%)
Year of experience as a shipboard leader	More than 20 years	56	14.1
	10–20 years	81	20.4
	Less than 10 years	259	65.4
Leadership positions	Ship masters	64	16.2
	Deck department officers	130	32.9
	Chief Engineer	27	6.8
	Engine department officers	84	21.2
	Bosun and other position	91	23
Shipping sectors	Passenger ships	33	8.3
	Tankers	117	29.5
	Container ships	20	5.1
	RoRo (Roll on Roll Off)	83	21.0
	Seismic vessels	11	2.8
	Fishing Vessels	13	3.3
	Oil industry vessels	39	9.8
	Other ship types (e.g., bulk carriers)	80	20.2

item. The questionnaires were designed with "forced responses" function, questions need to be answered before proceeding further, therefore no missing values was recorded in the dataset. Data analysis were performed using Excel, SPSS v25 and RStudio. Following Kline (2015) and Crawford and Kelder (2019)'s suggestions regarding the reporting of fit indices, we reported the $\chi 2$, RMSEA, Bentler's comparative fit index (CFI), Tucker–Lewis's goodness-of-fit index (TLI), and the Standardized Root Mean Square Residual (SRMR) to indicate the model-data fit. Cronbach's alpha, AVE, Construct Reliability (C.R.) were also be assessed. The overall research methodology aligns with both Carpenter (2018) and DeVellis (2016)' guidelines on scale development and reporting.

4. Results

4.1. Results of Stage 1: Content adequacy assessment with subject matter experts

Based on the rationale and criteria described in Section 3, the following Table 3 summarizes the results of S-CVI, I-CVI and kappa (K) – the measures that quantify the consensus level of expert opinions on each of the 65 safety leadership self-efficacy measurement items. As shown in the table, the value of the Kappa statistics (K) of all items has all reached above 0.74, which indicates good agreement among SMEs. The CVI of the overall scale has also produced a result of S-CVI/Ave = 0.96, which reflected that the individual items as well as the scale in total has a high level of content validity.

The items contained in the scale have fulfilled the criteria and appeared to be reasonably measure safety leadership self-efficacy of shipboard officers as perceived by the 20 SMEs. Although item 36, 43, 61 have a slightly lower rating compare to the rest (I-CVI≥ 0.79), they are still within the criteria for inclusion. Accordingly, it can be said that each item is suitable for the given purpose, all items have been kept for next stage of analysis.

4.2. Results of Stage 2: Scale purification

In stage 2, an iterative approach was taken to conduct EFA with the first available 150 samples to purify the measurement items and to explore the latent constructs that cause covariance among items. Factorability of the items was firstly examined, the KMO has yielded an overall measure of sampling adequacy of 0.962, Bartlett's test of sphericity was also significant ($\chi 2$ (325) = 4175.945, $p < .000$), which indicates the existence of a strong relationship between the variables.

The initial result of the analysis was a pattern matrix initially consisting of 7 factors with eigenvalues >1 that account for 76.917% of the variance. Thirty-nine items were dropped during the EFA process due to insignificant loading (<0.5) or high cross-loading (≥0.4). The iterative analysis process has yielded extraction of three factors with 26 items to be considered for inclusion in a hypothesized factor structure for the safety leadership self-efficacy scale, which accounts for 74.821% of the variance but enhances the overview of the matrix considerably. As shown in Table 4, 26 items comprising three factors with loadings vary between 0.523 and 0.859. Each item had a unique contribution to one of these three factors.

Results of the analysis have revealed that safety leadership self-efficacy is a multidimensional construct, which consists of three dimensions (factors) reflecting leader's confidence in their ability to enact safety leadership activities as of now. The items clustered on factor 1 were given the label as leaders' efficacy in *safety motivation facilitation*, it refers to the extent to which shipboard leaders could simulate follower's safety motivation. The items in general related to how leaders use social skills to influence, motivate, and build relationships with crew members to succeed with regards to safety. Items that loaded on the second factor were associated with shipboard leaders' competence for safety management, which includes identifying, managing, controlling and

Table 3
Results of I-CVI, S-CVI and kappa for all items.

Notation	Item description	Importance		I-CVI	*Pc*	*K*
		Rating 3,4,5	Rating 1 or 2			
I1	Have the ability to foresee risks	18	2	0,9474	0,0002	0,95
I2	Able to make changes in personnel and task assignments to ensure safe and efficient operations	18	2	0,9474	0,0002	0,95
I3	Have the ability to change the operation to improve safety	20	0	1,0526	0,0000	1,05
I4	Have the ability to establish new rules and work procedures to improve safety	19	1	1,0000	0,0000	1,00
I5	Capable of gathering safety information to make necessary changes	19	1	1,0000	0,0000	1,00
I6	Encourage learning as a basis for improving safety	19	1	1,0000	0,0000	1,00
I7	Able to identify hazards proactively	19	1	1,0000	0,0000	1,00
I8	Able to proactively manage safety risks	19	1	1,0000	0,0000	1,00
I9	Able to use formal authority to ensure crew members adhere to the safety procedures and policies	19	1	1,0000	0,0000	1,00
I10	Ensure achievable safety goals are set	19	1	1,0000	0,0000	1,00
I11	Prioritize safety over other business targets and activities	19	1	1,0000	0,0000	1,00
I12	Follow up crew members to ensure that tasks are completed in a timely and efficient manner	16	4	0,8421	0,0046	0,84
I13	Make concrete plans and programs for the safety activities	18	2	0,9474	0,0002	0,95
I14	Have sufficient knowledge of the technical performance of the vessel	20	0	1,0526	0,0000	1,05
I15	Provide expert knowledge to crew members	18	2	0,9474	0,0002	0,95
I16	Have the capacity to manage the technical skills of the crew members	19	1	1,0000	0,0000	1,00
I17	When undesirable incidents occur, be able to follow the established	20	0	1,0526	0,0000	1,05

(continued on next page)

Table 3 (*continued*)

Notation	Item description	Importance		I-CVI	*Pc*	*K*
		Rating 3,4,5	Rating 1 or 2			
	procedures to deal with the situation					
I18	When undesirable incidents occur, be able to improvise to handle the situation effectively	18	2	0,9474	0,0002	0,95
I19	Able to develop effective teams to operate safely	20	0	1,0526	0,0000	1,05
I20	Allocate resources adequately to ensure safe and efficient operation	20	0	1,0526	0,0000	1,05
I21	Able to ensure necessary safety precautions are being carried out by conducting regular supervision	17	3	0,8947	0,0011	0,89
I22	Participate actively in workforce safety activities and initiatives	18	2	0,9474	0,0002	0,95
I23	Able to make sound decisions and the right choices	19	1	1,0000	0,0000	1,00
I24	Able to mobilize the resources to make effective decisions in a timely manner	18	2	0,9474	0,0002	0,95
I25	Confident that crew members will follow up leaders' decisions	18	2	0,9474	0,0002	0,95
I26	Able to initiate and engage in toolbox sessions during safety meetings on board	18	2	0,9474	0,0002	0,95
I27	Involve crew members actively in recommending revisions to established procedures	19	1	1,0000	0,0000	1,00
I28	Able to delegate work tasks effectively and encourage crew members to accept responsibility for safety	18	2	0,9474	0,0002	0,95
I29	Actively listen to the crew members, and promote their involvement in decision making	19	1	1,0000	0,0000	1,00
I30	Seriously consider the subordinates' suggestions and initiatives for improving safety	19	1	1,0000	0,0000	1,00
I31	Able to successfully foster effective collaboration among crew members	18	2	0,9474	0,0002	0,95
I32	Able to foster positive attitudes and mutual respect among crew members	18	2	0,9474	0,0002	0,95
I33	Monitor performance and ensure that safety procedures are followed by crew members	18	2	0,9474	0,0002	0,95
I34	Use appropriate sanctions to respond to unsafe actions	16	4	0,8421	0,0046	0,84
I35	Able to closely observe crew performance during safety drills on board, and highlight shortcomings and good work	18	2	0,9474	0,0002	0,95
I36	Encourage crew members to create peer pressures to avoid safety complacency	15	5	0,7895	0,0148	0,79
I37	Treat all crew members with dignity and respect	20	0	1,0526	0,0000	1,05
I38	Willing to deal with resistance from crew members in an open and constructive manner	20	0	1,0526	0,0000	1,05
I39	Concerned with how crew members perceive justice and seek to lead in a fair manner	18	2	0,9474	0,0002	0,95
I40	Appear honest and credible to others	19	1	1,0000	0,0000	1,00
I41	Challenge their own and the team's performance against safety objectives to avoid complacency	16	4	0,8421	0,0046	0,84
I42	Set high safety standards for vessel operations	18	2	0,9474	0,0002	0,95
I43	Pioneer in achieving high safety standards	15	5	0,7895	0,0148	0,79
I44	Use logical arguments and factual evidence to ensure crew members' compliance with safety rules/ procedures	17	3	0,8947	0,0011	0,89
I45	Use good seamanship in	19	1	1,0000	0,0000	1,00

(*continued on next page*)

Table 3 (*continued*)

Notation	Item description	Importance		I-CVI	*Pc*	*K*
		Rating 3,4,5	Rating 1 or 2			
	leading and training the crew					
I46	Have the necessary competence to provide proper directions to the crew	20	0	1,0526	0,0000	1,05
I47	Provide feedback on task performance frequently	16	4	0,8421	0,0046	0,84
I48	Foster open and frequent communication among crew members on safety issues	19	1	1,0000	0,0000	1,00
I49	Able to clearly articulate the desired safety behaviours and work practices	18	2	0,9474	0,0002	0,95
I50	Have the cultural awareness to communicate effectively with all crew members	19	1	1,0000	0,0000	1,00
I51	Circulate important safety information among crew members	19	1	1,0000	0,0000	1,00
I52	Able to lead by example, and communicate the importance of safety through both words and actions	20	0	1,0526	0,0000	1,05
I53	Care about crew member' safety, express compassion and empathy where appropriate	20	0	1,0526	0,0000	1,05
I54	Provide recognition and incentives to crew members for promoting positive safety on board ship	18	2	0,9474	0,0002	0,95
I55	Provide positive emotional support and take care of the crew's welfare	17	3	0,8947	0,0011	0,89
I56	Make the crew more confident to accomplish their tasks	17	3	0,8947	0,0011	0,89
I57	Encourage people to report errors, near-misses or other safety-related information without fear of the consequences	20	0	1,0526	0,0000	1,05
I58	Confident in ensuring the motivation of crews to follow Safety Management Systems (SMS)	18	2	0,9474	0,0002	0,95
I59	Will not bend safety rules to achieve performance targets	18	2	0,9474	0,0002	0,95
I60	Willing to reflect on, and revise leader's decisions based on feedback from the crew	18	2	0,9474	0,0002	0,95
I61	EXplain and justify the activities to be performed to give more purpose to the task	15	5	0,7895	0,0148	0,79
I62	Able to galvanize the crews' support to achieve safety standards and goals	17	3	0,8947	0,0011	0,89
I63	Aware of their influence and know what leadership strategies or tactics are needed to ensure safety in various situations	17	3	0,8947	0,0011	0,89
I64	Capable of sourcing the pertinent information for decision making	18	2	0,9474	0,0002	0,95
I65	Capable of keeping safety information updated	19	1	1,0000	0,0000	1,00

Note: I-CVI refers to content validity index for each item, Pc is the probability of a chance occurrence. Kappa statistics (K): <. 40 is poor, 0.40-0.59 Fair, 0.60-0.74 is Good, 0.75–1.00 is Excellent (Cicchetti and Sparrow, 1981).

handling risk and hazardous situations during ship operations. Accordingly, factor 2 was labelled as *safety management* efficacy. The third group of items included specific, discrete verbal and nonverbal leadership behaviours and initiations that encourage subordinates to be involved in safety activities, which in general reflected leaders' efficacy on taking *safety initiative*.

The EFA process has reduced the 65 items measurement scale to a more manageable number. As shown in Table 5, the factor correlations ranged from 0.730 to 0.763, suggesting a higher order factor that should be tested during next CFA stage.

In this stage, the overall Cronbach's α of the scale with 26 items was 0.979. The three subscales have also obtained excellent internal consistency: Cronbach's α has reached 0.971 for efficacy in safety motivation facilitation, 0.933 for efficacy in safety management and 0.923 for efficacy in taking safety initiatives. The Corrected Item-Total Correlation was ranged from 0.619 to 0.874. The Alpha If Item Deleted also showed that the α value would not be improved if any of the items being eliminated, thus all 26 items derived from EFA were worthy of retention for next scale validation stage.

4.3. Results of Stage 3: Scale validation and reliability assessment

In Stage 3, a CFA analysis was conducted using 396 samples with maximum likelihood robust estimation to validate the model derived

Table 4
Results from Exploratory Factor Analysis ($n = 150$).

Factor label	Items	Loading	Communalities	
			Initial	Extracted
Factor 1: Efficacy in Safety Motivation	I57	0.859	0.779	0.720
Cronbach's α = 0.971	I58	0.834	0.770	0.752
	I56	0.811	0.800	0.756
	I40	0.782	0.703	0.614
	I63	0.742	0.724	0.652
	I49	0.673	0.841	0.816
	I48	0.673	0.865	0.833
	I39	0.671	0.774	0.709
	I53	0.617	0.772	0.737
	I37	0.578	0.757	0.660
	I46	0.560	0.807	0.739
	I44	0.546	0.798	0.726
	I50	0.544	0.766	0.723
	I60	0.534	0.721	0.674
Factor 2: Efficacy in Safety Management	I30	0.729	0.834	0.846
Cronbach's α = 0.933	I29	0.725	0.838	0.808
	I18	0.718	0.722	0.695
	I2	0.675	0.610	0.486
	I24	0.531	0.797	0.743
	I8	0.523	0.748	0.662
Factor 3: Efficacy in Safety Initiative	I26	0.846	0.794	0.798
Cronbach's α = 0.923	I47	0.730	0.719	0.671
	I43	0.653	0.716	0.684
	I27	0.651	0.798	0.769
	I35	0.602	0.774	0.672
	I10	0.587	0.681	0.581

Table 5
Factor correlation matrix.

Factor	1	2	3
1	1.000		
2	0.750	1.000	
3	0.763	0.730	1.000

through Stage 2 (EFA). Two items (I37 and I43) were dropped due to low r-square value during the initial CFA. The final model, as illustrated in the following Fig. 2, was tested and it revealed that the model fits the data well, the goodness-of-fit indices are adequate with $\chi^2 MLR$ (249, N = 396) = 493.904 (p < .001), R-CFI = 0.947, R-TLI = 0.941, CFI = 0.944, TLI = 0.938, RMSEA = 0.050 (90% CI, [0.045,0.055]), Standardized RMR = 0.034.

The result confirms a second-order model in which safety leadership self-efficacy (second-order factor) is comprised of three first-order factors including efficacy in safety management, efficacy in safety motivation facilitation and efficacy in taking safety initiatives. The final CFA estimation is presented in the following Table 6.

All standardized coefficient beta (β) are above 0.7, R-squared are above 0.5 indicating superb explanatory power. The standard structural coefficients of the first order factor on safety leadership self-efficacy construct are the estimates of the validity of the factors, thus the larger the factor loadings are, the stronger the evidence that the factors represent the underlying construct. The loadings are high (i.e., 0.946, 0.961 and 0.963), which indicates that the safety leadership self-efficacy can be well explained by these three first-order factors and reflected the contribution of safety leadership efficacy on its three sub-constructs is good. Parameter estimates for the confirmatory factor model are significant at the 0.001 level. The overall internal reliability of SLSES is 0.971. Cronbach's α of the subscales and Composite Reliability (C.R.) were calculated as shown in Table 7.

As shown in Table 6 and 7, the factor loadings of the observed variables (standardized λ) are significant between 0.707 and 0.861, which indicates good convergent validity. Cronbach's alpha of the subscales were ranged from 0.887 to 0.954, AVEs are above 0.6, and the composite reliabilities of each dimension have also exceeded the recommended upper level of 0.70, indicating reasonable reliability of the model. Content validity index of the scale was recalculated based on the result of stage 3, S-CVI/Ave is 0.914, indicating excellent content validity of the scale. Based on the three stages presented above, the final Safety Leadership Self-Efficacy Scale (SLSES) was constructed. All factors and their items remained in the final scale appeared to have good conceptual consistency, adequately explained safety leadership of shipboard officers, and successfully covered what we have tried to identify as the core functions of a safety leader.

5. Discussion

This study presented the development and validation process of a Safety Leadership Self-Efficacy Scale (SLSES) to prepare an instrument to aid in understanding and predicting safety leadership of shipboard officers. The resulting scale has demonstrated adequate measurement properties with good validity and reliability.

SLSES consists of three subscales (factors) to reflect leader's efficacy in their ability to facilitate motivations, manage safety and take safety initiatives. The first factor, efficacy in motivation facilitation, reflected an important leadership function which is to inspire motivation of their

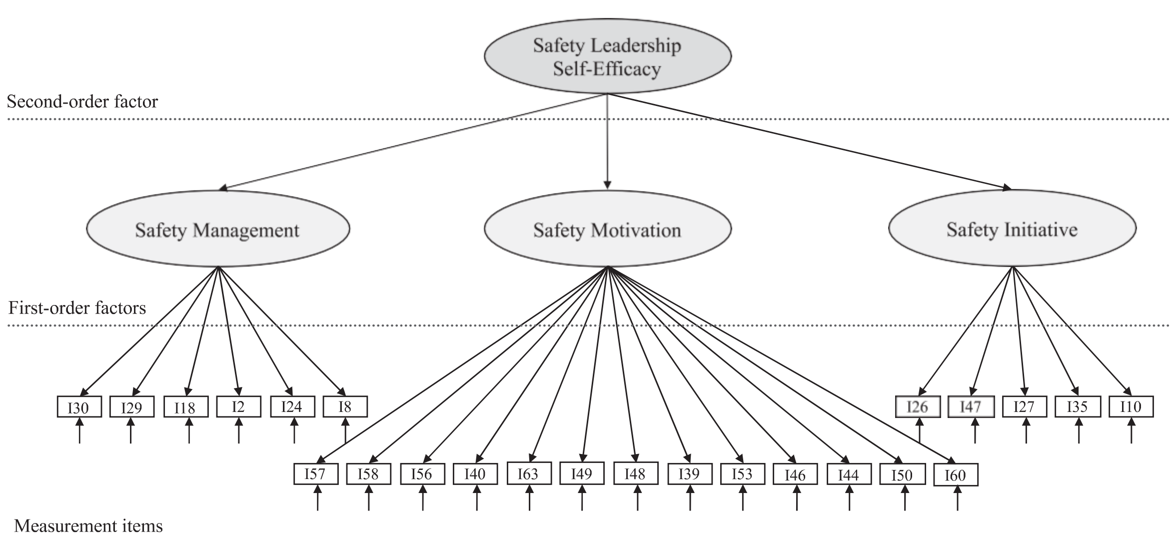


Fig. 2. Measurement model.

Table 6
Final result from Confirmatory Factor Analysis ($n = 396$).

Notation	Item	Estimate B	Estimate β	R^2	S.E.	z-value	P(>|z|)	Cronbach Alpha
Efficacy in safety motivation facilitation			*0.946					0.954
I57	Encourage people to report errors, near-misses or other safety-related information without fear of the consequences	1.000	0.767	0.588			1.116	
I58	Confident in ensuring the motivation of crews to follow Safety Management Systems (SMS)	1.096	0.794	0.631	0.065	16.925	0.000	
I56	Make the crew more confident to accomplish their tasks	1.020	0.804	0.646	0.053	19.186	0.000	
I40	Appear honest and credible to others	0.978	0.739	0.546	0.053	18.547	0.000	
I63	Aware of their influence and know what leadership strategies or tactics are needed to ensure safety in various situations	0.994	0.799	0.639	0.074	13.384	0.000	
I49	Able to clearly articulate the desired safety behaviours and work practices	1.085	0.849	0.721	0.069	15.628	0.000	
I48	Foster open and frequent communication among crew members on safety issues	1.083	0.826	0.683	0.069	15.650	0.000	
I39	Concerned with how crew members perceive justice and seek to lead in a fair manner	0.988	0.762	0.580	0.062	15.860	0.000	
I53	Care about crew member' safety, express compassion and empathy where appropriate	0.952	0.771	0.594	0.056	17.033	0.000	
I46	Have the necessary competence to provide proper directions to the crew	1.154	0.807	0.651	0.076	15.095	0.000	
I44	Use logical arguments and factual evidence to ensure crew members' compliance with safety rules/procedures	0.990	0.804	0.646	0.056	17.597	0.000	
I50	Have the cultural awareness to communicate effectively with all crew members	1.063	0.722	0.521	0.083	12.761	0.000	
I60	Willing to reflect on, and revise leader's decisions based on feedback from the crew	0.916	0.760	0.578	0.074	12.457	0.000	
Efficacy in safety management			*0.961					0.906
I30	Seriously consider the subordinates' suggestions and initiatives for improving safety	1.000	0.806	0.650			1.076	
I29	Actively listen to the crew members, and promote their involvement in decision making	1.078	0.814	0.662	0.074	14.596	0.000	
I18	When undesirable incidents occur, be able to improvise to handle the situation effectively	1.092	0.791	0.625	0.093	11.704	0.000	
I2	Able to use formal authority to ensure crew members adhere to the safety procedures and policies	1.047	0.707	0.500	0.096	10.918	0.000	
I24	Able to mobilize the resources to make effective decisions in a timely manner	1.098	0.861	0.741	0.083	13.213	0.000	
I8	Able to proactively manage safety risks	0.977	0.745	0.555	0.069	14.096	0.000	
Efficacy in safety initiative			*0.963					0.887
I26	Able to initiate and engage in toolbox sessions during safety meetings on board	1.000	0.801	0.641			1.279	
I47	Provide feedback on task performance frequently	0.953	0.769	0.591	0.063	15.040	0.000	
I27	Involve crew members actively in recommending revisions to established procedures	0.963	0.807	0.651	0.038	25.197	0.000	
I35	Able to closely observe crew performance during safety drills on board, and highlight shortcomings and good work	0.931	0.814	0.662	0.050	18.646	0.000	
I10	Ensure achievable safety goals are set	0.760	0.723	0.523	0.054	14.156	0.000	
	SLSES TOTAL							**0.971**

Table 7
Cronbach's α, composite reliability and average variance extracted.

Factor	Cronbach's α	Composite Reliability (C.R.)	Average Variance Extracted (AVE)
Efficacy in safety motivation facilitation	0.954	0.954	0.617
Efficacy in safety management	0.906	0.908	0.622
Efficacy in safety initiative	0.887	0.888	0.614

crew members to actively participate, freely report and pay attention to the procedures in order to succeed with regards to safety. The items listed under this subscale incorporated various leadership behaviours that directly or indirectly facilitate crew members motivation for safety, such as encouraging people to report errors, near-misses or other safety-related information without fear of the consequences, using logical arguments and factual evidence to ensure crew members' compliance with safety rules and procedures, etc. The extent to which leaders create a motivation system to encourage their followers' safety behaviours, namely safety motivation, is closely linked to the transformational leadership (Du and Sun, 2012). Transformational leaders inspire confidence, articulate goals, motivate subordinates to take extra efforts and so that it can improve the performance beyond expectation (Zohar, 2002). The items grouped into this factor are largely in line with transformational leadership theory which implies that the exercise of good transformational leadership behaviours would reflect safety leadership potentials to motivate subordinates in engaging in safety efforts.

Items loaded on the second factor were associated with shipboard leaders' competence for safety management, which is another core feature of safety leadership. Items used to assess this factor included several key management practices related to the needed for standardization, reliability, as well as the required improvising skills. Measurement items included the extent to which the shipboard leaders could proactively managing risks, mobilizing resource, implementing measures to ensure safety compliance, improvising to handle dynamic situations during ship operations, etc. These items are mainly associated with the transactional leaders' behaviours that aimed to ensure the expected performance standards are met (Martínez-Córcoles and Stephanou, 2017), though they also include items that reflect on the inclusion of subordinates and improvisation, more characteristic of transformational leadership behaviours (Bass and Avolio, 1997). Lately, there has been some discussions regarding the distinction between the "safety management" and "safety leadership", as these two terms have been used interchangeably in maritime context. Our research finding has shown that safety management is one dimention of safety leadership. Good shipboard leaders need to exercise both formal and informal leadership functions to not only enforce the safety rules to ensure people behave in a safe manner, but also to use good seamanship, influence practices and social skills to increase subordinate's risk awareness, motivation and willingness to act safely.

The third subscale is used to measure shipboard leaders' efficacy in taking safety initiative, which has made the highest contribution to the overall safety leadership self-efficacy ($\lambda = 0.963$). Leaders proficiency in exercising specific, discrete verbal and nonverbal leadership behaviours and initiations to encourage subordinates to be involved in safety activities, reflect leaders' efficacy on taking safety initiatives. They include setting goals, monitoring behaviour, providing feedback, and such. The items under the subscale on safety initiative also predominantly reflects a transactional leadership style (Stogdill and Bass, 1981).

The findings of this study reflect previous research that concludes that a combined approach of transformational and transactional leadership behaviours are most benefitial for safety leadership (Clarke, 2013). The SLSES demonstrates that there is no dichotomy between transactional and transformational leadership styles, but rather that safety leadership incorporates both. Meanwhile, it is also provides the important insight that the transactional and transformational leadership styles vary in importance in terms of leaders abilities to motivate, manage safety and take safety initiatives. This provides direction to future studies of leadership studies in the maritime industry. Finally, the proposed SLSES highlights the need for adaptive safety leadership, to handle complexity and uncertainty while achieving sustainable safety performance (Hollnagel, 2014).

Studies have recognized that effective leadership requires leaders to be skilled in use of influence (Yukl and Falbe, 1990), have good level of motivation and confidence towards their own leadership capabilities (Allen et al., 2014), and have psychological and behavioral resources to deal with the emerging demands during times of change and stress (Fredrickson, 2001; Hannah et al., 2008). SLSES incorporated the items that could help in assessing these aspects. It has also several important benefits for the shipowners, crew management companies and maritime training providers, as it forms a valuable source of information regarding the shipboard officer's leadership potential for safety and can serve as a means or a basis for decisions regarding future training and other personal development efforts. The scale can be used before and after the mandatory STCW leadership training to identify the area of safety leadership they are weakest in to guide the training effort. Subordinates would not want to follow a leader who appears to lack in confidence. Vice versa, when a leader does not exhibit confidence in their own decisions and actions, they do not engender confidence in their subordinates. It is expected SLSES could lead to diverse approach in practice to acknowledge and augment one's safety leadership capacity.

Despite the contribution of the proposed SLSES, future research should be conducted. In this study, by following up on an expert consensus survey, we used 150 samples for EFA, 396 samples for CFA, which is in accordance with the sampling recommendations (Worthington and Whittaker, 2006a, 2006b). Since the communalities for all items in the initial EFA were high, sample size have relatively little impact on the quality of the factor analysis solution, which means that "accurate recovery of population solutions may be obtained using a fairly small sample" (MacCallum et al., 1999, p. 90). However, follow-up studies should use a larger sample size to validate the developed scale, to conduct correlational analysis and to assess the predictability of SLSES for safety culture, near-misses reporting rate, or other indicators of actual safety performance. In addition, there are many sociodemographic factors (e.g., nationality, education, seniority, gender) and shipping sector-specific characteristics could affect leadership styles and safety behaviors. It is worthwhile to expand research in this area to obtain a fuller picture of maritime safety leadership phenomenon.

As organizations evolve in an increasingly complex environment – characterized by new technological, regulatory, social and economic challenges, the dynamic situations occurring at sea and shore, the amount of administration procedures and papers often intensify the pressure and demands placed on the leaders. When evaluating the safety leadership self-efficacy, personal factors as well as the context and situations encountered by the leaders might need to be considered. The evaluation of leaders' self-efficacy for safety should involve an appraisal of the interaction of the perceived capabilities with the situational demands and obstacles.

6. Conclusion

While regulatory bodies make substantial efforts in promulgating safety rules and conventions to enhance safety standards, the effect and consequently the safety performance ultimately depends upon how organizations and their leaders value safety and approach its implementation. Safety leadership is a key driver to a mature safety management system and this study can add to this area. Given that this is the first safety leadership self-efficacy measurement scale in a maritime context, it may provide a distinct contribution to theory-building and practice of leadership training in maritime education and training institutions. SLSES can be used as an instrument to diagnose shipboard leader's self-efficacy level and allows the shipping companies to examine the belief, attitude and behavioural patterns prior to the promotion and selection of leaders. By providing an understanding of the current level of safety leadership self-efficacy, it can help training instructors to determine the best approach to increase trainees' self-efficacy based on the relative scores in each safety leadership dimension.

In conclusion, we expect that the SLSES could lead to diverse approach in maritime research and training practice to augment individual safety leadership capacities and to create a high safety leadership efficacy climate.

Acknowledgement

The authors are grateful for the support from Norwegian Shipowners' Association, the member institutes of the Norwegian National Joint PhD program in Nautical Operations, and the Korean Institute of Maritime and Fisheries Technology for their seafarer leadership training expertise and valuable support in the data collection process. The Safety Leadership Self-Efficacy Scale (SLSES) and its scoring instructions are available upon request at no cost.

References

Allen, M.T., Bynum, B.H., Oliver, J.T., Russell, T.L., Young, M.C., Babin, N.E., 2014. Predicting leadership performance and potential in the US Army Officer Candidate School (OCS). Military Psychol. 26 (4), 310–326.
Anderson, D.W., Krajewski, H.T., Goffin, R.D., Jackson, D.N., 2008. A leadership self-efficacy taxonomy and its relation to effective leadership. Leadership Quart. 19 (5), 595–608.
Bandura, A., 1986. Social Foundations of Thought and Action: A Social Cognitive Theory. Prentice Hall, Englewood Cliffs, N.J.
Bandura, A., Walters, R.H., 1977. Social Learning Theory, Vol. 1. Prentice-hall Englewood Cliffs, NJ.
Barnett, M., Gatfield, D., Pekcan, C., 2003. A Research agenda in maritime crew resource management. Proceedings of the International Conference on Team Resource Management in the 21st Century.
Bandura, A., 2006. Guide for constructing self-efficacy scales. Self-efficacy Beliefs of Adolescents 5 (1), 307–337.
Bass, B.M., 1985. Leadership and Performance Beyond EXpectations. Free Press;Collier Macmillan, New York.
Bass, B.M., Avolio, B.J., 1997. Full Range Leadership Development: Manual for the Multifactor Leadership Questionnaire. Mind Garden.
Batalden, B.-M., Sydnes, A.K., 2014. Maritime safety and the ISM code: a study of investigated casualties and incidents. WMU J. Maritime Aff. 13 (1), 3–25.
Bentley, T.A., Haslam, R.A., 2001. A comparison of safety practices used by managers of high and low accident rate postal delivery offices. Saf. Sci. 37 (1), 19–37.
Besikçi, E.B., 2019. Strategic leadership styles on maritime safety. Ocean Eng. 185, 1–11.
Carpenter, S., 2018. Ten steps in scale development and reporting: a guide for researchers. Commun. Methods Meas. 12 (1), 25–44.
Chen, C.-F., Chen, S.-C., 2014. Measuring the effects of Safety Management System practices, morality leadership and self-efficacy on pilots' safety behaviors: Safety motivation as a mediator. Saf. Sci. 62, 376–385.
Cicchetti, D.V., Sparrow, S.A., 1981. Developing criteria for establishing interrater reliability of specific items: applications to assessment of adaptive behavior. Am. J. Mental Deficiency 86 (2), 127–137.
Clarke, S., 2013. Safety leadership: A meta-analytic review of transformational and transactional leadership styles as antecedents of safety behaviours. J. Occup. Org. Psychol. 86 (1), 22–49.
Cooper, C.D., Scandura, T.A., Schriesheim, C.A., 2005. Looking forward but learning from our past: potential challenges to developing authentic leadership theory and authentic leaders. Leadership Quart. 16 (3), 475–493.
Crawford, J.A., Kelder, J.-A., 2019. Do we measure leadership effectively? Articulating and evaluating scale development psychometrics for best practice. Leadership Quart. 30 (1), 133–144.
de Koster, R.B.M., Stam, D., Balk, B.M., 2011. Accidents happen: the influence of safety-specific transformational leadership, safety consciousness, and hazard reducing systems on warehouse accidents. J. Oper. Manage. 29 (7), 753–765.

DeVellis, R.F., 2016. Scale Development: Theory and Applications, 26. Sage Publications.
Du, X., Sun, W., 2012. Research on the relationship between safety leadership and safety climate in coalmines. Procedia Eng. 45, 214–219.
Fabrigar, L.R., Wegener, D.T., MacCallum, R.C., Strahan, E.J., 1999. Evaluating the use of exploratory factor analysis in psychological research. Psychol. Methods 4 (3), 272.
Farooq, R., 2016. Role of structural equation modeling in scale development. J. Adv. Manage. Res. 13 (1), 75–91.
Fredrickson, B.L., 2001. The role of positive emotions in positive psychology: the broaden-and-build theory of positive emotions. Am. Psychol. 56 (3), 218.
Ginsburg, L.R., Chuang, Y.T., Blair Berta, W., Norton, P.G., Ng, P., Tregunno, D., Richardson, J., 2010. The relationship between organizational leadership for safety and learning from patient safety events. Health Services Res. 45 (3), 607–632.
Graeff, C.L., 1983. The situational leadership theory: a critical view. Acad. Manag. Rev. 8 (2), 285–291.
Graen, G.B., Uhl-Bien, M., 1995. Relationship-based approach to leadership: Development of leader-member exchange (LMX) theory of leadership over 25 years: Applying a multi-level multi-domain perspective.
Grech, M., Horberry, T., Koester, T., 2008. Human Factors in the Maritime Domain. CRC Press.
Hannah, S.T., Avolio, B.J., Luthans, F., Harms, P.D., 2008. Leadership efficacy: review and future directions. Leadership Quart. 19 (6), 669–692.
Hatcher, L.A., 1994. Step-by-Step Approach to Using the SAS System for Factor Analysis and Structural Equation Modeling. SAS Publishing, Cary, NC. USA.
Håvold, J.I., 2005. Safety-culture in a Norwegian shipping company. J. Saf. Res. 36 (5), 441–458.
Hofmann, D.A., Morgeson, F.P., 1999. Safety-related behavior as a social exchange: the role of perceived organizational support and leader-member exchange. J. Appl. Psychol. 84 (2), 286–296.
Hollnagel, E., 2014. Safety-I and safety-II: The past and future of safety management. Ashgate Publishing, Ltd.
IMO, 2017. International Convention on Standards of Training, Certification and Watchkeeping for Seafarers,(STCW) 1978, as amended in 1995/2010. International Maritime Organisation, London, UK.
Kim, T.-E., Gausdal, A.H., 2017. Leading for safety: a weighted safety leadership model in shipping. Reliab. Eng. Syst. Saf. 165, 458–466.
Kim, T.-E., Gausdal, A.H., 2020. Leaders' influence tactics for safety: an exploratory study in the maritime context. Safety 6 (1), 8.
Kim, T.-e., Mallam, S., 2020. A Delphi-AHP study on STCW leadership competence in the age of autonomous maritime operations. WMU J. MaritimeAff. (19), 163–181.
Kim, T.-E., Nazir, S., Øvergård, K.I., 2016. A STAMP-based causal analysis of the Korean Sewol ferry accident. Saf. Sci. 83, 93–101.
Kjellen, U., 1982. An evaluation of safety information systems at six medium-sized and large firms. J. Occup. Acc. 3 (4), 273–288.
Leveson, N., 2011. Engineering a Safer World: Systems Thinking Applied to Safety. MIT Press.
Li, Y., Liu, Z., Lan, J., Ji, M., Li, Y., Yang, S., You, X., 2018. The influence of self-efficacy on human error in airline pilots: the mediating effect of work engagement and the moderating effect of flight experience. Curr. Psychol. 1–12.
MacCallum, R.C., Widaman, K.F., Zhang, S., Hong, S., 1999. Sample size in factor analysis. Psychol. Methods 4 (1), 84.
Martínez-Córcoles, M., Stephanou, K., 2017. Linking active transactional leadership and safety performance in military operations. Saf. Sci. 96, 93–101.
Mattson, M.M., Von, U.T.S., Hellgren, J., Hasson, H., Tafvelin, S., 2019. Leading for safety: a question of leadership focus. Saf. Health Work 10 (2), 180–187.
McCormick, M.J., 2001. Self-efficacy and leadership effectiveness: applying social cognitive theory to leadership. J. Leadership Stud. 8 (1), 22–33.
Mullen, J.E., Kelloway, E.K., 2009. Safety leadership: a longitudinal study of the effects of transformational leadership on safety outcomes. J. Occup. Org. Psychol. 82 (2), 253–272.
Nunnally, J.C., 1994. Psychometric Theory 3E. Tata McGraw-Hill Education.
O'Connor, P., 2011. Assessing the effectiveness of bridge resource management training. Int. J. Aviation Psychol. 21 (4), 357–374.
O'Dea, A., Flin, R., 2001. Site managers and safety leadership in the offshore oil and gas industry. Saf. Sci. 37 (1), 39–57.
Oltedal, H., McArthur, D., 2011. Reporting practices in merchant shipping, and the identification of influencing factors. Saf. Sci. 49 (2), 331–338.
Oltedal, H.A., Lützhöft, M., 2018. Managing Maritime Safety. Routledge.
Paglis, L.L., 2010. Leadership self-efficacy: research findings and practical applications. J. Manage. Dev. 29 (9), 771–782.
Paglis, L.L., Green, S.G., 2002. Leadership self-efficacy and managers' motivation for leading change. J. Org. Behav. 23 (2), 215–235.
Pilbeam, C., Doherty, N., Davidson, R., Denyer, D., 2016. Safety leadership practices for organizational safety compliance: Developing a research agenda from a review of the literature. Saf. Sci. 86, 110–121.
Ross, J., 2011. How leadership can create an enduring safety culture. In: 11th AusIMM Underground Operators' Conference 2011, The Australasian Institute of Mining and Metallurgy, Melbourne, pp. 275–280.
Schröder-Hinrichs, J.U., Hollnagel, E., Baldauf, M., 2012. From Titanic to Costa Concordia-a century of lessons not learned. WMU J. Maritime Aff. 11 (2), 151–167.
Shi, J., Mo, X., Sun, Z., 2012. "Content validity index in scale development." *Zhong nan da xue xue bao. Yi xue ban* = J. Cent. South Univ. Med. Sci. 37 (2), 152–155.
Slišković, A., Penezić, Z., 2015. Occupational stressors, risks and health in the seafaring population. Rev. Psychol. 22 (1–2), 29–40.
Stajkovic, A.D., Luthans, F., 1998. Self-efficacy and work-related performance: a meta-analysis. Psychol. Bull. 124 (2), 240.
Stogdill, R.M., Bass, B.M., 1981. Stogdill's Handbook of Leadership. Free Press.
Ullman, J.B., 2006. Structural equation modeling: reviewing the basics and moving forward. J Pers Assess 87 (1), 35–50.
Wahl, A.M., Kongsvik, T., 2018. Crew resource management training in the maritime industry: a literature review. Wmu J. Maritime Aff. 17 (3), 377–396.
Wood, R., Bandura, A., 1989. Social cognitive theory of organizational management. Acad. Manag. Rev. 14 (3), 361–384.
Worthington, R.L., Whittaker, T.A., 2006a. Scale development research – a content analysis and recommendations for best practices. Counseling Psychol. 34 (6), 806–838.
Worthington, R.L., Whittaker, T.A., 2006b. Scale development research: a content analysis and recommendations for best practices. Counseling Psychol. 34 (6), 806–838.
Wu, T.-C., 2005. The validity and reliability of safety leadership scale in universities of Taiwan. Int. J. Technol. Eng. Edu. 2 (1), 27–42.
Wynd, C.A., Schmidt, B., Schaefer, M.A., 2003. Two quantitative approaches for estimating content validity. West. J. Nurs. Res. 25 (5), 508–518.
Yang, C.-C., Wang, Y.-S., Chang, S.-T., Guo, S.-E., Huang, M.-F., 2009. A study on the leadership behavior, safety culture, and safety performance of the healthcare industry. World Acad. Sci. Eng. Technol. 53.
Yukl, G., Falbe, C.M., 1990. Influence tactics and objectives in upward, downward, and lateral influence attempts. J. Appl. Psychol. 75 (2), 132–140.
Zamanzadeh, V., Ghahramanian, A., Rassouli, M., Abbaszadeh, A., Alavi-Majd, H., Nikanfar, A.-R., 2015. Design and implementation content validity study: development of an instrument for measuring patient-centered communication. J. Caring Sci. 4 (2), 165.
Zohar, D., 2002. Modifying supervisory practices to improve subunit safety: a leadership-based intervention model. J. Appl. Psychol. 87 (1), 156–163.
Zohar, D., 2003. The effects of leadership dimensions, safety climate, and assigned priorities on minor injuries in work groups. J. Org. Behav. 23 (1), 75–92.

APPENDIX F

JORNAL ARTICLE:

Holistic case study on the explosion of ammonium nitrate in Tianjin Port

sustainability

MDPI

Case Report

Holistic Case Study on the Explosion of Ammonium Nitrate in Tianjin Port

Gending Yu [1], Yih-Shing Duh [1,2,3,*], Xiaodong Yang [1,4], Yongzhao Li [5], Yangqing Chen [6], Yuqi Li [1], Jingling Li [1], Rongguo Chen [1], Lingzhu Gong [1,*], Bin Yang [3] and Jiulai Huang [3]

1 Fuzhou Green Chemical and Cleaner Production Industry Technology Innovation Center, College of Ecological Environment and Urban Construction, Fujian University of Technology, Fuzhou 350118, China; gendingyu@fjut.edu.cn (G.Y.); 18250162677@163.com (X.Y.); li@fjut.edu.cn (Y.L.); lil118@163.com (J.L.); chen_rongguo@126.com (R.C.)
2 Gulei Innovation Institute, College of Chemistry and Chemical Engineering, Xiamen University, Xiamen 361005, China
3 Xibaoyuan Chemical Technology Co., Ltd., Xiamen 361000, China; xby@xibaoyuan.com (B.Y.); hjl@xibaoyuan.com (J.H.)
4 Fujian Xinsen Carbon Co., Ltd., Nanping 354000, China
5 Guangxi Key Laboratory of Electrochemical and Magnetochemical Functional Materials, Guilin University of Technology, Gulin 541001, China; yongzhaoli1123@163.com
6 Chongqing Rail Transit Co., Ltd., Chongqing 401120, China; chenyangqing0628@163.com
* Correspondence: yihshingduh@xmu.edu.cn (Y.-S.D.); gonglingzhu@sina.com (L.G.); Tel.: +86-22863265 (ext. 802) (Y.-S.D.); Fax: +86-22863267 (Y.-S.D.)

Abstract: On 12 August 2015, Tianjin port, Tianjin City, China, a catastrophic explosion of Ruihai International Logistics Co., Ltd. (Tianjin, China) killed 173 and hurt almost 798 people, accompanying a financial loss of almost USD 2 billion. The ignition of the first fire due to the autocatalytic decomposition of nitrocellulose was verified by differential scanning calorimeter (DSC) isothermal tests. A crater with a diameter of 97 m was created by the second explosion. For the second catastrophic explosion, an amount of 577 tons of trinitrotoluene was determined by the average through scaling law, crater inverse analysis and blast effects on structures. The overpressure against distance for consequence analysis was conducted using Baker's, Sadovski's and Alonso's methodologies. A distinctive scenario of "two-successive-sympathetic detonations-following-a-fire" was proposed and discussed. Isothermal time-to-maximum-rate was validated to be approximately 9 days for the nitrocellulose inside the containers with an internal temperature of 60 °C stored at Tianjin port. A fatality radius chosen at the overpressure of 0.6 bar was ascertained to be nearly 410 m from the explosion origin.

Keywords: sustainability; risk management; nitrocellulose; ammonium nitrate; case study

Citation: Yu, G.; Duh, Y.-S.; Yang, X.; Li, Y.; Chen, Y.; Li, Y.; Li, J.; Chen, R.; Gong, L.; Yang, B.; et al. Holistic Case Study on the Explosion of Ammonium Nitrate in Tianjin Port. *Sustainability* **2022**, *14*, 3429. https://doi.org/10.3390/su14063429

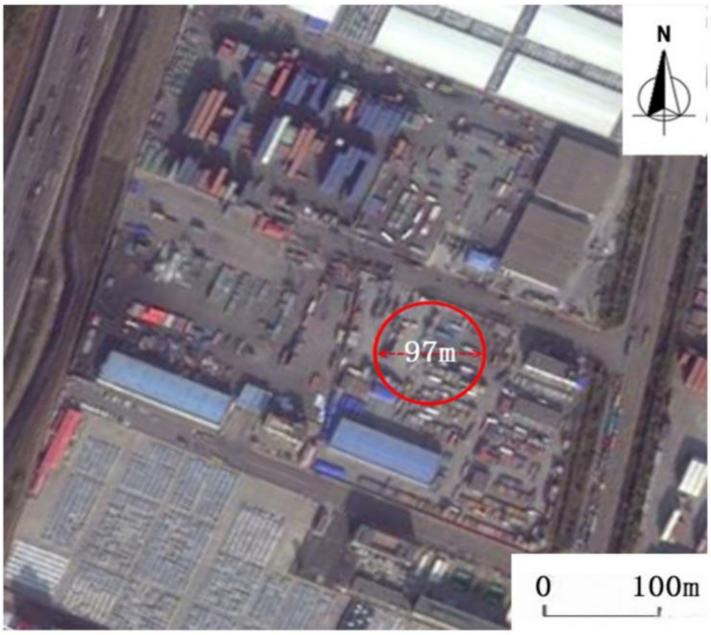
Academic Editor: José Ignacio Álvarez

Received: 6 February 2022
Accepted: 10 March 2022
Published: 15 March 2022

1. Introduction

1.1. Occurrence of the Incident

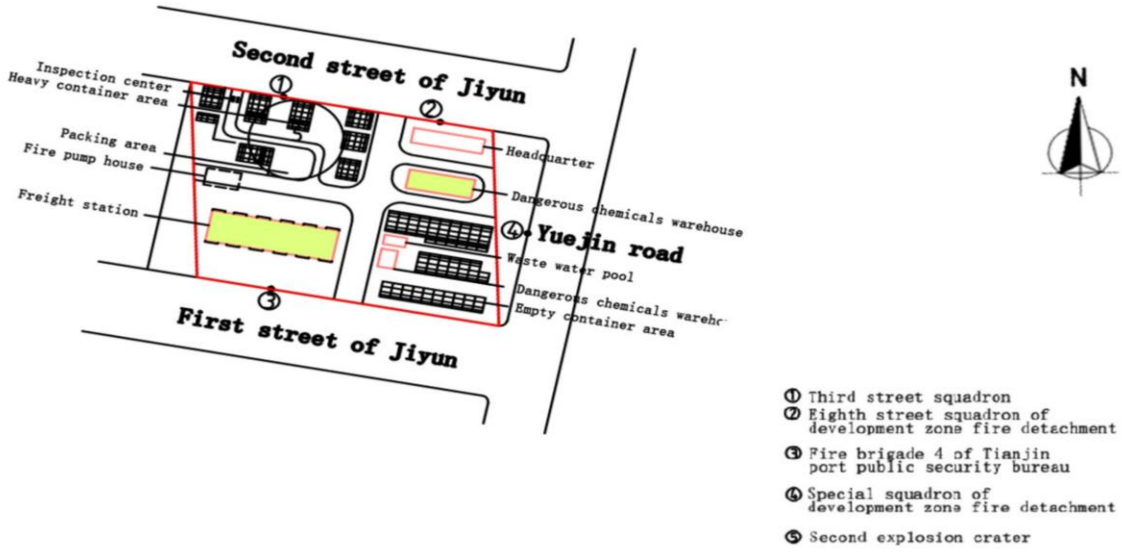
At 22:51:46 on 12 August 2015, the warehouse of the Ruihai company for storing the hazardous materials, located at Jiyun road, Binhai new district of Tianjin port was first reported to catch fire in a container [1]. A container of dry nitrocellulose (NC) accompanied with spontaneous combustion was suspected to be the scene of the fire in the beginning. Thermal radiation and burning flame were the significant conditions that sped up the rapid fire spread throughout the storage area. In the summertime, because the container did not easily dissipate heat, the temperature of NC continued to rise to its auto-ignition temperature (AIT) and spontaneously burned. Infelicitously, the fire kindled by NC ultimately propagated to the containers of ammonium nitrate (AN) causing the consecutive explosions. Particularly, the second explosion caused the most catastrophic consequence. During the firefighting, the first explosion happened at 23:34:06 and the second larger explosion proceeded at 23:34:37; a videotape filmed the amazing explosions with extremely destructive powers and sparkling flashes. It exhibited the features of two rapidly successive explosions, which occurred extremely quickly with a time interval as short as 32 s. Six large fires and more than ten small fire sites were caused after the second explosion. At 16:40 on 14 August, the fire at the site was entirely extinguished. Figure 1 shows the pictures of explosion region before and after the occurrence of the tragedy. According to the statistics in the public media, 165 deaths with 8 missing individuals and 798 hospitalized injuries were reported. Besides, hundreds of buildings were demolished and an economic destruction roughly USD 2 billion.



(**a**)

(**b**)

Figure 1. *Cont.*



(**c**)

Figure 1. (**a**) The picture of the explosion region before the incident took by satellite; (**b**) the picture of the explosion region after the incident took by satellite; (**c**) Interior layout of Ruihai International Logistics Co., Ltd. before the incident.

1.2. Major Incidents Caused by Ammonium Nitrate

Since the 20th century, no less than 40 severe explosions were related to AN. Eleven representative catastrophes ignited by AN are summarized in Table 1.

Table 1. Eleven major incidents caused by AN.

Incident Number	Location	Date	Quantity (Tons)	Fatalities/Injuries	Reference
1	Morgan, NJ, USA	4 October 1918	1000	64/100	[2]
2	Oppau, Germany	21 September 1921	450	561/1952	[3]
3	Tessenderloo, Belgium	29 April 1942	150	>100/NA	[2]
4	Texas City (TX, USA)	16 April 1947	2300	>500/3500	[3]
5	Brest, France	28 July 1947	3000	30/>1000	[2]
6	Shenzen, China	5 August 1993	65	18/873	[4]
7	Toulouse, France	21 September 2001	300	30/3000	[3]
8	Ryongchon, North Korea	22 April 2004	NA	161/1300	[3]
9	Monclova, Coahuila, Mexico	4 September2007	22–25	28/130	[3]
10	Tianjin Port, China	12 August 2015	800	173/798	[1]
11	Beirut Port, Lebaron	4 August 2020	2750	204/>7000	[5]

NA: Not available.

Several explosion incidents with less fatalities and injuries which occurred in Toulouse (France) [6] and West (TX, USA) [7,8] were reported. In 2020, a disastrous explosion in the warehouse of Beirut port which storing 2750 tons of ammonium nitrate exploded [9,10]. Society has suffered such a loss of properties and at the sacrifice of many human lives, and the industry should learn from the historical explosions caused by ammonium nitrate [11,12]; however, we have not [13].

1.3. Thermal Hazards and Autocatalytic Decomposition of Nitrocellulose

NC is a thermally unstable compound because of the presence of $-NO_2$ group, which has been classified as a flammable solid by the United Nations Committee of Experts on the Transports of Dangerous Goods (UN-TDG) and U.S. Department of Transportation (US-DOT). NC was numbered as UN 2556 or UN 3040 [14]. US-DOT classified it as the class

4.1 flammable solid [15]. Commercial NC was wetted with alcohols or water to suppress the sensitivity to explosive properties. Since 1955, the thermal decompositions of NC were studied by chemical analysis and spectroscopy [16]. In these two decades, some incidents caused by unstable features of the NC attracted researchers' interests to validate the thermal stability of NC. Considerable exertions have been contributed to the the reactive instability of NC by calorimetry, thermogravimetry analysis (TGA), mass spectrometry, and surface technique [17,18]. In particular, by calorimetry and TGA, the exothermic onset temperature was determined non-isothermally to be of approximately 182 °C [19,20]. The enthalpy change of thermal decomposition was detected as high as 2591 Jg^{-1} [21]. A research review on the kinetics of NC at 50–500 °C was reported by Brill and Gongwer [22]. An autocatalytic reaction of first order owing to the slower reaction to the O-NO_2 homeless in the 100–200 °C range was proposed and discussed by Kimura [23]. Thereafter, the autocatalytic kinetics of the thermal decomposition of NC were explored by several laboratories [24–26]. Most of these previous studies of kinetic triplets were put forward, however, without extending to the application of hazard analysis in the chemical industry. A study of thermal explosion of NC was declared by Luo et al. [27] using the Ozawa-Friedman method and bench-scale thermal explosion test as well as the Frank–Kamenetskii theory. An upper critical ambient temperature (UCAT) of the nitrocellulose decreased from 132.5 °C to 96.4 °C relative to the ignition dimension increased from 0.1 m to 1.6 m [27]. In the official report of Tianjin explosion, the first fire is reported to have been initiated by the ignition of NC caused by the autocatalytic decomposition in container at an internal temperature of approximately 60 °C [1]. Nevertheless, it is a regret that there is no direct evidence or experimental data to support this hypothesis up to now. One of the important objectives in this work is to predict the auto-ignition of NC from 60 °C with an experimental approach.

1.4. Fire and Explosion Hazards of Ammonium Nitrate

Ammonium nitrate has been used to make explosives and fertilizer since 1910 [28]. Neat AN cannot be ignited at room temperature; however, it can burn with the inductions of fire and contaminant. The oxygen balance of AN is approximately 20%, which reveals that the excess oxygen content serving as a donor for combustible materials. There are two commercial AN, ammonium nitrate of fertilizer grade (FGAN) and technical grade (TGAN) which hold the common chemical structure. In 2013, a fire happened at an AN plant in West (TX, USA) that eventually led to a serious explosion resulting in 15 deaths [13,29]. Nevertheless, in 2014 a similar event in Athens (TX, USA) only burned the warehouse out without further explosion [30]. A multiplicity of AN behaviors under different fire sites make it hard for the emergency staff to respond correctly. The National Fire Protection Association (NFPA) 400 classified AN as a Class 2 Oxidizer [31]. NFPA also assigned the AN as an instability rating of three to alert the personnel of emergency response that AN could be capable of detonating when confined at a fire site. The United Nations (UN) classified AN-Based Fertilizers (UN 2067) to be a Division 5.1 Oxidizer as well [32]. Besides, the United States Department of Transportation (US-DOT) followed this oxidizer classification. Being an oxidizer, it can facilitate the spread of fire and strengthen the combustion of contacted materials, even without air. Though AN is quite safe at ambient temperature, the thermal hazards of AN at high temperatures have been reported [33,34]. Contaminants, confinements, and external fire complicated the firefighting and enhanced the risk of AN stored in warehouse under fire [35,36]. An uncontrolled fire in particular will worsen the warehouse storing AN to cause an explosion with high probability [37].

1.5. Explosion Hazards and Susceptibility to Detonation of AN

Accidental explosions induced by AN were internationally responsible for several catastrophes. Not a few complete works had been executed by the U.S. Bureau of Mines in 1960s on the basis of the Texas City (TX, USA) disaster related to AN [38–40]. The detonations of AN resulted majorly from the influences of adjacent explosions. A sympathetic detonation (SD) is a phenomenon of coherent detonation induced by a donor detonation.

The fact is that the SD is triggered passively by the concussion of explosion pieces or gigantic pressure impulse from the neighboring "explosion donor". The detonation of high explosive occurs within a time of ms and the pressure is a value of GPa. When sympathetic detonation occurred, it took place a time scale less than 1 ms after impact from donor detonation. This means that the incident blast from a donor is extremely strong as the "acceptor explosive" detonates almost instantly. An investigation on the SD of AN regarding to the ammonium nitrate-fuel oil (AN-FO) was posed [38–40]. They indicated that an AN-FO acceptor against a 16-gage steel faced AN-FO donor, the SD could be ignited within a distance of 53 feet or equivalent to 16 charge diameters (i.e., the ratio of gap to diameter was equal to 16). However, with AN acceptor, the initiation occurred at approximately 5.5 charge diameters separation (i.e., the ratio of gap to diameter was equal to 5.5) [38–40]. The separation across which AN-FO and AN can be sympathetically detonated by an AN-FO donor was surprisingly huge, which had never been imagined. Their investigations showed that unexpectedly large safety distances inevitably hindered SD when the industry stored explosives or AN.

Until today, part of the occurred contingencies in the Tianjin incident were not declared. This study will stress the following major objectives/focuses: (1) how long will the first fire take from the NC container spontaneously ignite due to the autocatalytic decomposition, (2) whether the NC is more hazardous in closed or open state, (3) the assessment model for trinitrotoluene (TNT) equivalent in the explosion, (4) how the crater with a diameter of 97 m can be formed, and (5) to assess the fatality radius of the human body by relating the blast overpressure versus distance to provide safety measures, on-site rescues and emergency responses in an AN warehouse under fire scenario.

2. Materials and Methods

2.1. Samples

A sample of NC with a nitrogen content of 11.7% was supplied by a local company. NC was sealed in an explosion-proof container and stored below 20 °C.

2.2. Differential Scanning Calorimetry

Thermal instability of NC was screened using a Mettler DSC 3 system coupled with a STAR^e V15 control system [41]. Disposable aluminum crucible (ME-27731) was used to determine thermal curves under closed or open conditions. The exothermic onset temperature (T_{onset}) was chosen at the deflection point defined by ASTM E537 [42]. Scanning rate was selected to be 4 K min^{-1} in temperature-programmed ramp. A typical isothermal aging curve with autocatalytic reaction can be verified by the characteristics of a long induction period, an acceleration period and a decay time. By obeying the ASTM E487 [43], the isothermal onset temperature can be defined as the maximum temperature at which a chemical compound or mixture may be held for a period under the conditions imposed on the test without exhibiting a measurable exothermic reaction. Taking a complete set of thermal curves using isothermal tests under several temperatures, the autocatalytic kinetics can be determined by following the ASTM E2070 [44]. The induction time (or termed as time-to-maximum-rate (TMR)) is the time an unstable compound or mixture held under isothermal conditions until it exhibits a distinct exothermic behavior [45]. TMR is a featured parameter to explain the induction time for the storage period of the NC from the time of arrival to that of the auto-ignition in conjunction with the first fire occurred.

2.3. Evaluation of Trinitrotoluene Equivalent

TNT equivalent is one of the cardinal physical quantities for evaluating the powers of explosions resulted from energetic explosives. Even if the detonation feasibility of AN was known not to be high, this catastrophic incident implied that this study on consequences must be performed for the purposes of safety measures and emergency responses. Traditionally, the overpressure of the explosion versus distance is evaluated, thus the simulated destructive influences on human bodies or demolition to buildings can be substantiated. For the modeling of detonations relating explosive chemicals, most of the traditional methodologies would like to use the TNT equivalent. One of the most significant viewpoints that must be weighed is to verify the safe distance for industry and community.

2.3.1. Trinitrotoluene Equivalent Model

A simplified approach applied the traditional TNT equivalent model from the conversion factor of explosive chemical into the effective TNT mass for assessing the power of shock wave resulted from explosion. It can be expressed as Equation (1) [46]:

$$\text{TNT equivalent mass} = m_{\text{TNT}} = m_{\text{AN}} \times \frac{\Delta H_{\text{AN}}}{\Delta H_{\text{TNT}}} \tag{1}$$

where m_{TNT} is the equivalent mass of TNT, m_{AN} is the mass of AN, ΔH_{TNT} is the heat of decomposition of TNT, ΔH_{AN} is the heat of decomposition of AN, and $\Delta H_{\text{AN}}/\Delta H_{\text{TNT}}$ is the equivalency efficiency of AN which links the realistic heat liberated in relation to TNT. The certainty for TNT equivalent can exhibit the heat generated to account for the blast powers correctly. AN possesses the m_{TNT} efficiency, which was generally adopted to be 0.35 by the heat of decomposition and Equation (1) [5,46].

2.3.2. Validation of Trinitrotoluene Equivalent

Damage–Distance Correlation

The endeavor to quantify the blast damage, distance, and m_{TNT} implicated an early study of blast power in the 1940s. The results of investigations into blast powers to buildings have been expressed in the following equation [47]:

$$R = A m_{\text{TNT}}^{1/3} \Big/ \left[1 + \left(700/m_{\text{TNT}}\right)^2\right]^{1/6} \tag{2}$$

where R is the distance (in inch), A is a constant for a given "category" of destruction (in feet per pound$^{1/3}$), and m_{TNT} is the TNT equivalent (in pounds).

Empirical Formula of Scaling Law

Scaling laws for evaluating the crater sizes have been known worldwide on ground explosions driven by the chemical and nuclear tests till today [48]. These two kinds of explosions were demonstrated to be analogous in accounting the crater size as a power of m_{TNT}; however, which order was not necessarily equivalent to be the first. The scaling law was determined experimentally through practical tests of ground explosions. Scaling of crater size in relation to m_{TNT} was presented in the following expression:

$$D = c m_{\text{TNT}}^{n} \tag{3}$$

where D is the crater diameter, n is the empirical index, and m_{TNT} is the TNT equivalent. Outcomes of reliable tests ranged from 1 kg to 5000 tons of TNT, however, which revealed that the constant n is not conventionally the same. In the earlier study, the diameter was proportional to the power of charge mass, ideally with a hypothetical index of 1/3 (i.e., the cube root of m_{TNT}) [49]. Table 2 summaries the scaling laws reported by Vortman [48] and compared those with explosion tests.

Table 2. Scaling laws for crater diameter related to TNT equivalent.

Author	Scaling Law	m_{TNT} (kg)	Description
Vortman	$D = 0.56\ m_{TNT}^{0.375}$	3.6, 29, 116, 454, 2720, 18,144	16 explosion tests on the surface of dry-lake at Nevada test site
Vortman	$D = 0.40\ m_{TNT}^{0.408}$	232, 4564, 18,144, 90,718, 453,592	5 explosion tests at the Watching Hill site
Vortman	$D = 0.32\ m_{TNT}^{0.426}$	3.63, 3.86, 13.83, 236, 250, 272, 4565, 4574, 4579, 18,144	30 explosion tests at the Downing Ford site
Adushkin and Khristoforov	$D = 0.606\ m_{TNT}^{0.34}$	1000–5,000,000	54 explosion tests on surface
Ambrosini and Luccioni	$D = 0.606\ m_{TNT}^{0.34}$	1, 2, 4, 7, 10, 250	6 explosion tests on surface
Ambrosini et al.	$D = 0.80\ m_{TNT}^{1/3}$	1–10	30 explosion tests; Scaling law revised from tests by Kinney and Graham

Inverse Analysis Based on Crater Size

On the basis of the abovementioned scaling law with a n of 1/3, any distance R from an explosive charge with mass m_{TNT} can be written by a scaled distance $Z = R\ m_{TNT}^{1/3}$. In the same approach, the scaled depth of crater can have the identical cube root related to m_{TNT}. Zhou et al. presented their calculations supported by eight-four results of the examined parameters of the craters created by TNT tests for inverse analysis [50].

2.4. *Influences of Blast Overpressure on Buildings and Personnel*

2.4.1. Shock Wave Blast Effects

Two of the most important factors, overpressure and impulse, representing the power of explosions are chiefly responsible for the destructive ability to humans, structures and environments. After the results obtained from this model, these data were then fitted to integrate equations showing the relationship among overpressure against distance or impulse in relation to distance, which are generally called "characteristic curves". These characteristic curves associate mathematical equations or impulse expressions significantly with the m_{TNT}. In brief, characteristic curves are capable of displaying the explicit plots of overpressure in conjunction with distance. In this work, three methodologies of Baker et al. Sadovski et al. and Alonso et al. were employed to assess the results of harms to human bodies and the powers of demolition to structures [51–53].

2.4.2. Baker's Methodology

Once m_{TNT} has been verified, the scaled distance Z_e can be assessed from the distance to the explosion point by scaling law, the Equation (4) can be applied for safe distance evaluation:

$$Ze = R/m_{TNT}^{1/3} \tag{4}$$

where Z_e is the scaled distance of TNT equivalent in mkg$^{1/3}$, R is the distance from the explosion origin in m, and m_{TNT} is the TNT equivalent in kg. Baker et al. utilized the following scaled distance of TNT equivalent to validate the relationship between overpressure and distance during detonation [51]. The formula for calculating the overpressure and safe distance of the shock wave generated by TNT explosion was expressed as follows:

$$\frac{\Delta P}{P} = \frac{1616\left[1 + \left(\frac{Z_e}{4.5}\right)^2\right]}{\sqrt{1 + \left(\frac{Z_e}{0.048}\right)^2}\sqrt{1 + \left(\frac{Z_e}{0.32}\right)^2}\sqrt{1 + \left(\frac{Z_e}{1.35}\right)^2}} \tag{5}$$

where ΔP is the overpressure of the shock wave in Pa and P is the ambient atmospheric pressure in Pa.

2.4.3. Sadovski's Methodology

By assuming the pseudo-spherical origin of the explosion, the overpressure of shock wave analyzed from quite a number of tests was proposed by Sadovski [52]:

$$\Delta P = 0.085 \frac{\sqrt[3]{m_{TNT}}}{R} + 0.3 \left(\frac{\sqrt[3]{m_{TNT}}}{R}\right)^2 + 0.8 \left(\frac{\sqrt[3]{m_{TNT}}}{R}\right)^3 \quad (6)$$

where ΔP is the overpressure in MPa, R is the distance from explosion origin, and m_{TNT} is TNT equivalent in kg.

2.4.4. Alonso's Methodology

By applying the methodology proposed by Alonso et al. [53], the overpressure can be confirmed by either one of the two regions, as expressed in Equation (7).

$$\Delta P = 1.13 \times 10^6 Z_e^{(-2.01)} \quad (7)$$

where ΔP is the overpressure in Pa, $1 \leq Z_e \leq 10$ and $1.13 \times 10^6 \geq \Delta P \geq 11{,}000$.

For $10 \leq Z_e \leq 100$ and $11{,}000 \geq \Delta P \geq 400$, the overpressure can be calculated by Equation (8) as follows:

$$\Delta P = 1.83 \times 10^5 Z_e^{(-1.16)} \quad (8)$$

Using the overpressure Equations (5)–(8), the characteristic curves can be validated and plotted. For the harm effects on human bodies stressed by Jeremic´ et al. [54] and Prugh [47] as well as other hurt limits underlined by Török et al. were presented [55]: 55 mbar for glasses rupture; 140 mbar for the beginning of lethality; 300 mbar for high lethality due to indirect effects of the explosion (impacted by flying objects or collapsing structure); 600 mbar for high lethality resulted from direct effects of overpressure.

3. Results and Discussion

3.1. Trinitrotoluene Equivalent

3.1.1. m_{TNT} Evaluation by Overpressure Effects

A distance of R = 300 m (948.25 ft) from the explosion crater, the construction of the traffic police detachment of the Tianjin Port Public Security Bureau was seriously demolished. By taking A = 9.5 on the basis of the constant proposed by Jarret [56], m_{TNT} in Equation (2) was calculated to be 1,112,104 lbs or 504 tons.

3.1.2. m_{TNT} Evaluation by Scaling Law

Based on practical tests, several constant C and index n in the Expression (3) were posed. Table 2 depicts the popular scaling law linked to the diameter and m_{TNT} [48,57–59]. Table 3 lists the crater diameters determined by the scaling laws, and explosion tests. Figure 2 shows the crater diameters in conjunction with the scaling laws, explosion tests and major incidents. Taking the photographs in Figure 1 into consideration, the diameter of the crater created by the explosion was 97 m. Therefore, the m_{TNT} of this incident by scaling law was verified to be 700 tons.

Comparisons: (1) 1921 Oppau AN explosion, m_{TNT} = 788 tons, D = 108 m (Pittman et al. 2014) [3], (2) 1964 TNT test at Watching Hill Site, m_{TNT} = 453.6 tons, D = 85.4 m (Vortman, 1968) [48], (3) 1993 Shenzhen AN explosion, m_{TNT} = 22.9 tons, D = 20 m (Jiang, 1998) [4], (4) 2001 Toulouse AN explosion, m_{TNT} = 157.5 tons, D = 60 m (Pittman et al. 2014) [3], (5) 2020 Beirut AN explosion, m_{TNT} = 950.3 tons, D = 112.9 m (6) 2015 Tianjin AN explosion, m_{TNT} = 700 tons, D = 97 m (this work).

Table 3. Crater diameters evaluated by the scaling laws and compared to explosion tests.

m_{TNT} (kg)	$D = 0.606\ m_{TNT}^{0.34}$ (m)	$D = 0.80\ m_{TNT}^{1/3}$ (m)	$D = 0.40\ m_{TNT}^{0.408}$ (m)
1	0.6	0.8	0.4
10	1.3	1.7	1.0
50	2.3	2.9	2.0
100	2.9	3.7	2.6
500	5.0	6.3	5.0
1000	6.3	8.0	6.7
5000	11.0	13.4	12.9
10,000	13.9	17.2	17.1
50,000	24.0	29.5	33.0
100,000	30.3	37.0	43.9
500,000	52.5	63.5	84.6
1,000,000	66.4	80.0	112.2
2,000,000	84.1	100.8	148.9
5,000,000	114.8	136.8	216.4
8,000,000	134.7	160.0	262.1
10,000,000	145.4	172.4	287.1

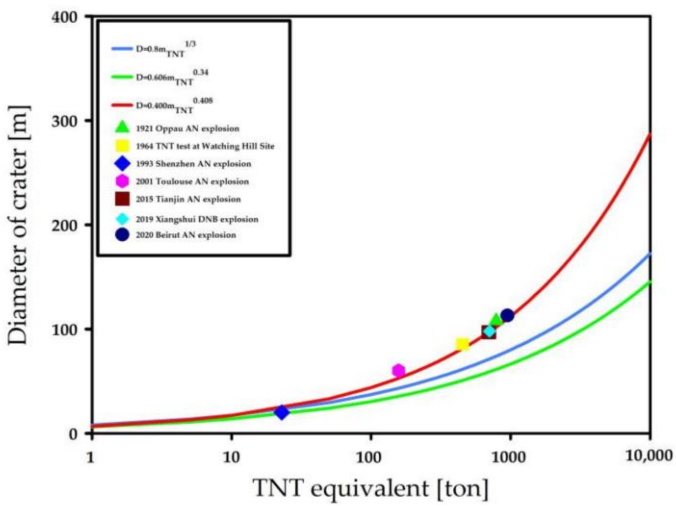


Figure 2. The crater diameters related to the scaling laws, explosion test and major incidents.

3.1.3. m_{TNT} Evaluation by Inverse Analysis

The methodology of inverse analysis according to the relationship between m_{TNT} versus the scaled distance shown in corresponding figures was proposed by Zhou et al. [50]. All the parameters linked to m_{TNT}, including the diameter and depth of craters were plotted in the published journal [50]. By setting a vertical line at zero (i.e., ground explosion) in the Z vs. scaled depth of bursts (m/kg$^{1/3}$) plot, with an intersection at $Z = D/m_{TNT}^{1/3} = 1.2$ and $D = 97$ m, the m_{TNT} can be calculated to be 528 tons for the major explosion.

3.2. Impact of Overpressure on Building and Human Body

In the following consequence analysis of the second explosion, by taking the average value of 577 tons from the three abovementioned m_{TNT}, the results between the resulting safety distances relative to overpressure using three different approaches were performed. In addition to Alonso's methodology, by using the overpressure equation associated with the corresponding interval in Equations (4) or (5), the characteristic curves associated ΔP with R are determined. When m_{TNT} was chosen as 577 tons, the distance R using 300, 400, 500, 1000 and 3000 m being taken into the aforementioned groups of overpressure formulas, the overpressures were determined and presented in Table 4. The overpressure against distance can be decided and shown in Figure 3, where the consequences of the damaged structures were presented by solid points confirmed by the pictures in their corresponding positions. Consequently, side-on overpressure in relation to distance can be plotted on several concentric circle diagrams regarding to the satellite map presented in Figure 4. Five representative pictures of damaged structures for comparisons are depicted in Figure 5. In parallel, the effects of explosion impacts on the human bodies and on the structures can be further assessed through the overpressure effects proposed by Prugh [47].

Table 4. Evaluation of overpressure by three approaches.

Approach	ΔP (MPa) (300 m)	ΔP (MPa) (400 m)	ΔP (MPa) (500 m)	ΔP (MPa) (1000 m)	ΔP (MPa) (3000 m)
Baker's	0.1111	0.0692	0.0425	0.0158	0.0047
Sadovski's	0.0638	0.0379	0.0262	0.0096	0.0026
Alonso's	0.0859	0.0482	0.0308	0.0076	0.0008

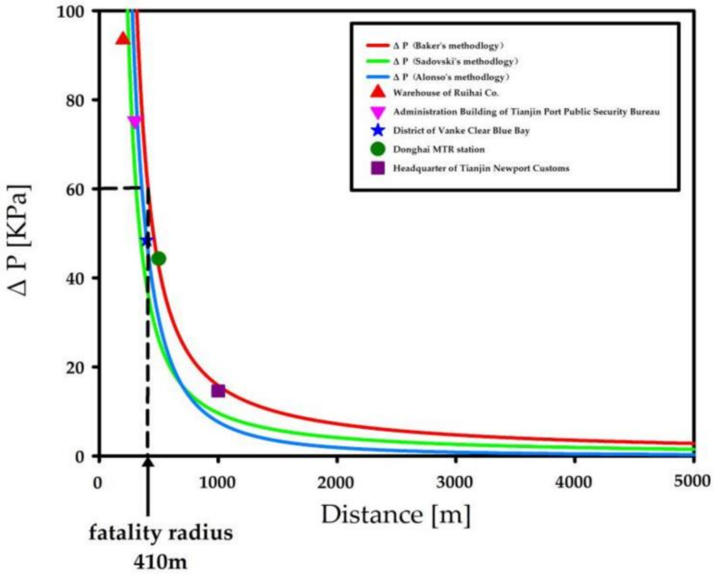


Figure 3. Overpressure and damages in Tianjin port vs. distances.

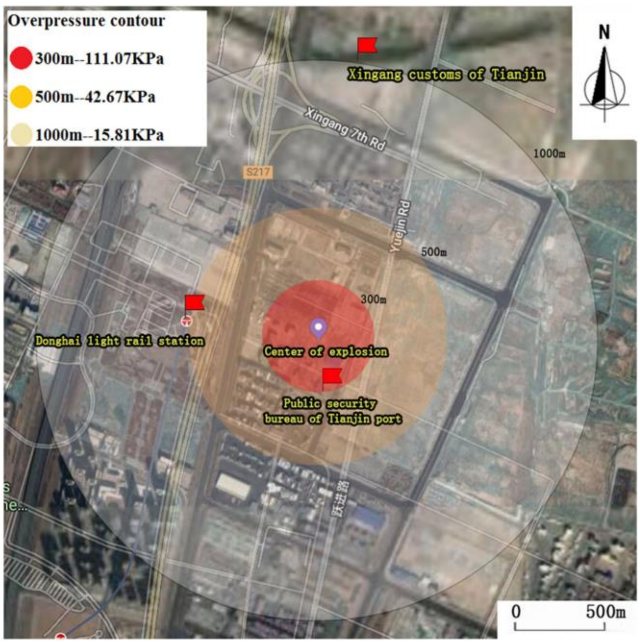
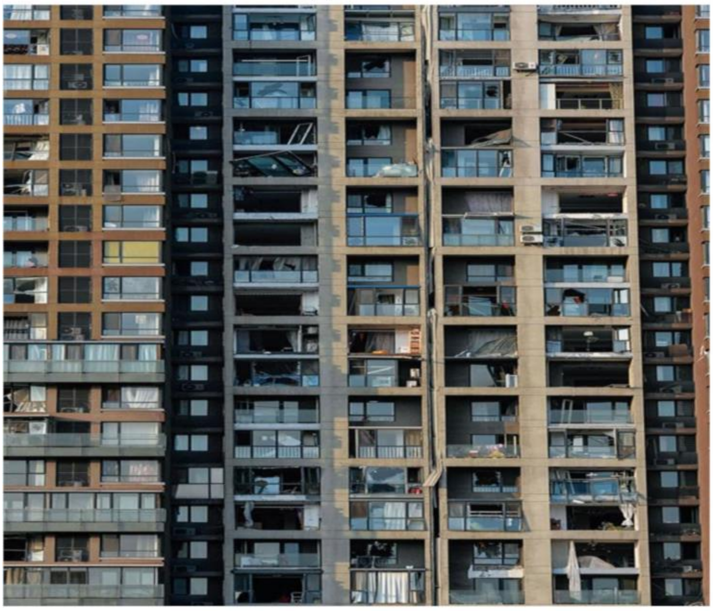


Figure 4. Map of overpressure vs. damages of objects in Tianjin port.

(**a**) 200 m

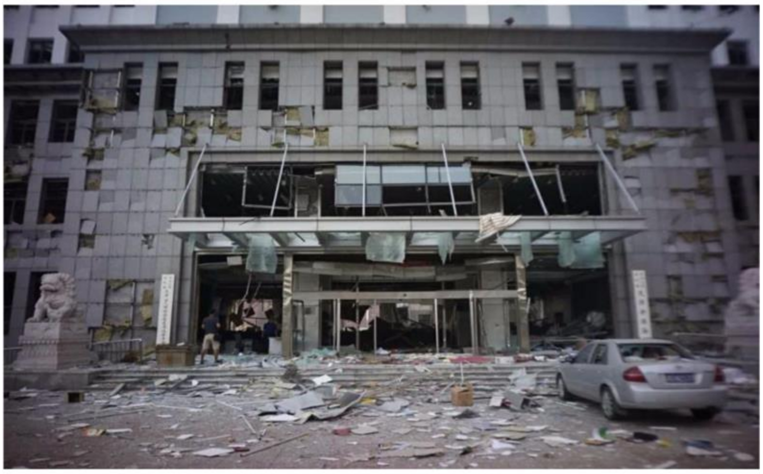
(**b**) 300 m



(**c**) 400 m

Figure 5. *Cont.*

(**d**) 500 m



(**e**) 1000 m

Figure 5. Damages after the explosion from the explosion center (**a**) Warehouse of Ruihai Co. (200 m); (**b**) Administration Building of Tianjin Port Public Security Bureau (300 m); (**c**) District of Vanke Clear Blue Bay (400 m); (**d**) Donghai MTR station (500 m) (**e**) Headquarters of Tianjin Newport Customs (1000 m).

One of the most intriguing parameters is to ascertain the separation distance, sometimes referred to as the safety distance. To reduce the deviations of m_{TNT} in evalution expressions, overpressure was evaluated by three aforementioned empirical methodologies. The results exhibited little differences in the safe distances acquired in the simulations among these methodologies. Characteristic curves shown in Figure 3 in accordance with each other were validated by the real demolished structures pictured in Figure 5. Expectantly, the safe distance decreased obviously versus overpressure in these three models, revealing that a safe enough distance can prevent or decrease the level of destruction on the communities, infrastructures, administrative regions and industries. It is clear that the m_{TNT} and safe distance both determine the destiny of risk and consequence of a detonation. In avoiding or diminishing the consequence of similar incident, it is cardinal to reevaluate the quantity of AN and safe distance for a warehouse or plant storing AN. Safe distances have to be considered from the following two points. The first is to prevent a domino effect or SD with enough separation for energetic chemicals stored in nearby zones. The second is that the m_{TNT} must be less than the allowable quantity required by international standards for production, operation, transportation, and storage [5]. It is distinct from Figure 3 that the overpressure resulting in death occurred at about 0.6 bar, which corresponds to the "fatality radius" intercepting the three characteristic curves at approximately 410 m from the explosion origin, illustrating that most victims were the firefighters involved in firefighting and some on-site employees of the Ruihai Company.

3.3. Autocatalytic Decomposition of Nitrocellulose

From the investigation report issued by the State Council, which clearly announced that the fire was directly caused by the auto-ignition of NC with a proof of video, literature related to the thermal hazards and chemical kinetics caused by the autocatalytic decomposition of NC was limited till now. Several studies demonstrated that the NC had an exothermic onset temperature at approximately 182 °C using differential scanning calorimetry (DSC) or TGA [17,18]. Figure 6 shows the thermal curve of exothermic reaction detected by a screening test using DSC. It is a regret that the traditionally non-isothermal method of DSC can provide the thermal curve, exothermic onset temperature, peak temperature, and enthalpy change. Exothermic phenomena of NC below 140 °C have never been observed by any calorimetry. To confirm the autocatalytic decomposition of NC, this study applied the isothermal tests regulated by both ASTM (American Society of Testing and Materials) E487 and E2046 to confirm the autocatalytic decomposition and detect the exothermic thermal curve associated with a distinctive time-to-maximum-rate [44,45]. Time-to-maximum-rate can be recognized as the synonym for the time to auto-ignition. Time-to-maximum-rate determined by DSC can be used to verify the storage time of NC in the accidental container from the time of arrival to auto-ignition. For DSC experiments the first temperature for isothermal test is suggested to be (T_{onset} 10) °C by ASTM E 487, where T_{onset} is acquired from a non-isothermal screening test. All the standard isothermal tests must be implemented every minus 10 °C from the onset temperature until the exothermic signal cannot be detected. For simulating the spread of NC outside the package drum and in dry status, it was detected in an open crucible. At 150 °C the exothermic signal was weak and almost undetectable. However, it was astonishing that the closed crucible experiment could discriminate the exothermic curves as low as 90 °C. In this study, NC was first found to be more hazardous or unstable under a closed than an open state. A typical thermal curve related to the autocatalytic decomposition of NC at 120 °C is depicted in Figure 7. The time-to-maximum-rate was measured to be 1985.8 min at 90 °C. The maximum temperature on the day of the incident was reported to be 36 °C at Tianjin port; moreover, the inner space of the container might reach as high as 60 °C [1]. According to this, a time-to-maximum-rate with the value of 12,400 min or 8.6 days was determined at 60 °C in Figure 8. In 2015, the weather of Tianjin Port was sunny in most days from July to August, and containers held an internal average temperature of up to 60 °C. Under such circumstances the NC in the closed container decomposed autocatalytically. As to the containers cannot effectively dissipate heat, the partially superheated NC carried out faster exothermic decomposition to accompany the extreme temperature rise and gas production. This ruptured the container, which ignited itself automatically. "The results revealed that the NC was induced to reach the autocatalytic decomposition by the container with an internal temperature approximately 60 °C. The hot spot inside the NC bag gradually accumulated heat and accelerated the NC to the auto-ignition after 9 days". Ignition occurred when the temperature of NC exceeded the AIT, which agreed with the recorded video. The burning substances spread to neighboring containers containing flammable or combustible goods, then extended to more containers loaded with AN. Under the strong influence of the surrounding fire, the AN containers exploded in the long run. The isothermal TMR of autocatalytic decompositions under open and closed pans were listed in Tables 5 and 6, respectively. Based on the chemical kinetics for autocatalytic decomposition of NC reported by Hai et al. [24], a simulation curve was depicted in Figure 8; it demonstrated that the time took more than 60 days for NC to auto-ignite at 60 °C. The induction was too long to be acceptable and cannot coincide with that of the incident. The Ruihai company received the business approval on 24 June, and it was recognized that the time was less than 20 days after the arrival of NC to auto-ignition.

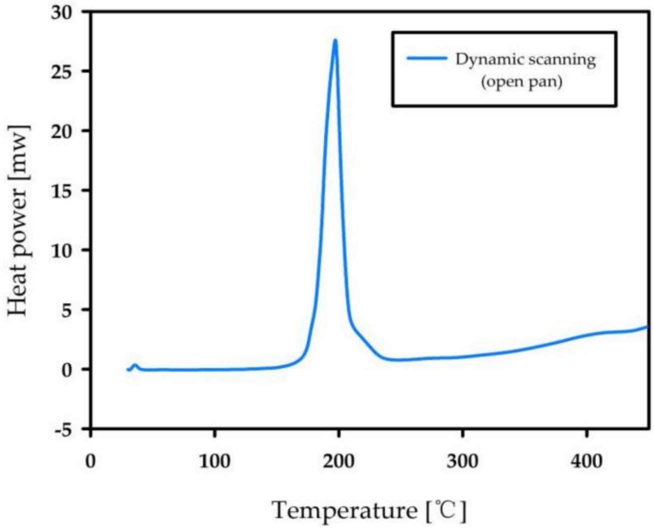


Figure 6. Thermal decomposition of nitrocellulose in an open crucible detected by DSC.

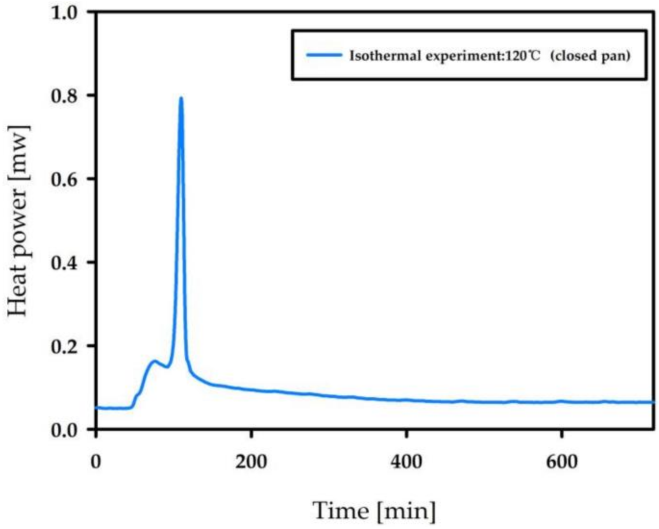


Figure 7. Autocatalytic decomposition of nitrocellulose detected by isothermal test at 120 °C.

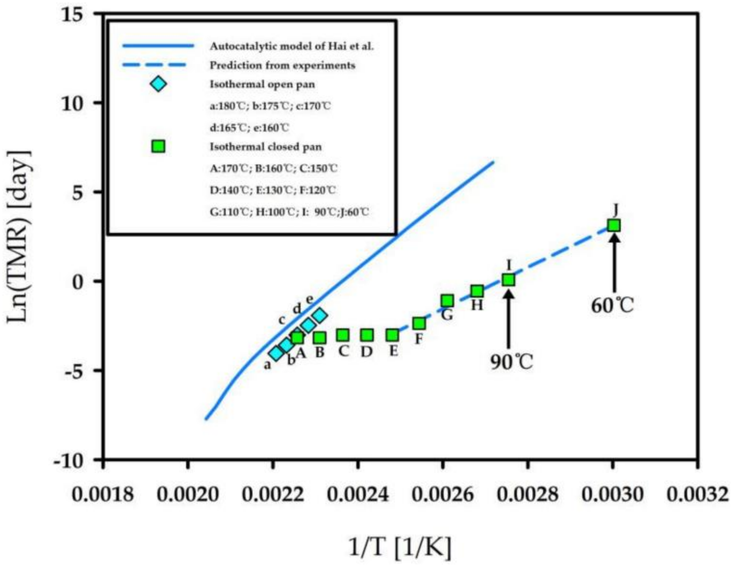


Figure 8. Time-to-maximum-rate of NC versus Temperature.

Table 5. Isothermal TMR of nitrocellulose in DSC open pan tests.

Temperature (°C)	Mass (mg)	TMR (min)
180	1.2	25.4
175	2.2	36.4
170	2.2	65.5
165	4.0	120.3
160	4.0	195.3

Table 6. Isothermal TMR of nitrocellulose in DSC closed pan tests.

Temperature (°C)	Mass (mg)	TMR (min)
170	2.2	46.1
160	1.5	47.1
150	1.5	65.0
140	1.5	78.9
130	1.5	106.5
120	1.5	132.8
110	1.5	357.3
100	2.2	859.0
90	1.5	1985.8

3.4. Incidents of Sympathetic Detonations

SD is typically induced by the propagation of detonation between two explosive chemicals. The neighboring acceptors adjacent to a detonating charge can be collided by the flying fragments and be stimulated by the shock wave generated from donor detonation. Experimental results exhibited that the detonation speed was extremely dependent on the size of the donor. A large number of processes leading to SD include initiation of explosion in the donor charge, an increase in pressure, the scattering of fragments of an exploding charge, and penetration of the high-speed projectiles into the target. Van Dolah conducted a large-scale test program using AN [38]. By analyzing the induced SD declared that from the initiation origin, it must span across 47 ft. to detonate acceptors sympathetically. The description of the AN explosion in Oppau at 1921, in accordance with the witnesses there, had two successive explosions, the first one being faint or unclear and the second one being fatal [3]. Another explosion of AN in West Fertilizer Company, an explosion started as a fire, which resisted for only 20 min then detonated after the 911 call. On 4 May 1988, a fire began in a large ammonium perchlorate (AP) warehouse located in Henderson, Nevada. This specific SD recognized as a specific incident was elucidated by Mniszewski [60]. Two large explosions occurred during the fire, each on the order of several hundred tons of TNT equivalent. A time interval of this SD propagation was first recorded as short as 4 min. Marlair et al. [61] summarized about nine AN fire scenarios that led to the subsequent explosions. In 2014 at Charleville, a transport accident of truck rollover was followed by an “explosions-following-a-fire-scenario” [61]. After 75 min passed from the time of the fire, the major explosion followed the first explosion about 1–2 min. Some articles examined the likelihood of an explosion of AN when exposed to fire scenarios, the detailed mechanism of an SD of AN under fire was obscure. Babrauskas [30] identified 58 separate AN incidents from 1920 to 2014, which were caused by an uncontrollable fire; from these events only 17 explosions occurred. It is identified that, for AN explosion in storage or transportation, an uncontrollable fire is the essential scenario but not decisive. It is conclusive that the catastrophes caused by AN detonations can be prevented or mitigated by extinguishing the fire before it being uncontrollable. Table 7 lists the major incidents of SD with the “two-successive-explosions-following-a-fire” scenario [30,60,61].

Table 7. Major incidents of SD with the "two-successive-explosions-following-a-fire" scenario.

Incident/Year	Chemical	Quantity (ton)	Ignition (Time)	First Explosion (Time)	Major Explosion (Time)
Oppau/1921	$(NH_4NO_3)(NH_4)_2SO_4$	5000	Blasting at 07:00	07:31	07:32
Nevada/1988	NH_4ClO_4	Several hundred tons	Fire at 11:15	11:53	11:57
Shenzhen/1993	AN	65	Fire at 13:10	13:26	14:27
Queensland/2014	AN	53	Fire by truck rollover at 09:00	10:10	10:12
Tianjin/2015	AN	430	Fire at 22:51:46	23:34:06	23:34:37

3.5. *Scenario of Two-Successive-SD-Following-a-Fire in Tianjin Incident*

Whether AN will detonate or not was decided significantly by the crucial conditions such as the dimension of the particle, porousness of AN, confinement, fire, charge quantity and bulk density. A project for the study on SD of AN was executed by the U.S. Bureau of Mines [38]. Application of 5400 lb ANFO with a donor size 60 inches and metal skin, a separation distance of 153 ft (43.3 m) for avoiding the sympathetic detonation was obtained [38,39]. Additionally, safety distances were confirmed to increase due to bin preheating for simulation of fire case. A 20′GP container with 5.69 m × 2.13 m × 2.18 m internal dimensions or volume of 33.2 m^3 can load about 10,000 kg of NC or 50,000 kg of AN. According to analysis using a container with a size of 80 inches (2.032 m), the SD must span across 232 ft (70.7 m), propagating the blast impact across all containers for the second disastrous explosion in Tianjin incident. For the incident, from the aforementioned scaling law, the second SD had the m_{TNT} of 700 tons to create the crater with a diameter of 97 m. A m_{TNT} of 700 tons was equal to approximately 1999 tons of AN (loaded in 39 containers). This fact showed that all the stacked AN in containers could explode by the phenomenon of SD due to the insufficient separation distance. It was deduced that the propagation speed of SD in the two explosions was almost 3000 ms^{-1}, an SD initiated inside a container needed near 0.006 s. At this rate, it traversed the second SD spending about 0.3 s (39 containers times 0.006 s for each container).

4. Lessons Learned

To prevent a similar major AN incident to the Tianjin disaster, it is of great importance to propose the lessons learned for the public, industry, stakeholder, regulatory body and government. This incident encompassed the auto-ignition by autocatalytic decomposition of NC in container at summer, SD of AN with an average quantity of 1649 tons. Some concluded lessons are suggested to be learned:

1. From the amount of fatality and injury, this is the most serious explosion of AN in the world since 1947 and before the incident at the Beirut Port occurred in 2020.
2. Most of the victims and injured individuals were firefighters, therefore the guides for fire fighting in an industrial plant or warehouse storing AN must be carefully planned before their actions for emergency responses [62].
3. The Ruihai company illegally stored too much AN and other dangerous chemicals.
4. Reactive substances, NC and AN were stacked together to create the difficulties for fire-fighting and the risks of fire hazards.
5. NC can be ignited by autocatalytic decomposition in containers during summertime due to poor heat removal.
6. The hazards of autocatalytic decomposition of NC were proven to be more severe in closed than open status.
7. NC is determined be ignited after about 9 days by autocatalytic decomposition in a container sustained at 60 °C.
8. AN in a confined container can explode under external fire and propagate severe SD.

9. A safety distance to prevent the SD caused by AN in a 20′GP container was determined to be 97 m in Dolah's studies, indicating all the stacked AN containers will explode within a few seconds by SD if one of them ignites the first explosion.
10. The m_{TNT} in conjunction with the second explosion was averaged to be 577 tons using scaling law, damage-distance correlation and inverse analysis.
11. NC and AN were reported to be the very materials to ignite the terrible first fire and disastrous explosion, respectively.
12. The incident was a typical event of "two-successive-explosions-following-a-fire".

5. Conclusions

AN has attracted attention from authorities over recent years due to various accidents. A study of the calamitous incident of Tianjin Port was implemented and discussed. The first fire initiated by NC under autocatalytic decomposition in a confined container was validated through ASTM standards and isothermal tests of DSC. The time to ignition of NC was validated to take 9 days in a container sustained at 60 °C. Suffering from the spreading fire and the blackbody radiations, the super-heated NC or AN underwent the first explosion under a thermal runaway. According to the formula relating to the influences of impulsing wave on structures, inverse analysis and the scaling law related to m_{TNT}, the average m_{TNT} was quantified to be 577 tons relative to AN of 1649 tons. Three different methodologies have been implemented to validate the aftereffects of the explosion. In this disastrous event, the destroyed buildings were essentially coincident with those photos posed, that moreover demonstrated the reliability of the power of the second explosion speculated. From the blast effects and overpressure to human body, a "fatality radius" was authenticated to be 410 m from the origin of explosion.

This incident exactly revealed a distinct scenario of "a fire following two successive explosion". Two explosions were corroborated to be sympathetic detonation; the first was not strong, but the second was crucial because more AN containers were stacked to be triggered and then suffered the SD. The explosion of a small amount of AN in a confined space may ignite the explosion of large quantity of AN via the effects of SD. The Ruihai International Logistics Co., Ltd. stored too huge quantity of labile NC and without corrective actions to prevent the SD of AN when catching fire. More through studies have to be conducted before the characteristics of fire/explosion of AN can be completely elucidated. As a guide to preventing potential catastrophe in the near future, this holistic case study discloses the importance of strengthening the existed regulations and promoting the risk awareness to store and operate AN safely by reducing the storage quantity.

Author Contributions: Conceptualization, Y.-S.D.; methodology, G.Y.; software, G.Y., Y.L. (Yuqi Li) and Y.C.; validation, Y.-S.D., Y.L. (Yongzhao Li), Y.C. and J.H.; formal analysis, X.Y. and R.C.; investigation, J.L.; resources, L.G. and B.Y.; data curation, Y.-S.D., X.Y. and J.H.; writing—original draft preparation, Y.-S.D.; writing—review and editing, Y.-S.D. and G.Y.; project administration, L.G. and B.Y.; funding acquisition, J.L. and L.G. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the leading project of science and technology plan of Fujian Province, grant number: 2020Y0055 and the APC was funded by the Scientific Research Foundation of Fuzhou, grant number: 2019-G-51.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The author wish to thank the government departments of China and the companies of media in China to provide for the emergency responses, information, reports, and photos of the incident for this study.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

Abbreviation	Description
AIT	Auto-ignition temperature
AN-FO	Ammonium nitrate-fuel oil
ARC	Accelerating rate calorimetry
ASTM	American Society of Testing and Materials
DDT	deflagration-to-detonation
DSC	Differential scanning calorimetry
FGAN	Fertilizer grade ammonium nitrate
MPD	*m*-Phenylenediamine
NFPA	National Fire Protection Association
SD	Sympathetic detonation
TGA	Thermogravimetry analysis
TGAN	Technical grade ammonium nitrate
TNT	Trinitrotoluene
UCAT	Upper critical ambient temperature
UN	The United Nations
US-DOT	The United States Department of Transportation
Nomenclature	
D	Diameter of explosion pit (m)
m_{TNT}	Mass of trinitrotoluene (kg)
R	Distance to the center of explosion (m)
P	Atmospheric pressure (Pa)
ΔP	Overpressure (Pa)
ΔH_{AN}	Heat of decomposition of ammonium nitrate (J)
ΔH_{NC}	Heat of decomposition of nitrocellulose (J)
ΔH_{TNT}	Heat of decomposition of trinitrotoluene (J)
T_{onset}	Exothermic onset temperature (°C)
TMR	Time-to-maximum-rate (min)
Subscript	
AN	Ammonium nitrate
NC	Nitrocellulose
TNT	Trinitrotoluene

References

1. The State Council of China. Report on the Special Major Fire Explosion Accident of Ruihai Company in Tianjin Port. 5 February 2016. Available online: http://www.gov.cn/foot/2016-%2002/05/content%205039788.htm (accessed on 28 February 2021).
2. Fire Protection Research Foundation. Variables Associated with the Classification of Ammonium Nitrate—A Literature Review. FRPF-2017-03. Available online: https://www.nfpa.org/-/media/Files/News-and-Research/Fire-statistics-and-reports/Hazardous-materials/RFANHazardClassification.pdf (accessed on 28 February 2021).
3. Pittman, W.; Han, Z.; Harding, B.; Rosas, C.; Jiang, J.; Pineda, A.; Mannan, M.S. Lessons to be learned from an analysis of ammonium nitrate disasters in the last 100 years. *J. Hazard. Mater.* **2014**, *280*, 472–477. [CrossRef]
4. Jiang, T. Explosion accident of warehouse storing Hazardous materials in Qingshuihe of Shenzhen City. *Saf. Technol. Manag.* **1998**, *19*, 18–21.
5. Yu, G.D.; Wang, Y.; Zheng, L.; Huang, J.; Li, J.L.; Gong, L.Z.; Chen, R.G.; Li, W.; Huang, J.L.; Duh, Y.S. Comprehensive study on the catastrophic explosion of ammonium nitrate stored in the warehouse of Beirut port. *Process Saf. Environ.* **2021**, *152*, 201–219. [CrossRef]
6. Guiochon, G. On the catastrophic explosion of the AZF plant in Toulouse. *Process Saf. Prog.* **2020**, *39*, e12197. [CrossRef]
7. Laboureur, D.M.; Han, Z.; Harding, B.Z.; Pineda, A.; Pittman, W.C.; Rosas, C. Case study and lessons learned from the ammonium nitrate explosion at the west fertilizer facility. *J. Hazard. Mater.* **2016**, *308*, 164–172. [CrossRef] [PubMed]
8. Banks, J. Dangerously close: The CSB's investigation into the fatal fire and explosion in West, Texas. *Process Saf. Prog.* **2016**, *35*, 312–316. [CrossRef]
9. Pasman, H.J.; Fouchier, C.; Park, S.; Quddus, N.; Laboureur, D. Beirut ammonium nitrate explosion: Are not we really learning auything? *Process Saf. Prog.* **2020**, *39*, e12203. [CrossRef]
10. Sivaraman, S.; Varadharajan, S. Investigative consequence analysis: A case study research of Beirut explosion accident. *J. Loss Prev. Process* **2021**, *69*, 104387. [CrossRef]
11. Prugh, R.W. Historical record of Ammonium nitrate disasters. *Process Saf. Prog.* **2020**, *39*, e12210. [CrossRef]

12. Boeck, L.R.; Mahan, P.W. Loss prevention learnings from Beirut and similar ammonium nitrate explosions. *Process Saf. Prog.* **2021**, e12322. [CrossRef]
13. Babrauskas, V. The ammonium nitrate explosion at West, Texas: A disaster that should have been avoided. *Fire Mater.* **2018**, *42*, 164–172. [CrossRef]
14. The UN Numbers from UN2001 to UN2100 as Assigned by the United Nations Committee of Experts on the Transport of Dangerous Goods. List of UN numbers 2001 to 2100. Available online: https://en.wikipedia.org/wiki/ (accessed on 28 February 2021).
15. U.S. Code of Federal Regulations Title 49, Section 172, Shipping Regulations and Proper Shipping Names of Class 4 "Flammable Solids". Available online: https://www.ecfr.gov/current/title-49 (accessed on 1 February 2022).
16. Phillips, R.W.; Orlick, C.A.; Steinberger, R. The kinetics of the thermal decomposition of nitrocellulose. *J. Am. Chem. Soc.* **1955**, *59*, 1034–1039. [CrossRef]
17. De la Ossa, M.A.F.; López-López, M.; Torre, M.; García-Ruiz, C. Analytical techniques in the study of highly-nitrated nitrocellulose. *Trends Anal. Chem.* **2011**, *30*, 1740–1755. [CrossRef]
18. Wang, K.; Liu, D.; Xu, S.; Cai, G. Research on the thermal history's influence on the thermal stability of EHN and NC. *Thermochim. Acta* **2015**, *610*, 23–28. [CrossRef]
19. Pourmortazavi, S.M.; Hosseini, S.G.; Rahimi-Nasrabadi, M.; Hajimirsadeghi, S.S.; Momenian, H. Effect of nitrate content on thermal decomposition of nitrocellulose. *J. Hazard. Mater.* **2009**, *162*, 1141–1144. [CrossRef]
20. Sovizi, M.R.; Hajimirsadeghi, S.S.; Naderizadeh, B. Effect of particle size on thermal decomposition of nitrocellulose. *J. Hazard. Mater.* **2009**, *168*, 1134–1139. [CrossRef]
21. Makashir, P.S.; Mahajan, R.R.; Agrawal, J.P. Studies on kinetics and mechanism of initial, thermal decomposition of nitrocellulose. *J. Therm. Anal. Calorim.* **1995**, *45*, 501–509. [CrossRef]
22. Brill, T.B.; Gongwer, P.E. Thermal Decomposition of Energetic Materials 69. Analysis of the Kinetics of Nitrocellulose at 50–500 °C. *Propellants Explos. Pyrotech.* **1997**, *22*, 38–44. [CrossRef]
23. Kimura, J. Kinetic Mechanism on Thermal Degradation of a Nitrate Ester Propellant. *Propellants Explos. Pyrotech.* **1988**, *13*, 8–12. [CrossRef]
24. Hai, Z.; Zhiming, X.; Pengjiang, G.; Rongzu, H.; Shengli, G.; Binke, N.; Yan, F.; Qizhen, S.; Rong, L. Estimation of the critical rate of temperature rise for thermal explosion of first-order autocatalytic decomposition reaction systems using non-isothermal DSC. *J. Hazard. Mater.* **2002**, *A94*, 205–210. [CrossRef]
25. Ning, B.; Hu, R.; Zhang, H.; Xia, Z.; Guo, P.; Liu, R.; Lu, G.; Jiang, J. Estimation of the critical rate of temperature rise for thermal explosion of autocatalytic decomposing reaction of nitrocellulose using non-isothermal DSC. *Thermochim. Acta* **2004**, *416*, 47–50. [CrossRef]
26. Wang, H.; Zhang, H.; Hu, R.; Yao, E.; Guo, P. Estimation of the critical rate of temperature rise for the thermal explosion of nitrocellulose using non-isothermal DSC. *J. Therm. Anal. Calorim.* **2014**, *115*, 1099–1110. [CrossRef]
27. Luo, Q.; Ren, T.; Shen, H.; Zhang, J.; Liang, D. The Thermal Properties of Nitrocellulose: From Thermal Decomposition to Thermal Explosion. Combust. *Sci. Technol.* **2018**, *190*, 579–590. [CrossRef]
28. Oxley, J. Snapshot of ammonium nitrate: History and use. *Process Saf. Prog.* **2020**, *39*, e12204. [CrossRef]
29. Babrauskas, V. The West, Texas, ammonium nitrate explosion: A failure of regulation. *J. Fire Sci.* **2017**, *35*, 396–414. [CrossRef]
30. Babrauskas, V. Explosions of ammonium nitrate fertilizer in storage or transportation are preventable accidents. *J. Hazard. Mater.* **2016**, *304*, 134–149. [CrossRef] [PubMed]
31. NFPA 400, Hazardous Materials Code. National Fire Protection Association: Quincy, MA, USA, 2016, 3rd ed. Available online: https://www.nfpa.org/Assets/files/AboutTheCodes/400/ProposedTIA1174_NFPA400.pdf (accessed on 28 February 2021).
32. United Nations. European Agreement Concerning the International Storage of Dangerous Goods by Road (ADR). 2014. Available online: https://unece.org/DAM/trans/danger/publi/adr/ADRagree_e.pdf (accessed on 30 August 2016).
33. Babrauskas, V.; Leggett, D. Thermal decomposition of ammonium nitrate. *Fire Mater.* **2020**, *44*, 250–268. [CrossRef]
34. Willey, R.J. The nature of ammonium nitrate decomposition and explosions. *Process Saf. Prog.* **2020**, *39*, e12214. [CrossRef]
35. Han, Z.; Sachdeva, S.; Papadaki, M.; Sam Mannan, M. Calorimetry studies of ammonium-Effect of inhibitors, confinement, and heating rate. *J. Loss Prevent. Process* **2015**, *19*, 724–728. [CrossRef]
36. Han, Z.; Pasman, H.J.; Sam Mannan, M. Extinguishing fires involving ammonium nitrate stock with water: Possible complications. *J. Fire Sci.* **2017**, *35*, 457–483. [CrossRef]
37. Babrauskas, V. Fire safety is the key to ammonium nitrate explosion safety. *Process Saf. Prog.* **2020**, *39*, e12200. [CrossRef]
38. Van Dolah, R.W.; Gibson, F.C.; Murphy, J.N. Sympathetic Detonation of Ammonium Nitrate and Ammonium Nitrate-Fuel Oil, Report of Investigations 6746. Bureau of Mines, U.S. Department of the Interior. 1966. Available online: https://www.researchgate.net/publication/235114474_Sympathetic_detonation_of_ammonium_nitrate_and_ammonium_nitrate-fuel_oil (accessed on 28 February 2021).
39. Van Dolah, R.W.; Gibson, F.C.; Murphy, J.N. Further Studies on Sympathetic Detonation, Report of Investigations 6903, Bureau of Mines, U.S. Department of the Interior. 1966. Available online: https://www.researchgate.net/publication/235184808_FURTHER_STUDIES_ON_SYMPATHETIC_DETONATION (accessed on 28 February 2021).
40. Van Dolah, R.W. Large-Scale Investigation of Sympathetic Detonation. *Ann. N. Y. Acad. Sci.* **1968**, *152*, 792–801. [CrossRef]
41. *DSC 3 Operation Instructions*; Mettler Company: Zurich, Switzerland, 2015.

42. *ASTM E537-20*; Standard Test Method for the Thermal Stability of Chemicals by Differential Scanning Calorimetry. ASTM International: West Conshohocken, PA, USA, 2020. Available online: https://www.astm.org/e0537-20.html(accessed on 1 February 2022).
43. *ASTM E487-20*; Standard Test Method for Constant-Temperature Stability of Chemical Materials. ASTM International: West Conshohocken, PA, USA, 2020. Available online: https://www.astm.org/e0487-20.html(accessed on 1 February 2022).
44. *ASTM E2070-13*; Standard Test Method for Kinetic Parameters by Differential Scanning Calorimetry Using Isothermal Methods. ASTM International: West Conshohocken, PA, USA, 2018. Available online: https://www.astm.org/e2070-13r18.html(accessed on 1 February 2022).
45. *ASTM E2046-19*; Standard Test Method for Reaction Induction Time by Thermal Analysis. ASTM International: West Conshohocken, PA, USA, 2019. Available online: https://www.astm.org/e2046-19.html(accessed on 1 February 2022).
46. Török, Z.; Ozunu, A. Hazardous Properties of Ammonium nitrate and modeling of explosion using TNT equivalency. *Environ. Eng. Manag. J.* **2015**, *14*, 2671–2678. [CrossRef]
47. Prugh, R.W. The effects of explosive blast on structures and personnel. *Process Saf. Prog.* **1999**, *18*, 5–16. [CrossRef]
48. Vortman, L.J. Craters from surface explosions and scaling laws. *J. Geophys. Res.* **1968**, *73*, 4621–4636. [CrossRef]
49. Lampson, C.W. *Final Report on Effects of Underground Explosions*; National Defense Research Committee of the Office of Scientific: Washington, DC, USA, 1946.
50. Zhou, X.; Bai, C.; Zhang, Y.; Wang, Z. Inverse analysis of explosives based on crater size. *Shock Waves* **2017**, *27*, 27–35. [CrossRef]
51. Baker, W.E.; Cox, P.A.; Westine, P.S.; Kulesz, J.J.; Strehlow, R.A. *Explosion Hazards and Evaluation*; Elsevier Scientific Publishing Company: New York, NY, USA, 1983. Available online: https://scholar.google.com/scholar_lookup?title=Explosion%20Hazards%20and%20Evaluation&author=W.E.%20Baker&publication_year=1983 (accessed on 28 February 2021).
52. Orlenko, L.P. *Fizika Vzriva*; Fizmatlit: Moscow, Russia, 2002. Available online: http://refhub.elsevier.com/S0950-4230(20)30519-2/sref9 (accessed on 1 February 2022).
53. Alonso, F.D.; Ferradas, E.G.; Perez, J.F.S.; Aznar, A.M.; Gimeno, J.R.; Alonso, J.M. Characteristic overpressure-impulse-distance curves for the detonation of explosives, pyrotechnics or unstable substances. *J. Loss Prev. Process* **2006**, *19*, 724–728. [CrossRef]
54. Jeremić, R.; Bajić, Z. An approach to determining the TNT equivalent of high explosives. *Sci. Tech. Rev.* **2006**, *6*, 58–62.
55. Török, Z.; Kovacs, L.A.; Ozunu, A. Ammonium nitrate explosion. Case study: The Mihăilesti accident (2004), Romania. *J. Environ. Res. Prot.* **2015**, *12*, 56–60.
56. Jarrett, D.E. Derivation of the British explosives safety distances. *Ann. N. Y. Acad. Sci.* **1968**, *152*, 18–35. [CrossRef]
57. Adushkin, V.V.; Khristoforov, B.D. Craters of large-scale surface explosions. *Combust. Explo. Shock* **2004**, *40*, 674–678. [CrossRef]
58. Ambrosini, R.D.; Luccioni, B.M. Craters produced by explosions on the soil surface. *J. Appl. Mech.* **2006**, *73*, 890–900. [CrossRef]
59. Kinney, G.F.; Graham, K.J. *Expolsive Shocks in Air*; Springer: Berlin, Germany; New York, NY, USA, 1985. Available online: http://refhub.elsevier.com/S0957-5820(21)00271-8/sbref0170 (accessed on 28 February 2021).
60. Mniszewski, K.R. The Pepcon Plant Fire/Explosion: A Rare Opportunity in Fire/Explosion Investigation. *J. Fire Prot. Eng.* **1994**, *6*, 63–78. [CrossRef]
61. Marlair, G.; Michot, C.; Turcotte, R.; Singh, S. Comments about the paper entitled "Lessons to be learned from an analysis of ammonium nitrate disasters in the last 100 years" by Pittman et al. (J. Hazard. Mater. 2014, 280, 472–477). *J. Hazard. Mater.* **2016**, *303*, 177–180. [CrossRef]
62. Babrauskas, V. Will Firefighters be Any Safer under the New Hazardous Materials code? *Fire Eng.* **2015**, *168*, 66–70.

APPENDIX G

STANDARDSS OF TRAINING, CERTIFICATION AND WATCHKEEPING FOR SEAFARERS 1978 (STCW)

Table A-II/1 (Officers in charge of a navigational watch)

Table A-11/2 (Masters and Chief Officers),

Table A-III/2 (Chief Engineering offices and Second Engineers)

Table A-II/1 (Officers in charge of a navigational watch)

STCW Code Table A-II/1

Specification of minimum standard of competence for officers in charge of a navigational watch on ships of 500 gross tonnage or more

Ref: https://www.edumaritime.net/stcw-code
Source: http://www.imo.org

Function: **Navigation at the operational level**

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Plan and conduct a passage and determine position	*Celestial navigation* Ability to use celestial bodies to determine the ship's position *Terrestrial and coastal navigation* Ability to determine the ship's position by use of: .1 landmarks .2 aids to navigation, including lighthouses, beacons and buoys .3 dead reckoning, taking into account winds, tides, currents and estimated speed	Examination and assessment of evidence obtained from one or more of the following: .1 approved in-service experience .2 approved training ship experience .3 approved simulator training, where appropriate .4 approved laboratory equipment training using chart catalogues, charts, nautical publications, radio navigational warnings, sextant, azimuth mirror, electronic navigation equipment, echo-sounding equipment, compass	The information obtained from nautical charts and publications is relevant, interpreted correctly and properly applied. All potential navigational hazards are accurately identified The primary method of fixing the ship's position is the most appropriate to the prevailing circumstances and conditions The position is determined within the limits of acceptable instrument/system errors The reliability of the information obtained from the primary method of position fixing is checked at appropriate intervals Calculations and measurements of navigational information are accurate
	Thorough knowledge of and ability to use nautical charts, and publications, such as sailing directions, tide tables, notices to mariners, radio navigational warnings and ships' routeing information		The charts selected are the largest scale suitable for the area of navigation and charts and publications are corrected in accordance with the latest information available
	Electronic systems of position fixing and navigation		

Source: IMO

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
	Ability to determine the ship's position by use of electronic navigational aids		Performance checks and tests to navigation systems comply with manufacturer's recommendations and good navigational practice
Plan and conduct a passage and determine position (*continued*)	*Echo-sounders* Ability to operate the equipment and apply the information correctly *Compass – magnetic and gyro* Knowledge of the principles of magnetic and gyro-compasses Ability to determine errors of the magnetic and gyro-compasses, using celestial and terrestrial means, and to allow for such errors *Steering control system* Knowledge of steering control systems, operational procedures and change-over from manual to automatic control and vice versa. Adjustment of controls for optimum performance *Meteorology* Ability to use and interpret information obtained from shipborne meteorological instruments Knowledge of the characteristics of the various weather systems, reporting procedures and recording systems Ability to apply the meteorological information available		Errors in magnetic and gyro-compasses are determined and correctly applied to courses and bearings The selection of the mode of steering is the most suitable for the prevailing weather, sea and traffic conditions and intended manoeuvres Measurements and observations of weather conditions are accurate and appropriate to the passage Meteorological information is correctly interpreted and applied

Source: IMO

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Maintain a safe navigational watch	*Watchkeeping* Thorough knowledge of the content, application and intent of the International Regulations for Preventing Collisions at Sea, 1972, as amended Thorough knowledge of the Principles to be observed in keeping a navigational watch The use of routeing in accordance with the General Provisions on Ships' Routeing The use of information from navigational equipment for maintaining a safe navigational watch Knowledge of blind pilotage techniques The use of reporting in accordance with the General Principles for Ship Reporting Systems and with VTS procedures	Examination and assessment of evidence obtained from one or more of the following: .1 approved in-service experience; .2 approved training ship experience .3 approved simulator training, where appropriate .4 approved laboratory equipment training	The conduct, handover and relief of the watch conforms with accepted principles and procedures A proper look-out is maintained at all times and in such a way as to conform to accepted principles and procedures Lights, shapes and sound signals conform with the requirements contained in the International Regulations for Preventing Collisions at Sea, 1972, as amended, and are correctly recognized The frequency and extent of monitoring of traffic, the ship and the environment conform with accepted principles and procedures A proper record is maintained of the movements and activities relating to the navigation of the ship Responsibility for the safety of navigation is clearly defined at all times, including periods when the master is on the bridge and while under pilotage

Source: IMO

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Maintain a safe navigational watch *(continued)*	*Bridge resource management* Knowledge of bridge resource management principles, including: .1 allocation, assignment, and prioritization of resources .2 effective communication .3 assertiveness and leadership .4 obtaining and maintaining situational awareness .5 consideration of team experience	Assessment of evidence obtained from one or more of the following: .1 approved training .2 approved in-service experience .3 approved simulator training	Resources are allocated and assigned as needed in correct priority to perform necessary tasks Communication is clearly and unambiguously given and received Questionable decisions and/or actions result in appropriate challenge and response Effective leadership behaviours are identified Team member(s) share accurate understanding of current and predicted vessel state, navigation path, and external environment
Use of radar and ARPA to maintain safety of navigation *Note*: Training and assessment in the use of ARPA is not required for those who serve exclusively on ships not fitted with ARPA. This limitation shall be reflected in the endorsement issued to the seafarer concerned	*Radar navigation* Knowledge of the fundamentals of radar and automatic radar plotting aids (ARPA) Ability to operate and to interpret and analyse information obtained from radar, including the following: Performance, including: .1 factors affecting performance and accuracy .2 setting up and maintaining displays .3 detection of misrepresentation of information, false echoes, sea return, etc., racons and SARTs	Assessment of evidence obtained from approved radar simulator and ARPA simulator plus in-service experience	Information obtained from radar and ARPA is correctly interpreted and analysed, taking into account the limitations of the equipment and prevailing circumstances and conditions

Source: IMO

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Use of radar and ARPA to maintain safety of navigation *(continued)* *Note*: Training and assessment in the use of ARPA is not required for those who serve exclusively on ships not fitted with ARPA. This limitation shall be reflected in the endorsement issued to the seafarer concerned	Use, including: .1 range and bearing; course and speed of other ships; time and distance of closest approach of crossing, meeting overtaking ships .2 identification of critical echoes; detecting course and speed changes of other ships; effect of changes in own ship's course or speed or both .3 application of the International Regulations for Preventing Collisions at Sea, 1972, as amended .4 plotting techniques and relative- and true-motion concepts .5 parallel indexing		Action taken to avoid a close encounter or collision with other vessels is in accordance with the International Regulations for Preventing Collisions at Sea, 1972, as amended Decisions to amend course and/or speed are both timely and in accordance with accepted navigation practice Adjustments made to the ship's course and speed maintain safety of navigation Communication is clear, concise and acknowledged at all times in a seamanlike manner Manoeuvring signals are made at the appropriate time and are in accordance with the International Regulations for Preventing Collisions at Sea, 1972, as amended

Source: IMO

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Use of radar and ARPA to maintain safety of navigation (*continued*) *Note*: Training and assessment in the use of ARPA is not required for those who serve exclusively on ships not fitted with ARPA. This limitation shall be reflected in the endorsement issued to the seafarer concerned	Principal types of ARPA, their display characteristics, performance standards and the dangers of over-reliance on ARPA Ability to operate and to interpret and analyse information obtained from ARPA, including: .1 system performance and accuracy, tracking capabilities and limitations, and processing delays .2 use of operational warnings and system tests .3 methods of target acquisition and their limitations .4 true and relative vectors, graphic representation of target information and danger areas .5 deriving and analysing information, critical echoes, exclusion areas and trial manoeuvres		
Use of ECDIS to maintain the safety of navigation Note: Training and assessment in the use of ECDIS is not required for those who serve exclusively on ships not fitted with ECDIS These limitations shall be reflected in the endorsements issued to the seafarer concerned	*Navigation using ECDIS* Knowledge of the capability and limitations of ECDIS operations, including: .1 a thorough understanding of Electronic Navigational Chart (ENC) data, data accuracy, presentation rules, display options and other chart data formats .2 the dangers of over-reliance .3 familiarity with the functions of ECDIS	Examination and assessment of evidence obtained from one or more of the following: .1 approved training ship experience .2 approved ECDIS simulator training	Monitors information on ECDIS in a manner that contributes to safe navigation Information obtained from ECDIS (including radar overlay and/or radar tracking functions, when fitted) is correctly interpreted and analysed, taking into account the limitations of the equipment, all connected sensors (including radar and AIS where interfaced), and prevailing circumstances and conditions

Source: IMO

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
	required by performance standards in force Proficiency in operation, interpretation, and analysis of information obtained from ECDIS, including: .1 use of functions that are integrated with other navigation systems in various installations, including proper functioning and adjustment to desired settings .2 safe monitoring and adjustment of information, including own position, sea area display, mode and orientation, chart data displayed, route monitoring, user-created information layers, contacts (when interfaced with AIS and/or radar tracking) and radar overlay functions (when interfaced) .3 confirmation of vessel position by alternative means .4 efficient use of settings to ensure conformance to operational procedures, including alarm parameters for anti-grounding, proximity to contacts and special areas, completeness of chart data and chart update status, and backup arrangements .5 adjustment of settings and values to suit the present conditions		Safety of navigation is maintained through adjustments made to the ship's course and speed through ECDIS-controlled track-keeping functions (when fitted) Communication is clear, concise and acknowledged at all times in a seamanlike manner

Source: IMO

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Use of ECDIS to maintain the safety of navigation *(continued)*	.6 situational awareness while using ECDIS including safe water and proximity of hazards, set and drift, chart data and scale selection, suitability of route, contact detection and management, and integrity of sensors		
Respond to emergencies	*Emergency procedures* Precautions for the protection and safety of passengers in emergency situations Initial action to be taken following a collision or a grounding; initial damage assessment and control Appreciation of the procedures to be followed for rescuing persons from the sea, assisting a ship in distress, responding to emergencies which arise in port	Examination and assessment of evidence obtained from one or more of the following: .1 approved in-service experience .2 approved training ship experience .3 approved simulator training, where appropriate .4 practical training	The type and scale of the emergency is promptly identified Initial actions and, if appropriate, manoeuvring of the ship are in accordance with contingency plans and are appropriate to the urgency of the situation and nature of the emergency
Respond to a distress signal at sea	*Search and rescue* Knowledge of the contents of the International Aeronautical and Maritime Search and Rescue (IAMSAR) Manual	Examination and assessment of evidence obtained from practical instruction or approved simulator training, where appropriate	The distress or emergency signal is immediately recognized Contingency plans and instructions in standing orders are implemented and complied with

Source: IMO

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Use the IMO Standard Marine Communication Phrases and use English in written and oral form	*English language* Adequate knowledge of the English language to enable the officer to use charts and other nautical publications, to understand meteorological information and messages concerning ship's safety and operation, to communicate with other ships, coast stations and VTS centres and to perform the officer's duties also with a multilingual crew, including the ability to use and understand the IMO Standard Marine Communication Phrases (IMO SMCP)	Examination and assessment of evidence obtained from practical instruction	English language nautical publications and messages relevant to the safety of the ship are correctly interpreted or drafted Communications are clear and understood
Transmit and receive information by visual signalling	*Visual signalling* Ability to use the International Code of Signals Ability to transmit and receive, by Morse light, distress signal SOS as specified in Annex IV of the International Regulations for Preventing Collisions at Sea, 1972, as amended, and appendix 1 of the International Code of Signals, and visual signalling of single-letter signals as also specified in the International Code of Signals	Assessment of evidence obtained from practical instruction and/or simulation	Communications within the operator's area of responsibility are consistently successful

Source: IMO

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Manoeuvre the ship	*Ship manoeuvring and handling* Knowledge of: .1 the effects of deadweight, draught, trim, speed and under-keel clearance on turning circles and stopping distances .2 the effects of wind and current on ship handling .3 manoeuvres and procedures for the rescue of person overboard .4 squat, shallow-water and similar effects .5 proper procedures for anchoring and mooring	Examination and assessment of evidence obtained from one or more of the following: .1 approved in-service experience .2 approved training ship experience .3 approved simulator training, where appropriate .4 approved training on a manned scale ship model, where appropriate	Safe operating limits of ship propulsion, steering and power systems are not exceeded in normal manoeuvres Adjustments made to the ship's course and speed to maintain safety of navigation

Source: IMO

Function: Cargo handling and stowage at the operational level

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Monitor the loading, stowage, securing, care during the voyage and the unloading of cargoes	*Cargo handling, stowage and securing* Knowledge of the effect of cargo, including heavy lifts, on the seaworthiness and stability of the ship Knowledge of safe handling, stowage and securing of cargoes, including dangerous, hazardous and harmful cargoes, and their effect on the safety of life and of the ship Ability to establish and maintain effective communications during loading and unloading	Examination and assessment of evidence obtained from one or more of the following: .1 approved in-service experience .2 approved training ship experience .3 approved simulator training, where appropriate	Cargo operations are carried out in accordance with the cargo plan or other documents and established safety rules/regulations, equipment operating instructions and shipboard stowage limitations The handling of dangerous, hazardous and harmful cargoes complies with international regulations and recognized standards and codes of safe practice Communications are clear, understood and consistently successful
Inspect and report defects and damage to cargo spaces, hatch covers and ballast tanks	Knowledge* and ability to explain where to look for damage and defects most commonly encountered due to: .1 loading and unloading operations .2 corrosion .3 severe weather conditions Ability to state which parts of the ship shall be inspected each time in order to cover all parts within a given period of time Identify those elements of the ship structure which are critical to the safety of the ship	Examination and assessment of evidence obtained from one or more of the following: .1 approved in-service experience .2 approved training ship experience .3 approved simulator training, where appropriate	The inspections are carried out in accordance with laid-down procedures, and defects and damage are detected and properly reported Where no defects or damage are detected, the evidence from testing and examination clearly indicates adequate competence in adhering to procedures and ability to distinguish between normal and defective or damaged parts of the ship

* It should be understood that deck officers need not be qualified in the survey of ships.

Source: IMO

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Inspect and report defects and damage to cargo spaces, hatch covers and ballast tanks (*continued*)	State the causes of corrosion in cargo spaces and ballast tanks and how corrosion can be identified and prevented Knowledge of procedures on how the inspections shall be carried out Ability to explain how to ensure reliable detection of defects and damages Understanding of the purpose of the "enhanced survey programme"		

Source: IMO

Function: Controlling the operation of the ship and care for persons on board at the operational level

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Ensure compliance with pollution-prevention requirements	*Prevention of pollution of the marine environment and anti-pollution procedures* Knowledge of the precautions to be taken to prevent pollution of the marine environment Anti-pollution procedures and all associated equipment Importance of proactive measures to protect the marine environment	Examination and assessment of evidence obtained from one or more of the following: .1 approved in-service experience .2 approved training ship experience .3 approved training	Procedures for monitoring shipboard operations and ensuring compliance with MARPOL requirements are fully observed Actions to ensure that a positive environmental reputation is maintained
Maintain seaworthiness of the ship	*Ship stability* Working knowledge and application of stability, trim and stress tables, diagrams and stress-calculating equipment Understanding of fundamental actions to be taken in the event of partial loss of intact buoyancy Understanding of the fundamentals of watertight integrity *Ship construction* General knowledge of the principal structural members of a ship and the proper names for the various parts	Examination and assessment of evidence obtained from one or more of the following: .1 approved in-service experience .2 approved training ship experience .3 approved simulator training, where appropriate .4 approved laboratory equipment training	The stability conditions comply with the IMO intact stability criteria under all conditions of loading Actions to ensure and maintain the watertight integrity of the ship are in accordance with accepted practice
Prevent, control and fight fires on board	*Fire prevention and fire-fighting appliances* Ability to organize fire drills Knowledge of classes and chemistry of fire Knowledge of fire-fighting systems	Assessment of evidence obtained from approved fire-fighting training and experience as set out in section A-VI/3	The type and scale of the problem is promptly identified and initial actions conform with the emergency procedure and contingency plans for the ship Evacuation, emergency shutdown and isolation

Source: IMO

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
	Knowledge of action to be taken in the event of fire, including fires involving oil systems		procedures are appropriate to the nature of the emergency and are implemented promptly The order of priority and the levels and time-scales of making reports and informing personnel on board are relevant to the nature of the emergency and reflect the urgency of the problem
Operate life-saving appliances	*Life-saving* Ability to organize abandon ship drills and knowledge of the operation of survival craft and rescue boats, their launching appliances and arrangements, and their equipment, including radio life-saving appliances, satellite EPIRBs, SARTs, immersion suits and thermal protective aids	Assessment of evidence obtained from approved training and experience as set out in section A-VI/2, paragraphs 1 to 4	Actions in responding to abandon ship and survival situations are appropriate to the prevailing circumstances and conditions and comply with accepted safety practices and standards
Apply medical first aid on board ship	*Medical aid* Practical application of medical guides and advice by radio, including the ability to take effective action based on such knowledge in the case of accidents or illnesses that are likely to occur on board ship	Assessment of evidence obtained from approved training as set out in section A-VI/4, paragraphs 1 to 3	The identification of probable cause, nature and extent of injuries or conditions is prompt and treatment minimizes immediate threat to life
Monitor compliance with legislative requirements	Basic working knowledge of the relevant IMO conventions concerning safety of life at sea, security and protection of the marine environment	Assessment of evidence obtained from examination or approved training	Legislative requirements relating to safety of life at sea, security and protection of the marine environment are correctly identified

Source: IMO

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Application of leadership and teamworking skills	Working knowledge of shipboard personnel management and training A knowledge of related international maritime conventions and recommendations, and national legislation Ability to apply task and workload management, including: .1 planning and co-ordination .2 personnel assignment .3 time and resource constraints .4 prioritization Knowledge and ability to apply effective resource management: .1 allocation, assignment, and prioritization of resources .2 effective communication onboard and ashore .3 decisions reflect consideration of team experiences .4 assertiveness and leadership, including motivation .5 obtaining and maintaining situational awareness	Assessment of evidence obtained from one or more of the following: .1 approved training .2 approved in-service experience .3 practical demonstration	The crew are allocated duties and informed of expected standards of work and behaviour in a manner appropriate to the individuals concerned Training objectives and activities are based on assessment of current competence and capabilities and operational requirements Operations are demonstrated to be in accordance with applicable rules Operations are planned and resources are allocated as needed in correct priority to perform necessary tasks Communication is clearly and unambiguously given and received Effective leadership behaviours are demonstrated Necessary team member(s) share accurate understanding of current and predicted vessel status and operational status and external environment Decisions are most effective for the situation

Source: IMO

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Application of leadership and teamworking skills (continued)	Knowledge and ability to apply decision-making techniques: .1 situation and risk assessment .2 identify and consider generated options .3 selecting course of action .4 evaluation of outcome effectiveness		
Contribute to the safety of personnel and ship	Knowledge of personal survival techniques Knowledge of fire prevention and ability to fight and extinguish fires Knowledge of elementary first aid Knowledge of personal safety and social responsibilities	Assessment of evidence obtained from approved training and experience as set out in section A-VI/1, paragraph 2	Appropriate safety and protective equipment is correctly used Procedures and safe working practices designed to safeguard personnel and the ship are observed at all times Procedures designed to safeguard the environment are observed at all times Initial and follow-up action on becoming aware of an emergency conforms with established emergency response procedures

----

Table A-11/2 (Masters and Chief Officers)

STCW Code Table A-II/2

Specification of Minimum Standard of Competence for Masters and Chief Mates on Ships of 500 Gross Tonnage or More

Ref: https://www.edumaritime.net/stcw-code
Source: http://www.imo.org

Function: Navigation at the management level

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Plan a voyage and conduct navigation	Voyage planning and navigation for all conditions by acceptable methods of plotting ocean tracks, taking into account, e.g.: .1 restricted waters .2 meteorological conditions .3 ice .4 restricted visibility .5 traffic separation schemes .6 vessel traffic service (VTS) areas .7 areas of extensive tidal effects Routeing in accordance with the General Provisions on Ships' Routeing Reporting in accordance with the General principles for Ship Reporting Systems and with VTS procedures	Examination and assessment of evidence obtained from one or more of the following: .1 approved in-service experience .2 approved simulator training, where appropriate .3 approved laboratory equipment training using: chart catalogues, charts, nautical publications and ship particulars	The equipment, charts and nautical publications required for the voyage are enumerated and appropriate to the safe conduct of the voyage The reasons for the planned route are supported by facts and statistical data obtained from relevant sources and publications Positions, courses, distances and time calculations are correct within accepted accuracy standards for navigational equipment All potential navigational hazards are accurately identified
Determine position and the accuracy of resultant position fix by any means	Position determination in all conditions: .1 by celestial observations .2 by terrestrial observations, including the ability to use appropriate charts, notices to mariners and other publications to assess the accuracy of the resulting position fix .3 using modern electronic	Examination and assessment of evidence obtained from one or more of the following: .1 approved in-service experience .2 approved simulator training, where appropriate .3 approved laboratory equipment training	The primary method chosen for fixing the ship's position is the most appropriate to the prevailing circumstances and conditions The fix obtained by celestial observations is within accepted accuracy levels The fix obtained by terrestrial observations is

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
	navigational aids, with specific knowledge of their operating principles, limitations, sources of error, detection of misrepresentation of information and methods of correction to obtain accurate position fixing	using: .1 charts, nautical almanac, plotting sheets, chronometer, sextant and a calculator .2 charts, nautical publications and navigational instruments (azimuth mirror, sextant, log, sounding equipment, compass) and manufacturers' manuals .3 radar, terrestrial electronic position-fixing systems, satellite navigation systems and appropriate nautical charts and publications	within accepted accuracy levels The accuracy of the resulting fix is properly assessed The fix obtained by the use of electronic navigational aids is within the accuracy standards of the systems in use. The possible errors affecting the accuracy of the resulting position are stated and methods of minimizing the effects of system errors on the resulting position are properly applied
Determine and allow for compass errors	Ability to determine and allow for errors of the magnetic and gyro-compasses Knowledge of the principles of magnetic and gyro-compasses An understanding of systems under the control of the master gyro and a knowledge of the operation and care of the main types of gyro-compass	Examination and assessment of evidence obtained from one or more of the following: .1 approved in-service experience .2 approved simulator training, where appropriate .3 approved laboratory equipment training using: celestial observations, terrestrial bearings and comparison between magnetic and gyro-compasses	The method and frequency of checks for errors of magnetic and gyro-compasses ensures accuracy of information

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Coordinate search and rescue operations	A thorough knowledge of and ability to apply the procedures contained in the International Aeronautical and Maritime Search and Rescue (IAMSAR) Manual	Examination and assessment of evidence obtained from one or more of the following: .1 approved in-service experience .2 approved simulator training, where appropriate .3 approved laboratory equipment training using: relevant publications, charts, meteorological data, particulars of ships involved, radiocommunication equipment and other available facilities and one or more of the following: .1 approved SAR training course .2 approved simulator training, where appropriate .3 approved laboratory equipment training	The plan for coordinating search and rescue operations is in accordance with international guidelines and standards Radiocommunications are established and correct communication procedures are followed at all stages of the search and rescue operations
Establish watchkeeping arrangements and procedures	Thorough knowledge of content, application and intent of the International Regulations for Preventing Collisions at Sea, 1972, as amended Thorough knowledge of the content, application and intent of the Principles to be observed in keeping a navigational watch	Examination and assessment of evidence obtained from one or more of the following: .1 approved in-service experience .2 approved simulator training, where appropriate	Watchkeeping arrangements and procedures are established and maintained in compliance with international regulations and guidelines so as to ensure the safety of navigation, protection of the marine environment and safety of the ship and persons on board

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Maintain safe navigation through the use of information from navigation equipment and systems to assist command decision making *Note*: Training and assessment in the use of ARPA is not required for those who serve exclusively on ships not fitted with ARPA. This limitation shall be reflected in the endorsement issued to the seafarer concerned	An appreciation of system errors and thorough understanding of the operational aspects of navigational systems Blind pilotage planning Evaluation of navigational information derived from all sources, including radar and ARPA, in order to make and implement command decisions for collision avoidance and for directing the safe navigation of the ship The interrelationship and optimum use of all navigational data available for conducting navigation	Examination and assessment of evidence obtained from approved ARPA simulator and one or more of the following: .1 approved in-service experience .2 approved simulator training, where appropriate .3 approved laboratory equipment training	Information obtained from navigation equipment and systems is correctly interpreted and analysed, taking into account the limitations of the equipment and prevailing circumstances and conditions Action taken to avoid a close encounter or collision with another vessel is in accordance with the International Regulations for Preventing Collisions at Sea, 1972, as amended
Maintain the safety of navigation through the use of ECDIS and associated navigation systems to assist command decision making Note: Training and assessment in the use of ECDIS is not required for those who serve exclusively on ships not fitted with ECDIS. This limitation shall be reflected in the endorsement issued to the seafarer concerned	Management of operational procedures, system files and data, including: .1 manage procurement, licensing and updating of chart data and system software to conform to established procedures .2 system and information updating, including the ability to update ECDIS system version in accordance with vendor's product development .3 create and maintain system configuration and backup files .4 create and maintain log files in accordance with established procedures .5 create and maintain route plan files in accordance with established procedures	Assessment of evidence obtained from one of the following: .1 approved in-service experience .2 approved training ship experience .3 approved ECDIS simulator training	Operational procedures for using ECDIS are established, applied, and monitored Actions taken to minimize risk to safety of navigation

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
	.6 use ECDIS log-book and track history functions for inspection of system functions, alarm settings and user responses Use ECDIS playback functionality for passage review, route planning and review of system functions		
Forecast weather and oceanographic conditions	Ability to understand and interpret a synoptic chart and to forecast area weather, taking into account local weather conditions and information received by weather fax Knowledge of the characteristics of various weather systems, including tropical revolving storms and avoidance of storm centres and the dangerous quadrants Knowledge of ocean current systems Ability to calculate tidal conditions Use all appropriate nautical publications on tides and currents	Examination and assessment of evidence obtained from one or more of the following: .1 approved in-service experience .2 approved laboratory equipment training	The likely weather conditions predicted for a determined period are based on all available information Actions taken to maintain safety of navigation minimize any risk to safety of the ship Reasons for intended action are backed by statistical data and observations of the actual weather conditions
Respond to navigational emergencies	Precautions when beaching a ship Action to be taken if grounding is imminent, and after grounding Refloating a grounded ship with and without assistance Action to be taken if collision is imminent and following a collision or impairment of the watertight integrity of the hull by any cause	Examination and assessment of evidence obtained from practical instruction, in-service experience and practical drills in emergency procedures	The type and scale of any problem is promptly identified and decisions and actions minimize the effects of any malfunction of the ship's systems Communications are effective and comply with established procedures Decisions and actions maximize safety of persons on board

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
	Assessment of damage control Emergency steering Emergency towing arrangements and towing procedure		
Manoeuvre and handle a ship in all conditions	Manoeuvring and handling a ship in all conditions, including: .1 manoeuvres when approaching pilot stations and embarking or disembarking pilots, with due regard to weather, tide, headreach and stopping distances .2 handling ship in rivers, estuaries and restricted waters, having regard to the effects of current, wind and restricted water on helm response .3 application of constant-rate-of-turn techniques .4 manoeuvring in shallow water, including the reduction in under-keel clearance caused by squat, rolling and pitching .5 interaction between passing ships and between own ship and nearby banks (canal effect) .6 berthing and unberthing under various conditions of wind, tide and current with and without tugs .7 ship and tug interaction .8 use of propulsion and manoeuvring systems	Examination and assessment of evidence obtained from one or more of the following: .1 approved in-service experience .2 approved simulator training, where appropriate .3 approved manned scale ship model, where appropriate	All decisions concerning berthing and anchoring are based on a proper assessment of the ship's manoeuvring and engine characteristics and the forces to be expected while berthed alongside or lying at anchor While under way, a full assessment is made of possible effects of shallow and restricted waters, ice, banks, tidal conditions, passing ships and own ship's bow and stern wave so that the ship can be safely manoeuvred under various conditions of loading and weather

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Manoeuvre and handle a ship in all conditions *(continued)*	.9 choice of anchorage; anchoring with one or two anchors in limited anchorages and factors involved in determining the length of anchor cable to be used .10 dragging anchor; clearing fouled anchors .11 dry-docking, both with and without damage .12 management and handling of ships in heavy weather, including assisting a ship or aircraft in distress; towing operations; means of keeping an unmanageable ship out of trough of the sea, lessening drift and use of oil .13 precautions in manoeuvring to launch rescue boats or survival craft in bad weather .14 methods of taking on board survivors from rescue boats and survival craft .15 ability to determine the manoeuvring and propulsion characteristics of common types of ships, with special reference to stopping distances and turning circles at various draughts and speeds .16 importance of navigating at reduced speed to avoid damage caused by own ship's bow wave and stern wave		

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Manoeuvre and handle a ship in all conditions (*continued*)	.17 practical measures to be taken when navigating in or near ice or in conditions of ice accumulation on board .18 use of, and manoeuvring in and near, traffic separation schemes and in vessel traffic service (VTS) areas		
Operate remote controls of propulsion plant and engineering systems and services	Operating principles of marine power plants Ships' auxiliary machinery General knowledge of marine engineering terms	Examination and assessment of evidence obtained from one or more of the following: .1 approved in-service experience .2 approved simulator training, where appropriate	Plant, auxiliary machinery and equipment is operated in accordance with technical specifications and within safe operating limits at all times

Function: Cargo handling and stowage at the management level

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Plan and ensure safe loading, stowage, securing, care during the voyage and unloading of cargoes	Knowledge of and ability to apply relevant international regulations, codes and standards concerning the safe handling, stowage, securing and transport of cargoes Knowledge of the effect on trim and stability of cargoes and cargo operations Use of stability and trim diagrams and stress-calculating equipment, including automatic data-based (ADB) equipment, and knowledge of loading cargoes and ballasting in order to keep hull stress within acceptable limits	Examination and assessment of evidence obtained from one or more of the following: .1 approved in-service experience .2 approved simulator training, where appropriate using: stability, trim and stress tables, diagrams and stress-calculating equipment	The frequency and extent of cargo condition monitoring is appropriate to its nature and prevailing conditions Unacceptable or unforeseen variations in the condition or specification of the cargo are promptly recognized and remedial action is immediately taken and designed to safeguard the safety of the ship and those on board Cargo operations are planned and executed in accordance with

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Plan and ensure safe loading, stowage, securing, care during the voyage and unloading of cargoes *(continued)*	Stowage and securing of cargoes on board ships, including cargo-handling gear and securing and lashing equipment Loading and unloading operations, with special regard to the transport of cargoes identified in the Code of Safe Practice for Cargo Stowage and Securing General knowledge of tankers and tanker operations Knowledge of the operational and design limitations of bulk carriers Ability to use all available shipboard data related to loading, care and unloading of bulk cargoes Ability to establish procedures for safe cargo handling in accordance with the provisions of the relevant instruments such as IMDG Code, IMSBC Code, MARPOL 73/78 Annexes III and V and other relevant information Ability to explain the basic principles for establishing effective communications and improving working relationship between ship and terminal personnel		established procedures and legislative requirements Stowage and securing of cargoes ensures that stability and stress conditions remain within safe limits at all times during the voyage

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Assess reported defects and damage to cargo spaces, hatch covers and ballast tanks and take appropriate action	Knowledge of the limitations on strength of the vital constructional parts of a standard bulk carrier and ability to interpret given figures for bending moments and shear forces Ability to explain how to avoid the detrimental effects on bulk carriers of corrosion, fatigue and inadequate cargo handling	Examination and assessment of evidence obtained from one or more of the following: .1 approved in-service experience .2 approved simulator training, where appropriate using: stability, trim and stress tables, diagrams and stress-calculating equipment	Evaluations are based on accepted principles, well-founded arguments and correctly carried out. The decisions taken are acceptable, taking into consideration the safety of the ship and the prevailing conditions
Carriage of dangerous goods	International regulations, standards, codes and recommendations on the carriage of dangerous cargoes, including the International Maritime Dangerous Goods (IMDG) Code and the International Maritime Solid Bulk Cargoes (IMSBC) Code Carriage of dangerous, hazardous and harmful cargoes; precautions during loading and unloading and care during the voyage	Examination and assessment of evidence obtained from one or more of the following: .1 approved in-service experience .2 approved simulator training, where appropriate .3 approved specialist training	Planned distribution of cargo is based on reliable information and is in accordance with established guidelines and legislative requirements Information on dangers, hazards and special requirements is recorded in a format suitable for easy reference in the event of an incident

Function: Controlling the operation of the ship and care for persons on board at the management level

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Control trim, stability and stress	Understanding of fundamental principles of ship construction and the theories and factors affecting trim and stability and measures necessary to preserve trim and stability Knowledge of the effect on trim and stability of a ship in the event of damage to and consequent flooding of a compartment and countermeasures to be taken Knowledge of IMO recommendations concerning ship stability	Examination and assessment of evidence obtained from one or more of the following: .1 approved in-service experience .2 approved training ship experience .3 approved simulator training, where appropriate	Stability and stress conditions are maintained within safe limits at all times

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Monitor and control compliance with legislative requirements and measures to ensure safety of life at sea, security and the protection of the marine environment	Knowledge of international maritime law embodied in international agreements and conventions Regard shall be paid especially to the following subjects: .1 certificates and other documents required to be carried on board ships by international conventions, how they may be obtained and their period of validity .2 responsibilities under the relevant requirements of the International Convention on Load Lines, 1966, as amended .3 responsibilities under the relevant requirements of the International Convention for the Safety of Life at Sea, 1974, as amended .4 responsibilities under the International Convention for the Prevention of Pollution from Ships, as amended .5 maritime declarations of health and the requirements of the International Health Regulations .6 responsibilities under international instruments affecting the safety of the ship, passengers, crew and cargo .7 methods and aids to prevent pollution of the marine environment by ships .8 national legislation for implementing international agreements and conventions	Examination and assessment of evidence obtained from one or more of the following: .1 approved in-service experience .2 approved training ship experience .3 approved simulator training, where appropriate	Procedures for monitoring operations and maintenance comply with legislative requirements Potential non-compliance is promptly and fully identified Planned renewal and extension of certificates ensures continued validity of surveyed items and equipment

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Maintain safety and security of the ship's crew and passengers and the operational condition of life-saving, fire-fighting and other safety systems	Thorough knowledge of life-saving appliance regulations (International Convention for the Safety of Life at Sea) Organization of fire drills and abandon ship drills Maintenance of operational condition of life-saving, fire-fighting and other safety systems Actions to be taken to protect and safeguard all persons on board in emergencies Actions to limit damage and salve the ship following a fire, explosion, collision or grounding	Examination and assessment of evidence obtained from practical instruction and approved in-service training and experience	Procedures for monitoring fire-detection and safety systems ensure that all alarms are detected promptly and acted upon in accordance with established emergency procedures
Develop emergency and damage control plans and handle emergency situations	Preparation of contingency plans for response to emergencies Ship construction, including damage control Methods and aids for fire prevention, detection and extinction Functions and use of life-saving appliances	Examination and assessment of evidence obtained from approved in-service training and experience	Emergency procedures are in accordance with the established plans for emergency situations

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Use of leadership and managerial skill	Knowledge of shipboard personnel management and training A knowledge of related international maritime conventions and recommendations, and national legislation Ability to apply task and workload management, including: .1 planning and co-ordination .2 personnel assignment .3 time and resource constraints .4 prioritization Knowledge and ability to apply effective resource management: .1 allocation, assignment, and prioritization of resources .2 effective communication on board and ashore .3 decisions reflect consideration of team experiences .4 assertiveness and leadership, including motivation .5 obtaining and maintaining situation awareness Knowledge and ability to apply decision-making techniques: .1 situation and risk assessment .2 identify and generate options .3 selecting course of action	Assessment of evidence obtained from one or more of the following: .1 approved training .2 approved in-service experience .3 approved simulator training	The crew are allocated duties and informed of expected standards of work and behaviour in a manner appropriate to the individuals concerned Training objectives and activities are based on assessment of current competence and capabilities and operational requirements Operations are demonstrated to be in accordance with applicable rules Operations are planned and resources are allocated as needed in correct priority to perform necessary tasks Communication is clearly and unambiguously given and received Effective leadership behaviours are demonstrated Necessary team member(s) share accurate understanding of current and predicted vessel state and

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Use of leadership and managerial skill (*continued*)	.4 evaluation of outcome effectiveness Development, implementation, and oversight of standard operating procedures		operational status and external environment Decisions are most effective for the situation Operations are demonstrated to be effective and in accordance with applicable rules
Organize and manage the provision of medical care on board	A thorough knowledge of the use and contents of the following publications: .1 International Medical Guide for Ships or equivalent national publications .2 medical section of the International Code of Signals .3 Medical First Aid Guide for Use in Accidents Involving Dangerous Goods	Examination and assessment of evidence obtained from approved training	Actions taken and procedures followed correctly apply and make full use of advice available

The relevant IMO Model Course(s) may be of assistance in the preparation of courses.

Source: IMO

Table A-III/2 (Chief Engineering offices and Second Engineers)

STCW Code Table A-III/2

Specification of minimum standard of competence for chief engineer officers and second engineer officers on ships powered by main propulsion machinery of 3,000 kW propulsion power or more

Ref: https://www.edumaritime.net/stcw-code

Source: IMO

Function: Marine engineering at the management level

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Manage the operation of propulsion plant machinery	Design features, and operative mechanism of the following machinery and associated auxiliaries: .1 marine diesel engine .2 marine steam turbine .3 marine gas turbine .4 marine steam boiler	Examination and assessment of evidence obtained from one or more of the following: .1 approved in-service experience .2 approved training ship experience .3 approved simulator training, where appropriate .4 approved laboratory equipment training	Explanation and understanding of design features and operating mechanisms are appropriate
Plan and schedule operations	*Theoretical knowledge* Thermodynamics and heat transmission Mechanics and hydromechanics Propulsive characteristics of diesel engines, steam and gas turbines, including speed, output and fuel consumption Heat cycle, thermal efficiency and heat balance of the following: .1 marine diesel engine .2 marine steam turbine .3 marine gas turbine .4 marine steam boiler	Examination and assessment of evidence obtained from one or more of the following: .1 approved in-service experience .2 approved training ship experience .3 approved simulator training, where appropriate .4 approved laboratory equipment training	The planning and preparation of operations is suited to the design parameters of the power installation and to the requirements of the voyage

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Plan and schedule operations *(continued)*	Refrigerators and refrigeration cycle Physical and chemical properties of fuels and lubricants Technology of materials Naval architecture and ship construction, including damage control		
Operation, surveillance, performance assessment and maintaining safety of propulsion plant and auxiliary machinery	*Practical knowledge* Start up and shut down main propulsion and auxiliary machinery, including associated systems Operating limits of propulsion plant The efficient operation, surveillance, performance assessment and maintaining safety of propulsion plant and auxiliary machinery Functions and mechanism of automatic control for main engine Functions and mechanism of automatic control for auxiliary machinery including but not limited to: .1 generator distribution systems .2 steam boilers .3 oil purifier .4 refrigeration system .5 pumping and piping systems .6 steering gear system .7 cargo-handling equipment and deck machinery	Examination and assessment of evidence obtained from one or more of the following: .1 approved in-service experience .2 approved training ship experience .3 approved simulator training, where appropriate .4 approved laboratory equipment training	The methods of preparing for the start-up and of making available fuels, lubricants, cooling water and air are the most appropriate Checks of pressures, temperatures and revolutions during the start-up and warm-up period are in accordance with technical specifications and agreed work plans Surveillance of main propulsion plant and auxiliary systems is sufficient to maintain safe operating conditions The methods of preparing the shutdown, and of supervising the cooling down of the engine are the most appropriate The methods of measuring the load capacity of the engines are in accordance with technical specifications Performance is checked against bridge orders Performance levels are in accordance with technical specifications

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Manage fuel, lubrication and ballast operations	Operation and maintenance of machinery, including pumps and piping systems	Examination and assessment of evidence obtained from one or more of the following: .1 approved in-service experience .2 approved training ship experience .3 approved simulator training, where appropriate	Fuel and ballast operations meet operational requirements and are carried out so as to prevent pollution of the marine environment

Function: Electrical, electronic and control engineering at the management level

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Manage operation of electrical and electronic control equipment	*Theoretical knowledge* Marine electrotechnology, electronics, power electronics, automatic control engineering and safety devices Design features and system configurations of automatic control equipment and safety devices for the following: .1 main engine .2 generator and distribution system .3 steam boiler Design features and system configurations of operational control equipment for electrical motors Design features of high-voltage installations Features of hydraulic and pneumatic control equipment	Examination and assessment of evidence obtained from one or more of the following: .1 approved in-service experience .2 approved training ship experience .3 approved simulator training, where appropriate .4 approved laboratory equipment training	Operation of equipment and system is in accordance with operating manuals Performance levels are in accordance with technical specifications
Manage trouble-shooting, restoration of electrical and electronic control equipment to operating condition	*Practical knowledge* Troubleshooting of electrical and electronic control equipment Function test of electrical, electronic control equipment and safety devices Troubleshooting of monitoring systems Software version control	Examination and assessment of evidence obtained from one or more of the following: .1 approved in-service experience .2 approved training ship experience .3 approved simulator training, where appropriate .4 approved laboratory equipment training	Maintenance activities are correctly planned in accordance with technical, legislative, safety and procedural specifications Inspection, testing and troubleshooting of equipment are appropriate

Function: Maintenance and repair at the management level

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Manage safe and effective maintenance and repair procedures	*Theoretical knowledge* Marine engineering practice *Practical knowledge* Manage safe and effective maintenance and repair procedures Planning maintenance, including statutory and class verifications Planning repairs	Examination and assessment of evidence obtained from one or more of the following: .1 approved in-service experience .2 approved training ship experience .3 approved workshop training	Maintenance activities are correctly planned and carried out in accordance with technical, legislative, safety and procedural specifications Appropriate plans, specifications, materials and equipment are available for maintenance and repair Action taken leads to the restoration of plant by the most suitable method
Detect and identify the cause of machinery malfunctions and correct faults	*Practical knowledge* Detection of machinery malfunction, location of faults and action to prevent damage Inspection and adjustment of equipment Non-destructive examination	Examination and assessment of evidence obtained from one or more of the following: .1 approved in-service experience .2 approved training ship experience .3 approved simulator training, where appropriate .4 approved laboratory equipment training	The methods of comparing actual operating conditions are in accordance with recommended practices and procedures Actions and decisions are in accordance with recommended operating specifications and limitations
Ensure safe working practices	*Practical knowledge* Safe working practices	Examination and assessment of evidence obtained from one or more of the following: .1 approved in-service experience .2 approved training ship experience .3 approved laboratory equipment training	Working practices are in accordance with legislative requirements, codes of practice, permits to work and environmental concerns

Function: Controlling the operation of the ship and care for persons on board at the management level

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Control trim, stability and stress	Understanding of fundamental principles of ship construction and the theories and factors affecting trim and stability and measures necessary to preserve trim and stability Knowledge of the effect on trim and stability of a ship in the event of damage to, and consequent flooding of, a compartment and countermeasures to be taken Knowledge of IMO recommendations concerning ship stability	Examination and assessment of evidence obtained from one or more of the following: .1 approved in-service experience .2 approved training ship experience .3 approved simulator training, where appropriate	Stability and stress conditions are maintained within safety limits at all times
Monitor and control compliance with legislative requirements and measures to ensure safety of life at sea, security and protection of the marine environment	Knowledge of relevant international maritime law embodied in international agreements and conventions Regard shall be paid especially to the following subjects: .1 certificates and other documents required to be carried on board ships by international conventions, how they may be obtained and the period of their legal validity .2 responsibilities under the relevant requirements of the International Convention on Load Lines, 1966, as amended .3 responsibilities under the relevant requirements of the International Convention for the Safety of Life at Sea, 1974, as amended	Examination and assessment of evidence obtained from one or more of the following: .1 approved in-service experience .2 approved training ship experience .3 approved simulator training, where appropriate	Procedures for monitoring operations and maintenance comply with legislative requirements Potential non-compliance is promptly and fully identified Requirements for renewal and extension of certificates ensure continued validity of survey items and equipment

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Monitor and control compliance with legislative requirements and measures to ensure safety of life at sea and protection of the marine environment (*continued*)	.4 responsibilities under the International Convention for the Prevention of Pollution from Ships, as amended .5 maritime declarations of health and the requirements of the International Health Regulations .6 responsibilities under international instruments affecting the safety of the ships, passengers, crew or cargo .7 methods and aids to prevent pollution of the environment by ships .8 knowledge of national legislation for implementing international agreements and conventions		
Maintain safety and security of the vessel, crew and passengers and the operational condition of life-saving, fire-fighting and other safety systems	A thorough knowledge of life-saving appliance regulations (International Convention for the Safety of Life at Sea) Organization of fire and abandon ship drills Maintenance of operational condition of life-saving, fire-fighting and other safety systems Actions to be taken to protect and safeguard all persons on board in emergencies Actions to limit damage and salve the ship following fire, explosion, collision or grounding	Examination and assessment of evidence obtained from practical instruction and approved in-service training and experience	Procedures for monitoring fire-detection and safety systems ensure that all alarms are detected promptly and acted upon in accordance with established emergency procedures

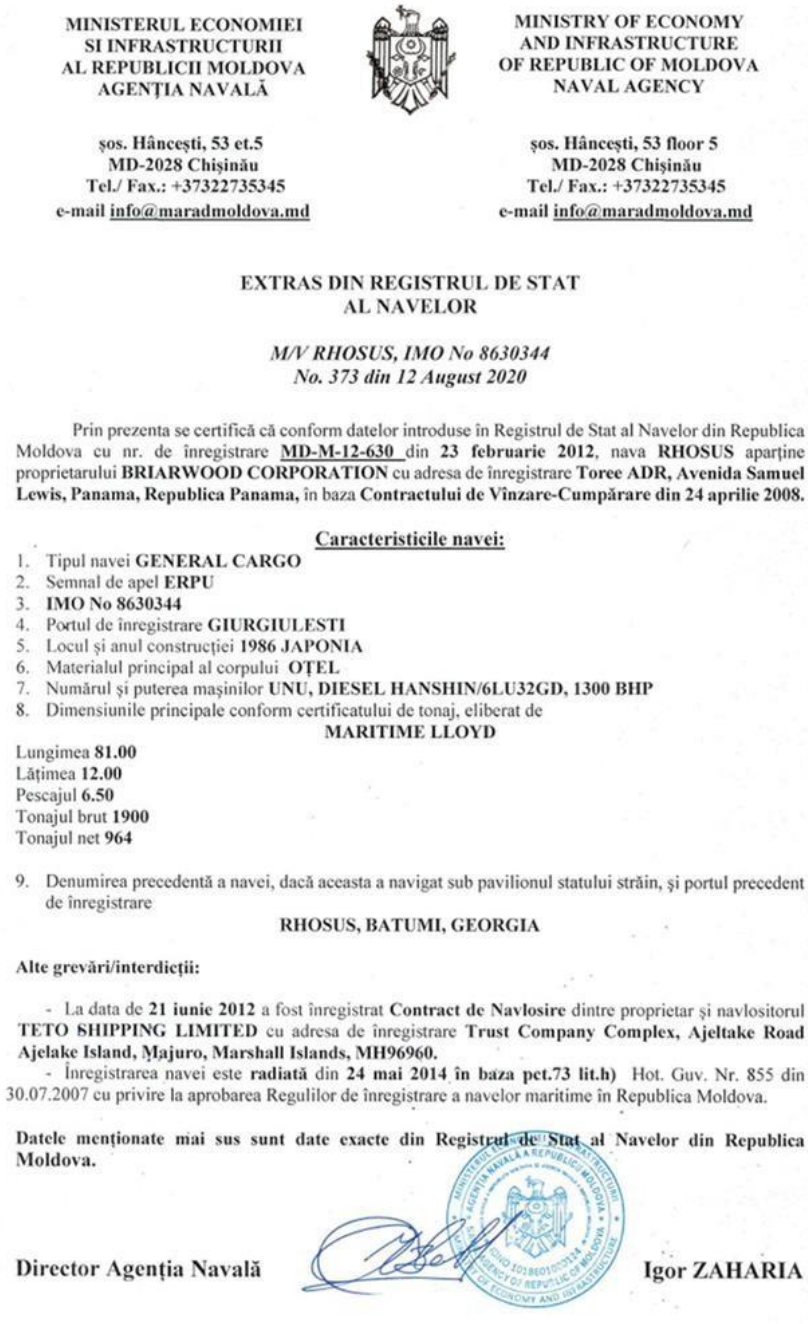
Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Develop emergency and damage control plans and handle emergency situations	Ship construction, including damage control Methods and aids for fire prevention, detection and extinction Functions and use of life-saving appliances	Examination and assessment of evidence obtained from approved in-service training and experience	Emergency procedures are in accordance with the established plans for emergency situations
Use leadership and managerial skills	Knowledge of shipboard personnel management and training A knowledge of international maritime conventions and recommendations, and related national legislation Ability to apply task and workload management, including: .1 planning and coordination .2 personnel assignment .3 time and resource constraints .4 prioritization Knowledge and ability to apply effective resource management: .1 allocation, assignment, and prioritization of resources .2 effective communication on board and ashore .3 decisions reflect consideration of team experience	Assessment of evidence obtained from one or more of the following: .1 approved training .2 approved in-service experience .3 approved simulator training	The crew are allocated duties and informed of expected standards of work and behaviour in a manner appropriate to the individuals concerned Training objectives and activities are based on assessment of current competence and capabilities and operational requirements Operations are demonstrated to be in accordance with applicable rules Operations are planned and resources are allocated as needed in correct priority to perform necessary tasks Communication is clearly and unambiguously given and received

Column 1	Column 2	Column 3	Column 4
Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Use leadership and managerial skills (*continued*)	.4 assertiveness and leadership, including motivation .5 obtaining and maintaining situation awareness Knowledge and ability to apply decision-making techniques: .1 situation and risk assessment .2 identify and generate options .3 select course of action .4 evaluation of outcome effectiveness Development, implementation, and oversight of standard operating procedures		Effective leadership behaviours are demonstrated Necessary team member(s) share accurate understanding of current and predicted vessel state and operational status and external environment Decisions are most effective for the situation Operations are demonstrated to be effective and in accordance with applicable rules

APPENDIX H

MV Rhosus Case study supporting documentation

1. Moldova vessel registration document



MINISTERUL ECONOMIEI
SI INFRASTRUCTURII
AL REPUBLICII MOLDOVA
AGENȚIA NAVALĂ

șos. Hâncești, 53 et.5
MD-2028 Chișinău
Tel./ Fax.: +37322735345
e-mail info@maradmoldova.md

MINISTRY OF ECONOMY
AND INFRASTRUCTURE
OF REPUBLIC OF MOLDOVA
NAVAL AGENCY

șos. Hâncești, 53 floor 5
MD-2028 Chișinău
Tel./ Fax.: +37322735345
e-mail info@maradmoldova.md

EXTRAS DIN REGISTRUL DE STAT
AL NAVELOR

M/V RHOSUS, IMO No 8630344
No. 373 din 12 August 2020

Prin prezenta se certifică că conform datelor introduse în Registrul de Stat al Navelor din Republica Moldova cu nr. de înregistrare **MD-M-12-630** din **23 februarie 2012**, nava **RHOSUS** aparține proprietarului **BRIARWOOD CORPORATION** cu adresa de înregistrare **Toree ADR, Avenida Samuel Lewis, Panama, Republica Panama,** în baza **Contractului de Vînzare-Cumpărare din 24 aprilie 2008.**

Caracteristicile navei:

1. Tipul navei **GENERAL CARGO**
2. Semnal de apel **ERPU**
3. **IMO No 8630344**
4. Portul de înregistrare **GIURGIULESTI**
5. Locul și anul construcției **1986 JAPONIA**
6. Materialul principal al corpului **OȚEL**
7. Numărul și puterea mașinilor **UNU, DIESEL HANSHIN/6LU32GD, 1300 BHP**
8. Dimensiunile principale conform certificatului de tonaj, eliberat de **MARITIME LLOYD**

Lungimea **81.00**
Lățimea **12.00**
Pescajul **6.50**
Tonajul brut **1900**
Tonajul net **964**

9. Denumirea precedentă a navei, dacă aceasta a navigat sub pavilionul statului străin, și portul precedent de înregistrare **RHOSUS, BATUMI, GEORGIA**

Alte grevări/interdicții:

- La data de **21 iunie 2012** a fost înregistrat **Contract de Navlosire** dintre proprietar și navlositorul **TETO SHIPPING LIMITED** cu adresa de înregistrare **Trust Company Complex, Ajeltake Road Ajelake Island, Majuro, Marshall Islands, MH96960.**
- Înregistrarea navei este **radiată** din **24 mai 2014 în baza pct.73 lit.h)** Hot. Guv. Nr. 855 din 30.07.2007 cu privire la aprobarea Regulilor de înregistrare a navelor maritime în Republica Moldova.

Datele menționate mai sus sunt date exacte din Registrul de Stat al Navelor din Republica Moldova.

Director Agenția Navală **Igor ZAHARIA**

Source: Organised Crime and Corruption Reporting Project (2020)

2. MV Rhosus bill of lading for 2,750 bags of ammonium

Page

CODE NAME: "CONGENBILL" EDITION 1994

Shipper

"RUSTAVI AZOT" LLC

BILL OF LADING

TO BE USED WITH CHARTER-PARTIES

B/L No. I

Consignee

TO THE ORDER OF

BANCO INTERNACIONAL DE MOCAMBIQUE

FIRST ORIGINAL

Notify

FABRICA DE EXPLOSIVOS
AV.SAMORA MACHEL, PARCELA 10
MATOLA-MOCAMBIQUE

Vessel: M/V "RHOSUS"

Port of loading: BATUMI PORT, PORT OF BLACK SEA

Port of discharge

BEIRA PORT-MOZAMBIQUE

Shipper's description of goods:

HIGH DENSITY AMMONIUM NITRATE
IMO 5.1

GROSS WEIGHT: 2750,40 MTS
NET WEIGHT: 2750,00 MTS
NUMBER OF FULL BIG BAGS - 2750 PCS

"CLEAN ON BOARD"
"FREIGHT PAYABLE AS PER CHARTER PARTY"

(of which on deck at Shipper's risk, the Carrier not being responsible for loss or damage howsoever arising)

Freight payable as per CHARTER-PARTY dated 04/ 09 /2013

FREIGHT ADVANCE.
Received on account of freight:

Time used for loading .... Days .... hours

SHIPPED at the Port of Loading in apparent good order and condition on board the Vessel for carriage to the Port of Discharge or so near thereto as she may safely get the goods specified above.
Weight, measure, quality, quantity, condition, contents and value unknown.
IN WITNESS whereof the Master or Agent of the said Vessel has signed the number of Bills of Lading indicated below all of this tenor and date, any one of which being accomplished the others shall be void.

FOR CONDITIONS OF CARRIAGE SEE OVERLEAF

Freight payable at: AS PER C/P

Place and date of issue: Batumi, Georgia on 23 /09/ 2013

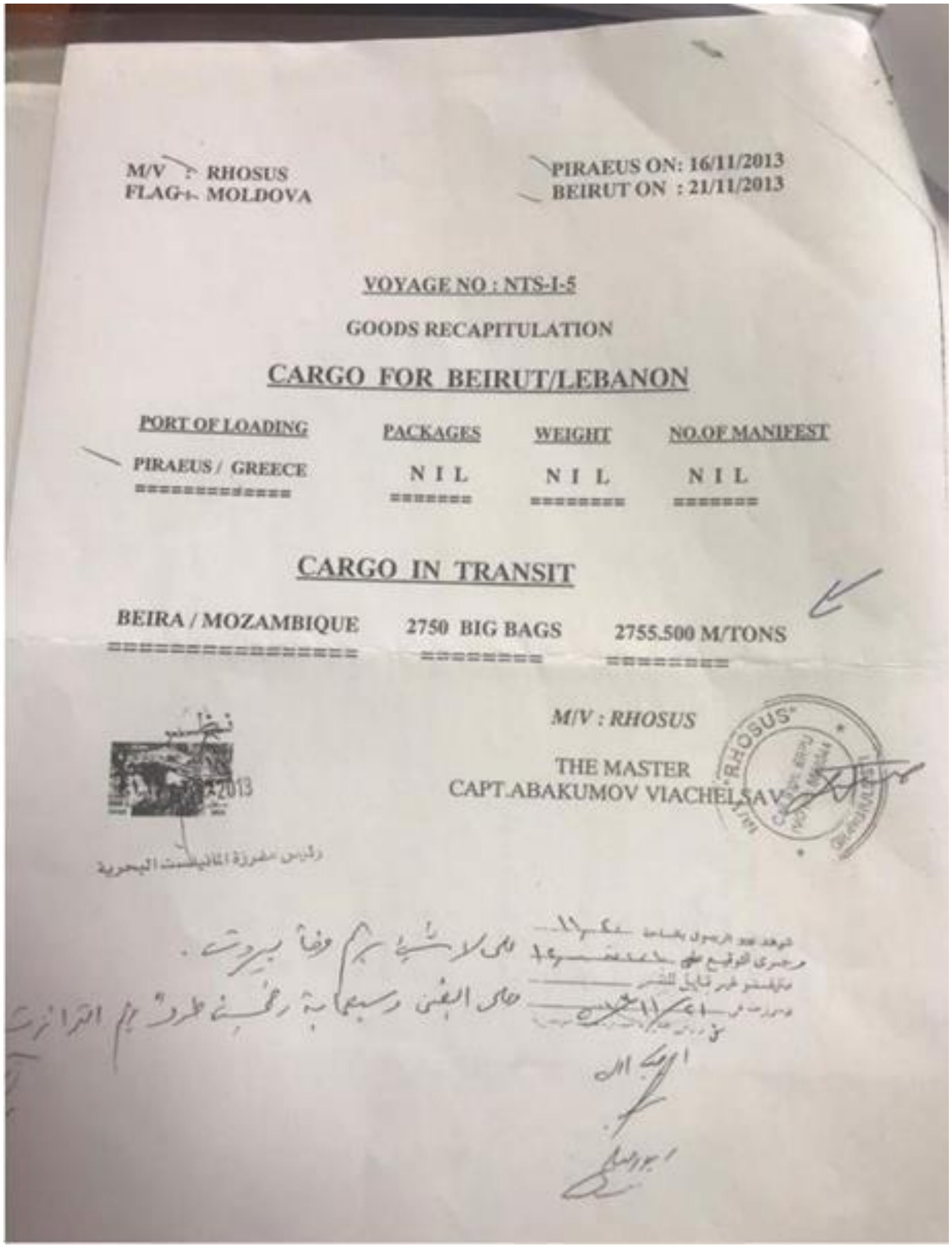
Number of original Bs/L: 3/3

Signature: The Master of m/v "RHOSUS" Capt. ABAKUMOV VIACHESLAV

Printed and sold by Fr. G. Knudtzons Bogtrykkeri A/S, 61 Vallensbaekvej, DK-2625 Vallensbaek, Telefax +45 43 66 07 08 by authority of The Baltic and International Maritime Council (BIMCO), Copenhagen

Source: Human Rights Watch (2021)

3. MV Rhosus unified list



M/V : RHOSUS
FLAG : MOLDOVA

PIRAEUS ON: 16/11/2013
BEIRUT ON : 21/11/2013

VOYAGE NO : NTS-I-5

GOODS RECAPITULATION

CARGO FOR BEIRUT/LEBANON

PORT OF LOADING	PACKAGES	WEIGHT	NO.OF MANIFEST
PIRAEUS / GREECE	N I L	N I L	N I L

CARGO IN TRANSIT

BEIRA / MOZAMBIQUE	2750 BIG BAGS	2755.500 M/TONS

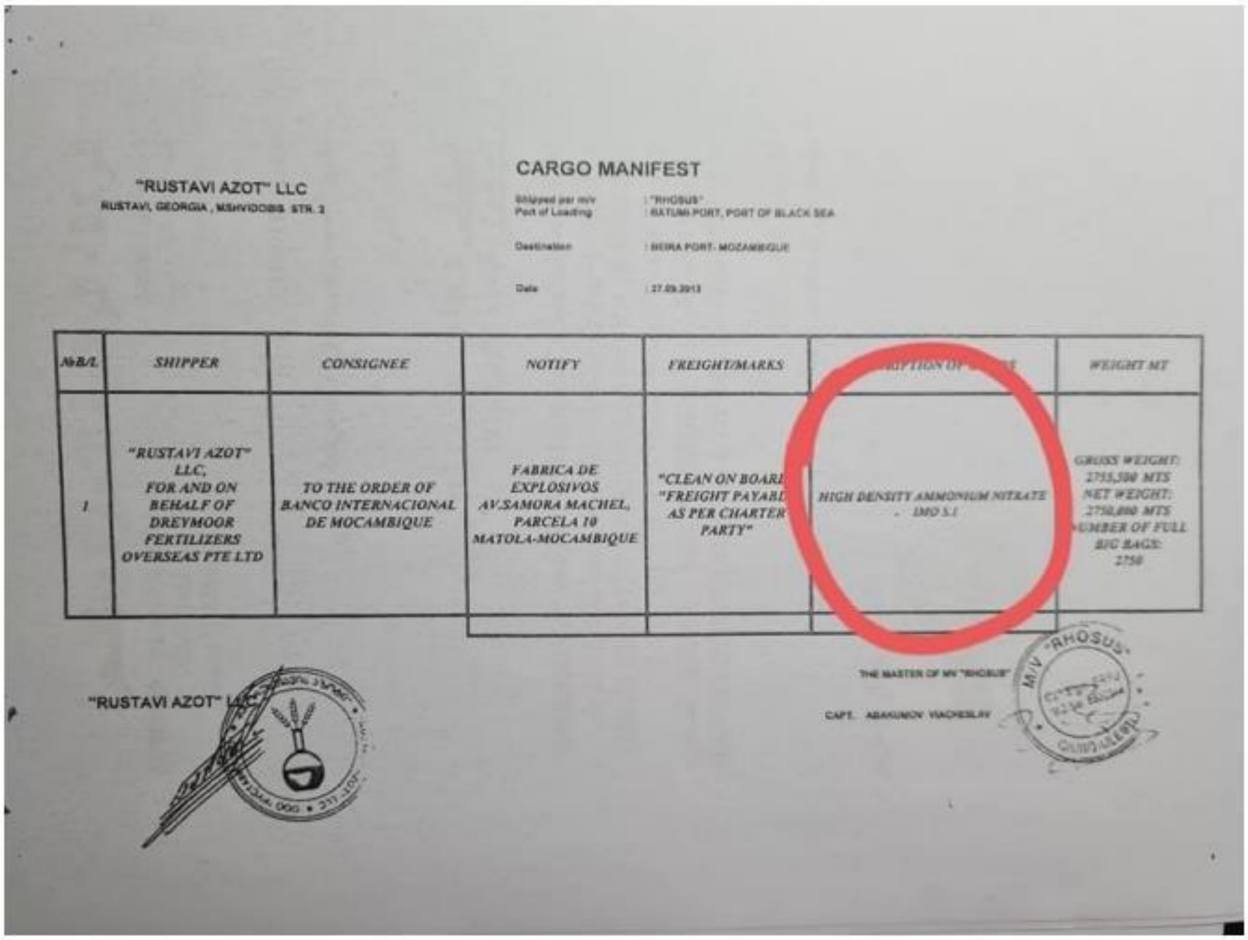
M/V : RHOSUS

THE MASTER
CAPT.ABAKUMOV VIACHELSAV

رئيس مفرزة المانيفست البحرية

Source: Human Rights Watch (2021)

4. MV Rhosus cargo manifest



"RUSTAVI AZOT" LLC
RUSTAVI, GEORGIA , MSHVIDOBIS STR. 2

CARGO MANIFEST

Shipped per m/v : "RHOSUS"
Port of Loading : BATUMI PORT, PORT OF BLACK SEA

Destination : BEIRA PORT- MOZAMBIQUE

Date : 27.09.2013

№B/L	SHIPPER	CONSIGNEE	NOTIFY	FREIGHT/MARKS	[illegible]IPTION OF [illegible]	WEIGHT MT
1	"RUSTAVI AZOT" LLC, FOR AND ON BEHALF OF DREYMOOR FERTILIZERS OVERSEAS PTE LTD	TO THE ORDER OF BANCO INTERNACIONAL DE MOCAMBIQUE	FABRICA DE EXPLOSIVOS AV.SAMORA MACHEL, PARCELA 10 MATOLA-MOCAMBIQUE	"CLEAN ON BOAR[illegible] "FREIGHT PAYAB[illegible] AS PER CHARTER PARTY"	HIGH DENSITY AMMONIUM NITRATE - IMO 5.1	GROSS WEIGHT: 2755,500 MTS NET WEIGHT: 2750,000 MTS [illegible]UMBER OF FULL BIG BAGS: 2750

"RUSTAVI AZOT" LLC

THE MASTER OF MV "RHOSUS"

CAPT. ABAKUMOV VIACHESLAV

Source: Human Rights Watch (2021)

5. Letter from Captain MV Rhosus \ Captain. Prokoshev Borys

مستند رقم ٣

TO WHOM IT MAY CONCERN

1. Master of the m/v Rhosus, Mr. Prokoshev Borys, under the flag of Moldova, owned and operated by Teto Shipping ltd. sailed from Piraeus Port to Beirut Port, with a full cargo of Ammonium Nitrate.

We hereby inform you that the ship-owner has abandoned the above vessel and is no longer paying the crew salaries and dues. The cargo owner likewise has abandoned the cargo on board the vessel. No bunkers or provision are available on board and the state of the cargo is such that it puts in peril anybody within the harbor and the ship-owner is taking no action in this respect and is no longer communicating with us.

We would therefore urge you to take all necessary steps to prevent any potential damage to the vessel and to avert any risk to the environment, to public safety and to the port facilities.

Prokoshev Borys

01.04.2014

M/V "RHOSUS"

Source: Human Rights Watch (2021)

REFERENCES

Ader, E., and Ader, M. (2022). Seafarer Abandonment World Map. Arcgis.com. Retrieved 6 August 2022, from https://www.arcgis.com/home/webmap/viewer.html?webmap=26f4e0ac76434ff7a31ad65ddb39212e.

Agapiou, A (2020). Damage Proxy Map of the Beirut Explosion on 4th of August 2020 as Observed from the Copernicus Sensors, Sensors, 20(21), 6382; https://doi.org/10.3390/s20216382

Ajzen, I. (2012). Martin Fishbein's legacy. The ANNALS of the American Academy of Political and Social Science, 640(1), 11–27. https://doi.org/10.1177/0002716211423363

Alamy. (2013). *MV Sewol*. https://www.alamy.com. Alamy. Retrieved from https://www.alamy.com/south-korea-16th-apr-2014-a-picture-taken-in-the-south-korean-sea-image68569127.html.

Alase, A. (2017). The Interpretative Phenomenological Analysis (IPA): A Guide to a Good Qualitative Research Approach. International Journal of Education And Literacy Studies, 5(2), 9. https://doi.org/10.7575/aiac.ijels.v.5n.2p.9

Ajzen, I. (2012a). Martin Fishbein's legacy. The ANNALS of the American Academy of Political and Social Science, 640(1), 11–27. https://doi.org/10.1177/0002716211423363

Allen, R. L. (1982) The Port Chicago Disaster and its Aftermath, The Black Scholar, 13:2-3, pp.3-29, DOI: 10.1080/00064246.1982.11414237

AMSA. (2010). STCW regulations explained. Australian Maritime Safety Authority. https://www.amsa.gov.au/qualifications-training/international-qualifications/stcw-regulations-explained

AMSA, Consequences to people. Australian Maritime Safety Authority. https://www.amsa.gov.au/consequences-people-0

AMSA, Regulated Australian and Foreign Flagged Vessels Annual Overview of Marine Incidents 2019. File:///C:/Users/cjm/Downloads/rav-and-ff-vessels-marine-incident-annual-report-2019-20.pdf

Antwi, S., & Hamza, K. (2015). Qualitative and quantitative research paradigms in business ... - core. https://core.ac.uk/download/pdf/234626233.pdf. https://core.ac.uk/download/pdf/234626233.pdf

Austin, J. (2016). LOSS OF PRESTIGE. Professional Mariner, Journal of the Maritime Industry. Retrieved from https://professionalmariner.com/flags-of-convenience-or-connivance-and-whos-really-accountable/

Avolio, B., and Bass, B. (2004). Multifactor leadership questionnaire: manual and sampler set (3rd ed.). Mind Garden.

BBC News, 2016. “China blasts: Tianjin report finds 123 people responsible.” Retrieved from: https://www.bbc.com/news/world-asia-china-35506311

BBC News, Beirut Explosion: What we know so far. Retrieved 29 October 2020, https://www.bbc.com/news/world-middle-east-53668493

Bandura, A. (1997). Self-Efficacy: The Exercise of Control. Journal of Cognitive Psychotherapy.

Barbuto, J., and Scholl, R. (1999). Leaders' Motivation and Perception of Followers' Motivation as Predictors of Influence Tactics Used. Psychological Reports, 84(3_suppl), 1087-1098. https://doi.org/10.2466/pr0.1999.84.3c.1087

Barling, J., Loughlin, C., and Kelloway, E. (2002). Development and test of a model linking safety-specific transformational leadership and occupational safety. Journal Of Applied Psychology, 87(3), 488-496. https://doi.org/10.1037/0021-9010.87.3.488

Bass, B. (1985). Leadership and performance beyond expectations. Collier Macmillan Publishers.

Beirut Explosion: Responding to Environmental Concerns in a COVID-19 Context – EECentre. (2021). Retrieved from: https://eecentre.org/2021/04/19/beirut-explosion-responding-to-environmental-concerns-in-a-covid-19-context/

Behaviour based safety: The right way to safety! DNV. (2015, December 1). https://www.dnv.com/news/behaviour-based-safety-the-right-way-to-safety--52968

Belford, A., Sabbagh, R., Orphanides, S., Farolfi, S., Moskowitz, E., Cerniauskas, S., Baquero, A., Shleynov, R., Kobeissi, R., Mukalled, D., Qaisi, E., Segnini, G., Poenariu, A., Tchobanov, A., Yordanov, A., Preasca, I., Korniienko, Y., Velikovsky, D., Shedrofsky, K., Sharife, K., Bakradze, N., Caldira, A., Atellah, J., Kovalev, A., Schaap, F. and Reuter, C., 2021. A Hidden Tycoon, African Explosives, and a Loan from a Notorious Bank: Questionable Connections Surround Beirut Explosion Shipment - OCCRP. [online] OCCRP. Retrieved from: https://www.occrp.org/en/investigations/a-hidden-tycoon-african-explosives-and-a-loan-from-a-notorious-bank-questionable-connections-surround-beirut-explosion-shipment

Berger, M., and Karklis, L. (2020, August 11). *How the Beirut Blast compared with similar explosions in Texas, China and France*. The Washington Post. https://www.washingtonpost.com/world/2020/08/09/how-beirut-blast-compared-with-similar-explosions-texas-china-france/

Berti, A. (2022) Handling dangerous goods in the wake of the Beirut explosion, Ship Technology. Available at: https://www.ship-technology.com/analysis/dangerous-goods-beirut-explosion/

Bettin, P., and Kennedy, J. (1990). Leadership experience and leader performance: Some empirical support at last. The Leadership Quarterly, 1(4), 219-228. https://doi.org/10.1016/1048-9843(90)90002-y

Beus, J., Dhanani, L., and McCord, M. (2015). A meta-analysis of personality and workplace safety: Addressing unanswered questions. Journal Of Applied Psychology, 100(2), 481-498. https://doi.org/10.1037/a0037916

Beus, J., McCord, M., and Zohar, D. (2016). Workplace safety. Organisational Psychology Review, 6(4), 352-381. https://doi.org/10.1177/2041386615626243

Bielic, T., Predovan, D., & ēulin, J. (2017). The role of the master in improving safety culture onboard ships. TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation, 11(1), 121–124. https://doi.org/10.12716/1001.11.01.14

Bronfenbrenner, U. (1994). Ecological models of human development. Oxford: Elsevier, Vol. 3(2nd Ed). Retrieved 10 October 2021, from.

Bychkovsky, Y., andamp; Melnyk, O. (2022, August). Research of the role and importance of Maritime Safety Leadership. https://www.researchgate.net/publication/362634650_RESEARCH_OF_THE_ROLE_AND_IMPORTANCE_OF_MARITIME_SAFETY_LEADERSHIP. Retrieved February 28, 2023, from https://www.researchgate.net/publication/362634650_RESEARCH_OF_THE_ROLE_AND_IMPORTANCE_OF_MARITIME_SAFETY_LEADERSHIP

Campbell, J., and Wiernik, B. (2015). The Modeling and Assessment of Work Performance. Annual Review Of Organizational Psychology And Organizational Behaviour, 2(1), 47-74. https://doi.org/10.1146/annurev-orgpsych-032414-111427

‘Cancer of the industry’: Beirut's blast proves lethal risk of abandoning ships. The Guardian. (2022). Retrieved 24 July 2022, from https://www.theguardian.com/environment/2020/aug/20/cancer-of-the-industry-beiruts-blast-proves-lethal-risk-of-abandoning-ships.

Carmanu, C. 2021. The Secrets Behind Moldova Naval Power. Retrieved from: https://www.zdg.md/en/?p=4816

Carriage of Divinylbenzene (DVB) in containers - The International Group of P&I Clubs. Igpandi.org. (2022). Retrieved 3 July 2022, from https://www.igpandi.org/article/carriage-divinylbenzene-dvb-containers.

CBC News (2021). Ship that delivered explosive material to Beirut port was never supposed to stop there, says Captain | CBC News. [online] Retrieved from: https://www.cbc.ca/news/world/rhosus-ammonium-nitrate-beirut-Captain-1.5678444

Cedre France. (2009), October 16). *Ocean Liberty*. Cedre. https://wwz.cedre.fr/en/Resources/Spills/Spills/Ocean-Liberty

Chambers, S. (2020). Map details rising incidents of crew abandonment - Splash247. Splash247. Retrieved 30 July 2022, from https://splash247.com/map-details-rising-incidents-of-crew-abandonment/.

Chandler, B., and Huntebrinker, T.A. (2003). Multisite success with systematic BBS: A case study. Professional Safety, USA, p48

Choudhry, R. M. (2014). Behavior-based safety on construction sites: A case study. Accident Analysis & Prevention, 70, 14–23. https://doi.org/10.1016/j.aap.2014.03.007

Campbell, J., and Wiernik, B. (2015). The Modeling and Assessment of Work Performance. Annual Review Of Organizational Psychology And Organizational Behaviour, 2(1), 47-74. https://doi.org/10.1146/annurev-orgpsych-032414-111427

Cheaito, M. A. and and Al-Hajj, S. (2020). A Brief Report on the Beirut Port Explosion. Mediterranean Journal of Emergency Medicine and Acute Care, 1(4), https://doi.org/10.52544/2642-7184(1)4001

Chen, D., Tian, H., (2012). Behavior-Based Safety for Accidents Prevention and Positive Study in China Construction Project, Procedia Engineering, Vol-43, p529-530

China blasts: Tianjin report finds 123 people responsible (2021). Retrieved from: https://www.bbc.com/news/world-asia-china-35506311

Choi, B., and Lee, S. (2018). An Empirically Based Agent-Based Model of the Sociocognitive Process of Construction Workers Safety Behaviour. Journal Of Construction Engineering And Management, 144(2), 04017102. https://doi.org/10.1061/(ASCE)co.1943-7862.0001421

Choi, B., Ahn, S., and Lee, S. (2017). Role of Social Norms and Social Identifications in Safety Behaviour of Construction Workers. I: Theoretical Model of Safety Behaviour under Social Influence. Journal Of Construction Engineering And Management, 143(5), 04016124. https://doi.org/10.1061/(ASCE)co.1943-7862.0001271

Choudhry and Fang, (2008). Why operatives engage in unsafe work behavior: Investigating factors on construction sites. Science Direct, Safety Science 46 (2008) 567-584 https://doi.org/10.1016/j.ssci.2007.06.027

Christian, M., Bradley, J., Wallace, J., and Burke, M. (2009). Workplace safety: A meta-analysis of the roles of person and situation factors. Journal Of Applied Psychology, 94(5), 1103-1127. https://doi.org/10.1037/a0016172

Christou, M. (1999). Analysis and control of major accidents from the intermediate temporary storage of dangerous substances in marshalling yards and port areas. Journal Of Loss Prevention In The Process Industries, 12(1), 109-119. https://doi.org/10.1016/s0950-4230(98)00043-6

Clarke, S. (2012). Safety leadership: A meta-analytic review of transformational and transactional leadership styles as antecedents of safety behaviours. Journal Of Occupational And Organizational Psychology, 86(1), 22-49. https://doi.org/10.1111/j.2044-8325.2012.02064.x

Collett, G., (2021). GitHub-forensic-architecture/Models: 3d models and other assets for investigations. [online] GitHub. Retrieved from: https://forensic-architecture.org/investigation/beirut-port-explosion

Conchie, S., and Donald, I. (2009). The moderating role of safety-specific trust on the relation between safety-specific leadership and safety citizenship behaviours. Journal Of Occupational Health Psychology, 14(2), 137-147. https://doi.org/10.1037/a0014247

Conchie, S., and Moon, S. (2010). Promoting active safety leadership Identifying the individual and organisational antecedents of active safety leadership in construction supervisors. Institute of Occupational Health Safety. Retrieved 26 September 2021, from https://iosh.com/media/1534/promoting-active-safety-leadership-full-research-report.pdf.

Conchie. S., and Moon. S., (2010). Factors affecting the supervision of safety. IOSH, Research report 10.2, p3-15

Cooper, D. (1998). Improving Safety Culture a Practical Guide. John Wiley & Sons.

Cooper, D., (2003). Psychology, Risk and Safety, understanding how personality and perception can influence risk taking. American Society of Safety Engineers, Professional Safety Journal. p39-40

Cooper, D., (2009). Behavioral Safety Interventions, A review of process design factors. Professional Safety Journal. USA, p1-3

Cooper, D. (2014). Strengthening safety leadership - behavioral safety. Behavioural-Safety.com. https://www.behavioral-safety.com/articles/strengthen%20safety%20leadership.pdf

Cooper, D. (2015). Peer-reviewed effective safety leadership - behavioral safety. Behavioural-Safety.com. https://behavioral-safety.com/articles/effective_leadership_cooper_0215.pdf

Creswell, J. W. (2013). Qualitative inquiry and research design: Choosing among five approaches. Sage Publications.

Darbra, R., and Casal, J. (2004). Historical analysis of accidents in seaports. Safety Science, 42(2), 85-98. https://doi.org/10.1016/s0925-7535(03)00002-x

DeJoy, D. M. (2005). Behavior change versus culture change: Divergent approaches to managing workplace safety. Safety Science, 43(2), 105–129. https://doi.org/10.1016/j.ssci.2005.02.001

Dicken, P. (2015). Global Shift, Mapping the Changing Contours of the World Economy (7th ed). London. Sage Publishing.

Dillon, B., Clayton-Ball, T., Bourke, J., andamp; Scales, J. (2016). Deloitte-au-HC-six-signature-traits-inclusive-leadership-020516 - the six signature traits of. Studocu. Retrieved February 28, 2023, from https://www.studocu.com/en-ca/document/mcgill-university/managerial-economics/deloitte-au-hc-six-signature-traits-inclusive-leadership-020516/12975237

Dóci, E., Hofmans, J., Nijs, S., and Judge, T. A. (2020). Leaders under pressure: Time pressure and state core self-evaluations as antecedents of transformational leadership behaviour. *European Journal of Work and Organizational Psychology*, *29*(4), 515–524. https://doi.org/10.1080/1359432x.2020.1714717

EDU Marintime. (2010). STCW table B-I/2 - list of certificates or documentary ... - edumaritime. https://www.edumaritime.net. https://www.edumaritime.net/stcw-code/stcw-table-b-i-2-list-of-certificates

Effectiveness of work health and safety interventions by regulators: A literature review. (2013). Safe Work Australia.

El Sayed M. J. (2020). Beirut Ammonium Nitrate Explosion: A Man-Made Disaster in Times of the COVID-19 Pandemic. Disaster Med Public Health Prep. 2020 Nov 18:1-5. doi: 10.1017/dmp.2020.451.

Ellis, J. (2011). Analysis of accidents and incidents occurring during transport of packaged dangerous goods by sea. Safety Science, 49(8-9), 1231-1237. https://doi.org/10.1016/j.ssci.2011.04.004

Eprints.kingston.ac.uk. (2021). Retrieved 20 October 2021, from https://eprints.kingston.ac.uk/id/eprint/48251/6/Umar-T-48251-AAM.pdf.

Ernst, P., Siu, A., and Weikum, G. (2015). KnowLife: a versatile approach for constructing a large knowledge graph for biomedical sciences. BMC Bioinformatics, 16(1). https://doi.org/10.1186/s12859-015-0549-5

Facts + statistics: Marine accidents. III. https://www.iii.org/fact-statistic/facts-statistics-marine-accidents

Fang, D., Wu, C., and Wu, H. (2015). Impact of the Supervisor on Worker Safety Behaviour in Construction Projects. Journal Of Management In Engineering, 31(6), 04015001. https://doi.org/10.1061/(ASCE)me.1943-5479.0000355

Fakih, L., Majzoub, A., Moussa, L., de Figueiredo, M. and Salloum, C., (2021). They Killed Us From the Inside. [online] Human Rights Watch. Retrieved from: https://www.hrw.org/report/2021/08/03/they-killed-us-inside/investigation-august-4-beirut-blast

Fitch, H. G., Herman, J., and Hopkins, B.L. (1976). Safe and unsafe behavior and its modification. Journal of Occupational Medicine, Vol 18, p618-622

Flags of convenience. ITF Global. (2021). https://www.itfglobal.org/en/sector/seafarers/flags-of-convenience

Forensic-Architecture (2020). Beirut Port Explosion. The University of London, Retrieved from: https://forensic-architecture.org/investigation/beirut-port-explosion [accessed 21 December 2021].

Forensic-Architecture, (2021). Beirut Port Explosion. [video], University of London, Retrieved from: https://forensic-architecture.org/investigation/beirut-port-explosion

Formal Safety Assessment. Imo.org. (2022). Retrieved 3 July 2022, from https://www.imo.org/en/OurWork/Safety/Pages/FormalSafetyAssessment.aspx.

Fu, G., Wang, J. and Yan, M. (2016). Anatomy of Tianjin Port fire and explosion: Process and causes. Process Safety Progress, 35(3), pp.216-220. https://doi.org/10.1002/prs.11837

Galieriková, A. (2019). The human factor and maritime safety. Transportation Research Procedia, 40, 1319–1326. https://doi.org/10.1016/j.trpro.2019.07.183

Gao, X., Jiang, L., and Xu, Q. (2020). Experimental and theoretical study on thermal kinetics and reactive mechanism of nitrocellulose pyrolysis by traditional multi kinetics and modeling reconstruction. *Journal of Hazardous Materials, 386*, 121645. https://doi.org/10.1016/j.jhazmat.2019.121645

Geller, E. (2001). The psychology of safety handbook. CRC Press.

Glaser, B. G., and Strauss, A. L. (2017). The constant comparative method of qualitative analysis*. *The Discovery of Grounded Theory*, 101–116. https://doi.org/10.4324/9780203793206-6

Global Firepower. (2023) world military strength rankings. Global Firepower - World Military Strength. (n.d.). https://www.globalfirepower.com/

Graen, G., and Uhl-Bien, M. (1995). Relationship-based approach to leadership: Development of leader-member exchange (LMX) theory of leadership over 25 years: Applying a multi-level multi-domain perspective. The Leadership Quarterly, 6(2), 219-247. https://doi.org/10.1016/1048-9843(95)90036-5

Graglia, D. (2023). How many survey responses do I need to be statistically valid?. SurveyMonkey. https://www.surveymonkey.com/curiosity/how-many-people-do-i-need-to-take-my-survey/

Grant, J.G. (2000). Behavior based safety: Involving the total organization. Occupational Health and Safety Vol 69(9), p64-65.

Gray, J., Grove, S. K., & Sutherland, S. (2017). Chapter 12. In Burns and Grove’s the practice of nursing research appraisal, synthesis, and generation of evidence. essay, Elsevier.

Griffin, M., and Neal, A. (2000). Perceptions of safety at work: A framework for linking safety climate to safety performance, knowledge, and motivation. Journal Of

Occupational Health Psychology, 5(3), 347-358. https://doi.org/10.1037/1076-8998.5.3.347

Guardian News and Media. (2015). *Tianjin explosion: China sets final death toll at 173, ending search for survivors*. The Guardian. https://www.theguardian.com/world/2015/sep/12/tianjin-explosion-china-sets-final-death-toll-at-173-ending-search-for-survivors

Hakkinen, J., and Posti, A. (2013). Review of maritime and port-related HNS accidents. IAME Conference 2013 Marseille, (Paper ID 39), 10-15. Retrieved 3 July 2022

Häkkinen, J., Malk, V., Posti, A., Penttinen, O., Mäkelä, R., and Kiiski, A. (2013). Environmental risk assessment of the most commonly transported chemicals: case study of Finnish coastal areas. WMU Journal Of Maritime Affairs, 12(2), 147-160. https://doi.org/10.1007/s13437-013-0046-5

Halle, R. (2023). The development and empirical testing of a safety leadership-safety behaviour structural model. Stellenbosch University. https://scholar.sun.ac.za/items/2d442f41-1f43-4a00-a90a-d653cd923797

Hamad, H., (2016). Flag of Convenience Practice: A Threat to Maritime Safety and Security. Journal of Social Science and Humanities Research, [online](ISSN:2456-2671). Retrieved from: https://www.researchgate.net/publication/308308749_Flag_of_Convenience_Practice_A_Threat_to_Maritime_Safety_and_Security

Hannah, S. T., Avolio, B. J., Luthans, F., & Harms, P. D. (2008). Leadership efficacy: Review and Future Directions. The Leadership Quarterly, 19(6), 669–692. https://doi.org/10.1016/j.leaqua.2008.09.007

Haber, G. D. (2016, July 18). The impact of the subconscious on risk-based decisions. dss. https://www.consultdss.com/content-hub/the-impact-of-the-subconscious-on-risk-based-decision-making/

Hasanspahić, N., Vujičić, S., Frančić, V., & Čampara, L. (2021). The role of the human factor in marine accidents. Journal of Marine Science and Engineering, 9(3), 261. https://doi.org/10.3390/jmse9030261

Harrald, J., Mazzuchi, T., Spahn, J., Van Dorp, R., Merrick, J., Shrestha, S., and Grabowski, M. (1998). Using system simulation to model the impact of human error in a maritime system. Safety Science, 30(1-2), 235-247. https://doi.org/10.1016/s0925-7535(98)00048-4

Harrington, A. (2011). Social theory. Sociology. https://doi.org/10.1093/obo/9780199756384-0054

Health and Safety Professionals Alliance. (2012). *Models of causation: Safety - OHS BOK*. www.ohsbok.org.au. http://www.ohsbok.org.au/wp-content/uploads/2013/12/32-Models-of-causation-Safety.pdf

Hetherington, C., Flin, R., & Mearns, K. (2006). Safety in shipping: The human element. Journal of Safety Research, 37(4), 401–411. https://doi.org/10.1016/j.jsr.2006.04.007

Hill, C., and Knox, S. (2022). Essentials of Interpretative Phenomenological Anaysis. Apa.org. Retrieved 30 July 2022, from https://www.apa.org/pubs/books/essentials-interpretative-phenomenological-analysis-sample-chapter.pdf

Hobfoll, S. (1989). Conservation of resources: A new attempt at conceptualizing stress. American Psychologist, 44(3), 513-524. https://doi.org/10.1037/0003-066x.44.3.513

Huang, Y.; Yip, T.L.; Liang, C. (2020). Risk Perception and Property Value: Evidence from Tianjin Port Explosion. Sustainability 2020, 12, 1169. https://doi.org/10.3390/su12031169

Holloway, & Wheeler. (1996). Qualitative research for nurses. Nursing Standard, 10(42), 28–28. https://doi.org/10.7748/ns.10.42.28.s39

Hopkins, A. (2006). What are we to make of safety behavior programs? Safety Science. USA, Vol44. p583-590

Human Rights Watch. (2021). “They Killed Us from the Inside” An investigation into the 4 August Beirut Blast. United States of America: Human Rights Watch. Retrieved from: https://www.hrw.org/sites/default/files/media_2021/08/lebanon0821_web.pdf

Ide, B., & Huang, J. (2015). After China blasts, questions about firefighting, Port Safety. Voice of America. https://www.voanews.com/a/after-china-blasts-questions-about-firefighting-port-safety/2917812.html

ILO. (2015) Investigation of occupational accidents and diseases: A practical guide for labour inspectors 2015. Geneva; ILO.

Llabres Pohl, I. (2023). (rep.). The State of Shipping and Oceans. Understanding the impact of global shipping on climate, the ocean and human health. Consultancy report for Seas at Risk (pp. 4–5). Brussels: Seas at Risk.

Lloyd, S., Balsari, S., Muqueeth, S., & Leaning, J. (2017). FXHARVARBD - HKJCDPRI. https://www.hkjcdpri.org.hk/download/casestudies/FXBDPRIStampede.pdf

IMO. (2014). KT139E e-reader: Leadership and teamwork, 2014 edition. Marine Society Shop. Retrieved January 29, 2023, from https://www.marinesocietyshop.org/kt139e-leadership-and-teamwork-2014-edition-e-reader

IMO. (2022). IMDG code. International Maritime Organization. https://www.imo.org/en/publications/Pages/IMDG%20Code.aspx

Inness, M., Turner, N., Barling, J., and Stride, C. (2010). Transformational leadership and employee safety performance: A within-person, between-jobs design. Journal Of Occupational Health Psychology, 15(3), 279-290. https://doi.org/10.1037/a0019380

International Maritime Organization, (IMO). (2023). Convention on the International Maritime Organization. International Maritime Organization. https://www.imo.org/en/About/Conventions/Pages/Convention-on-the-International-Maritime-Organization.

International Maritime Organisation, (IMO). Seafarer Abandonment. Retrieved 31 October 2020, https://www.imo.org/en/OurWork/Legal/Pages/Seafarer-abandonment.aspx

International Transport Workers Federation (ITWF) (2021). Flags of convenience. International Transport Workers Federation https://www.itfglobal.org/en/sector/seafarers/flags-of-convenience. [accessed 21 December 2021].

International Maritime Organisaton (1991). Resolution A.716(17) adopted on 6 November 1991. The International Maritime Dangerous Goods Code (IMDG CODE). https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/AssemblyDocuments/A.716(17).pdf

International Maritime Organisation (2002). Resolution MSC.122(75) (adopted on 24 May 2002). Adoption of the International Maritime Dangerous Goods (IMDG) Code. https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MSCResolutions/MSC.122(75).pdf

“IOSH Certified Behavioral Science for Leadership in Safety Program”, (2021), e-learning course, Behavioral Safety Services Training, UK, Darren Sutton, available at: https://www.behaviouralsafetyservices.com/courses/iosh-certificated-behavioural-science-for-leadership-in-safety-program/lessons/module-1-leadership-understanding-your-leadership-style-effective-traits-building-culture/

Iyengar, R. (2015, August 14). *Searching questions asked in the aftermath of the Tianjin blasts*. Time. https://time.com/3997727/tianjin-blast-china-ruihai-warehouse-chemicals-zoning/

Ismail, S. Raphael, W. and Durand, E. (2021). Case study of the Beirut port explosion using 3D laser scan and nonlinear finite element model, Research on Engineering Structures and Materials, 7(4), pp551-577

J, L., X, B., Z, R., and J, W. (2014). *Statistic Analysis and Countermeasures of Hazardous Chemicals Accidents Occurring in China during 2011–2013*, 142–147.

Jacobs, A., Hernández, J. C., and Buckley, C. (2015). *Behind deadly tianjin blast, shortcuts and lax rules*. The New York Times. https://www.nytimes.com/2015/08/31/world/asia/behind-tianjin-tragedy-a-company-that-flouted-regulations-and-reaped-profits.html

Jitwasinkul, B., Hadikusumo, B., and Memon, A. (2016). A Bayesian Belief Network model of organizational factors for improving safe work behaviours in Thai construction industry. Safety Science, 82, 264-273. https://doi.org/10.1016/j.ssci.2015.09.027

Jones, J., and Wuebker, L. (1993). Safety locus of control and employees' accidents. Journal Of Business And Psychology, 7(4), 449-457. https://doi.org/10.1007/bf01013758

Ju, D., Qin, X., Xu, M., and DiRenzo, M. (2016). Boundary conditions of the emotional exhaustion-unsafe behaviour link: The dark side of group norms and personal control. Asia Pacific Journal Of Management, 33(1), 113-140. https://doi.org/10.1007/s10490-015-9455-7

Kallada, S. (2020). Can shippers change EmS code and give a different emergency schedule? IMDG Code Compliance Center. Available at: https://shashikallada.com/can-shippers-change-ems-code-and-give-a-different-emergency-schedule/

KAMIS, A. S., AHMAD FUAD, A. F., SAADON, M. S., and FADZIL, M. N. (2020). The impact of basic training on seafarers' safety knowledge, attitude and behaviour. *Journal of Sustainability Science and Management*, *15*(6), 137–158. https://doi.org/10.46754/jbsd.2020.08.012

Kapp, E. (2012). The influence of supervisor leadership practices and perceived group safety climate on employee safety performance. Safety Science, 50(4), 1119-1124. https://doi.org/10.1016/j.ssci.2011.11.011

Keating, J. How neglected cargo became a 'ticking time bomb in Beirut. Retrieved 15 October 2020, https://www.theglobeandmail.com/world/article-how-an-abandoned-ship-became-a-ticking-time-bomb-in-beirut/

Kee, D., Jun, G. T., Waterson, P., and Haslam, R. (2017). A systemic analysis of south korea Sewol ferry accident – striking a balance between learning and accountability. *Applied Ergonomics*, *59*, 504–516. https://doi.org/10.1016/j.apergo.2016.07.014

Kelloway, E., Mullen, J., and Francis, L. (2006). Divergent effects of transformational and passive leadership on employee safety. Journal Of Occupational Health Psychology, 11(1), 76-86. https://doi.org/10.1037/1076-8998.11.1.76

Kelman, J., (2008). Hazards in the Maritime Transport of Bulk Materials and Containerised Products. In: Symposium Series No. 154. [online] London, UK: CWA International, pp.1-15. Available at: https://www.icheme.org/media/9736/xx-paper-41.pdf

Khalili, L. (2020). Behind the Beirut explosion lies the lawless world of international shipping - Professor Laleh Khalili. Qmul.ac.uk. Retrieved 2 July 2022, from https://www.qmul.ac.uk/mei/news-and-opinion/items/behind-the-beirut-explosion-lies-the-lawless-world-of-international-shipping---professor-laleh-khalili.html.

Khan, S. N. (2014). Qualitative research method: Grounded theory. *International Journal of Business and Management*, *9*(11). https://doi.org/10.5539/ijbm.v9n11p224

Kilzer, E., & Skinner, B. F. (1953). Science and human behavior. The American Catholic Sociological Review, 14(2), 121. https://doi.org/10.2307/3707860

Kim, T., & Gausdal, A. H. (2017). Leading for safety: A Weighted Safety Leadership Model in shipping. Reliability Engineering & System Safety, 165, 458–466. https://doi.org/10.1016/j.ress.2017.05.002

Kim, T., & Sydnes, A. (2020). Safety Leadership Self-Efficacy Scale (SLSES) in Maritime Context (self-evaluation). ResearchGate.

Kim, T., Sydnes, A. K., & Batalden, B.-M. (2021). Development and validation of a safety leadership self-efficacy scale (SLSES) in maritime context. Safety Science, 134, 105031. https://doi.org/10.1016/j.ssci.2020.105031

Koettl, C. (2021). Ship Cited in Beirut Blast Hasn't Sailed in 7 Years. We Found It. New York Times. Published 7 August, 2020 Updated 14 October, 2021 https://www.nytimes.com/2020/08/07/world/middleeast/lebanon-explosion-ship.html [accessed 21 December 2021].

Komives- Chapter 1. prezi.com. (2021). Retrieved 20 October 2021, from https://prezi.com/bemfgitwvakm/komives-chapter-1/.

Kwon, Yisug, and Leveson, N. (2017). System Theoretic Safety Analysis of the Sewol-ho ferry accident in South Korea. *INCOSE International Symposium, 27*(1), 461–476. https://doi.org/10.1002/j.2334-5837.2017.00372.x

Larouzee, J., and Le Coze, J.-C. (2020). Good and bad reasons: The Swiss cheese model and its critics. *Safety Science*, *126*, 104660. https://doi.org/10.1016/j.ssci.2020.104660

Lee, Y., Schumm, W. R., Lockett, L., Newsom, K. C., and Behan, K. (2016). Teaching statistics with current and historical events. *Comprehensive Psychology*, *5*, 216522281664790. https://doi.org/10.1177/2165222816647900

Lekka, C., and Healey, N. (2021). RR952 - A review of the literature on effective leadership be.... Hse.gov.uk. Retrieved from https://www.hse.gov.uk/research/rrhtm/rr952.htm.

Leung, M., Chan, I., and Yu, J. (2012). Preventing construction worker injury incidents through the management of personal stress and organizational stressors. Accident Analysis and Prevention, 48, 156-166. https://doi.org/10.1016/j.aap.2011.03.017

Leung, M., Liang, Q., and Olomolaiye, P. (2016). Impact of Job Stressors and Stress on the Safety Behaviour and Accidents of Construction Workers. Journal Of Management In Engineering, 32(1), 04015019. https://doi.org/10.1061/(asce)me.1943-5479.0000373

Leveson, N. G. (2012). Engineering a Safer World. https://doi.org/10.7551/mitpress/8179.001.0001

Leveson, N. G. (2017). *Engineering a safer world systems thinking applied to safety*. The MIT Press.

Liang, H., and Zhang, S. (2019). Impact of supervisors safety violations on an individual worker within a construction crew. Safety Science, 120, 679-691. https://doi.org/10.1016/j.ssci.2019.08.014

Liang, H., Lin, K., Zhang, S., and Su, Y. (2018). The Impact of Coworkers™ Safety Violations on an Individual Worker: A Social Contagion Effect within the Construction Crew. International Journal Of Environmental Research And Public Health, 15(4), 773. https://doi.org/10.3390/ijerph15040773

Liu, L., Liang, S., Liu, H. et al. (2018) Migration of Cr2O 2-7 and Butanone in Soil and Groundwater System After the Tianjin Port 8·12 Explosion. Transactions of Tianjin University 24, 522–531 (2018). https://doi.org/10.1007/s12209-018-0149-3

Long, Douglas G. (2013). Delivering high performance: The third generation organisation. Gower Publishing Limited.

Lu, C., and Yang, C. (2010). Safety leadership and safety behaviour in container terminal operations. Safety Science, 48(2), 123-134. https://doi.org/10.1016/j.ssci.2009.05.003

Lützhöft, M., Grech, M. R., and Porathe, T. (2011). Information environment, fatigue, and culture in the maritime domain. *Reviews of Human Factors and Ergonomics*, *7*(1), 280–322. https://doi.org/10.1177/1557234x11410391

Maritime Sustainability and the human element - promoting the safety. https://www.researchgate.net/profile/Yong-Chia/publication/328225118_Maritime_Sustainability_and_the_Human_Element_-_Promoting_the_Safety_Culture_Onboard/links/5bbf5c75a6fdcc2c91f69e9c/Maritime-Sustainability-and-the-Human-Element-Promoting-the-Safety-Culture-Onboard.pdf

Matsimbe, J., Ghambi, S., and Samson, A. (2020). Engineering and technology quarterly. *Assessment of Safety Culture and Maturity in Mining Environments: Case of Njuli Quarry*, *3*(2). https://doi.org/10.31014/aior.1995

McGarry, S. L., Balsari, S., Muqueeth, S., & Leaning, J. (2018). Preventing the preventable: The 2015 Tianjin explosions. PreventionWeb. https://www.preventionweb.net/publication/preventing-preventable-2015-tianjin-explosions

McVeigh, K. Roth, A. Cancer of the industry: Beirut's blast proves lethal risk of abandoning ships. The Guardian, Accessed 31 October, 2020. https://www.theguardian.com/environment/2020/aug/20/cancer-of-the-industry-beiruts-blast-proves-lethal-risk-of-abandoning-ships

Mehan, A., and Jansen, M. (2020). Beirut Blast: A port city in crisis. Research Gate. Retrieved 30 June 2022, from https://www.researchgate.net/publication/343587855_Beirut_Blast_A_port_city_in_crisis?.

Moldova denies any responsibility for the Beirut explosion | tellerreport.com. Tellerreport.com. (2022). Retrieved 24 July 2022, from https://www.tellerreport.com/news/2020-08-05-moldova-denies-any-responsibility-for-the-beirut-explosion.S1Lww5_OZv.html.

Mullai, A. (2007). A Risk Analysis Framework for Maritime Transport of Packaged Goods - A Validating Demonstration Volume II; Engineering Logistics. Lund University of Technology. Retrieved 29 June 2022

Mullen, J., and Kelloway, E. (2009). Safety leadership: A longitudinal study of the effects of transformational leadership on safety outcomes. Journal Of Occupational And Organizational Psychology, 82(2), 253-272. https://doi.org/10.1348/096317908x325313

Murray, M., Fitzpatrick, D., and O'Connell, C. (1997). Fishermen’s blues: Factors related to accidents and safety among Newfoundland fishermen. Work and Stress, 11(3), 292-297. https://doi.org/10.1080/02678379708256842

Nakhoul, S. (2020). Initial investigations point to negligence as cause of Beirut blast, source says. Reuters. Retrieved 1 July 2022, from https://www.reuters.com/article/us-lebanon-security-blast-warehouse-idCAKCN2511G7.

UNCTAD. (2022) Handbook of Statistics 2023. https://hbs.unctad.org/merchant-fleet/

Nævestad, T.-O., Phillips, R. O., Størkersen, K. V., Laiou, A., & Yannis, G. (2019). Safety culture in maritime transport in Norway and Greece: Exploring national, sectorial and organizational influences on unsafe behaviours and work accidents. Marine Policy, 99, 1–13. https://doi.org/10.1016/j.marpol.2018.10.001

Neal, A., and Griffin, M. (2006). A study of the lagged relationships among safety climate, safety motivation, safety behaviour, and accidents at the individual and group levels. Journal Of Applied Psychology, 91(4), 946-953. https://doi.org/10.1037/0021-9010.91.4.946

Neal, A., Griffin, M., and Hart, P. (2000). The impact of organizational climate on safety climate and individual behaviour. Safety Science, 34(1-3), 99-109. https://doi.org/10.1016/s0925-7535(00)00008-4

Neame, C., Davies, J., and Chen, C. (2015). Tianjin Port Explosion, AUGUST 2015. hfw.com. Retrieved 3 July 2022, from https://www.hfw.com/Tianjin-Port-explosion-August-2015.

New York Times, (2020). MV Rhosus underway [image] Retrieved from: https://www.nytimes.com/2020/08/07/world/middleeast/lebanon-explosion-ship.html

Northouse, P. G. (2013). Leadership: Theory and Practice (6th ed.). Thousand Oaks, CA: Sage.

Nykänen, M., Salmela-Aro, K., Tolvanen, A., & Vuori, J. (2019). Safety self-efficacy and internal locus of control as mediators of safety motivation – randomized controlled trial (RCT) study. Safety Science, 117, 330–338. https://doi.org/10.1016/j.ssci.2019.04.037

Ocon, R., & McFarlane, O. (2007). International Latin American and Carribbean Conference for Engineering and Technology. In Reducing Employee Injuries Through Behavior Based Safety (pp 1–9). Tampico; Fifth LACCEI.

Offshore Energy (2012) Moldova to Stop Flag of Convenience Practice, retrieved 2 October 2020, https://www.offshore-energy.biz/moldova-to-stop-flag-of-convenience-practice/

offshore-energy.biz. (2022). APL Austria Hit by Major Fire off South Africa. Retrieved 4 July 2022, from https://www.offshore-energy.biz/apl-austria-hit-by-major-fire-off-south-africa/.

Organised Crime and Corruption Reporting Project (OCCRP) (2020). Moldova naval agency vessel registration document. [image] Retrieved from: https://www.occrp.org/en/investigations/a-hidden-tycoon-african-explosives-and-a-loan-from-a-notorious-bank-questionable-connections-surround-beirut-explosion-shipment [accessed 21 December 2021].

Organised crime and corruption reporting project (OCCRP) (2020). MV Rhosus bill of lading Georgia. [image] Retrieved from: https://www.occrp.org/en/investigations/a-hidden-tycoon-african-explosives-and-a-loan-from-a-notorious-bank-questionable-connections-surround-beirut-explosion-shipment [accessed 21 December 2021].

Özbağ, G. K. (2016). The role of personality in leadership: Five factor personality traits and ethical leadership. Procedia - Social and Behavioral Sciences, 235, 235–242. https://doi.org/10.1016/j.sbspro.2016.11.019

Ozbilir, T. (2021). Leading the way to safety: An investigation of S.A.F.E.R. Leadership (thesis). Saint Mary's University, Nova Scotia.

Paris MoU. (2020). Paris Mou. Paris MoU. https://parismou.org/

Patel, D. A., & Jha, K. N. (2016). Evaluation of construction projects based on the safe work behavior of co-employees through a neural network model. Safety Science, 89, 240–248. https://doi.org/10.1016/j.ssci.2016.06.020

Pilbeam, C., Doherty, N., Denyer, D., and Davidson, R. (2016). Safety leaders: who are they?; what do they do?. Iosh.com. Retrieved 3 October 2021, from https://iosh.com/media/3424/safety-leaders-who-are-they-what-do-they-do.pdf.

Port of Beirut. Ship Technology. (2022). https://www.ship-technology.com/projects/port-of-beirut/

Priambodo, M., and Siregar, M. (2018). Road Sign Detection Distance and Reading Distance at an Uncontrolled Intersection. E3S Web of Conferences, 65, 09004. https://doi.org/10.1051/e3conf/20186509004

Pybus, R. (1996). Safety management. Butterworth-Heinemann.

Rao, P. S. (2014). Ammonium Nitrate. In *Encyclopedia of Toxicology (Third Edition)* (3rd ed., pp. 209–211). essay, Academic Press.

P&I Club experience of NHS Incidents. (2022). Retrieved 3 July 2022, from https://www.imt-ip.pt/sites/IMTT/Portugues/TransporteMaritimo/Convencao-HNS/Documents/presentation-8.pdf.

BBC News (2020). Beirut explosion: Captain explains why Rhosus was in Beirut. BBC News. Retrieved 24 July 2022, from https://www.bbc.com/news/av/world-middle-east-53701648.

Reason, J. T. (1997). Managing the risks of organizational accidents (1st Edition). Routledge Taylor andamp; Francis Group.

Pasovic, E. (2020). Offshore companies and convoluted ownership structure helped obscure the true ownership of the MV Rhosus. [image] Retrieved from: https://www.occrp.org/en/investigations/a-hidden-tycoon-african-explosives-and-a-loan-from-a-notorious-bank-questionable-connections-surround-beirut-explosion-shipment [accessed 21 December 2021].

Pilbeam, C., Denyer, D., Davidson, R., & Doherty, N. Safety leaders who are they what do they do?. https://iosh.com/media/3424/safety-leaders-who-are-they-what-do-they-do.pdf. https://iosh.com/media/3424/safety-leaders-who-are-they-what-do-they-do.pdf

Popek, M. (2019). Factors influencing on the environment during hazardous goods transportation by the sea. IOP Conference Series: Earth And Environmental Science, 214, 012052. https://doi.org/10.1088/1755-1315/214/1/012052

Priambodo, M. I., & Siregar, M. L. (2018). Road sign detection distance and reading distance at an uncontrolled intersection. E3S Web of Conferences, 65, 09004. https://doi.org/10.1051/e3sconf/20186509004

Rao, P. S. (2014). Ammonium Nitrate. In *Encyclopedia of Toxicology (Third Edition)* (3rd ed., pp. 209–211). essay, Academic Press.

Reason, J. T. (1990). Human error. Cambridge University Press.

Rigby, S. E. (2021). Blast wave time of arrival: A reliable metric to determine pressure and yield of high explosive detonations. Fabig Newsletter Issue 079, pp18-25. Retrieved from: https://www.researchgate.net/publication/349605549_Blast_wave_time_of_arrival_A_reliable_metric_to_determine_pressure_and_yield_of_high_explosive_detonations/figures?lo=1 [accessed 21 December 2021].

Rigby, S.E., Lodge, T.J., Alotaibi, S. Preliminary yield estimation of the (2020) Beirut explosion using video footage from social media. Shock Waves 30, 671–675 (2020). https://doi.org/10.1007/s00193-020-00970-z

Rozelier, M. (2020). From the Rhosus' Departure to the Port Explosion, Chronicle of a Disaster Foretold. Le Commerce. https://www.lecommercedulevant.com/article/30040-from-the-rhosus-departure-to-the-port-explosion-chronicle-of-a-disaster-foretold [accessed 21 December 2021].

Rutter, D. R., & Bunce, D. J. (1989). The theory of reasoned action of Fishbein and Ajzen: A test of towriss's amended procedure for measuring beliefs. British Journal of Social Psychology, 28(1), 39–46. https://doi.org/10.1111/j.2044-8309.1989.tb00844.x

Safety Leadership. (2021). Behavioural Science for Leadership in Safety | IOSH Certificated. Retrieved January 7, 2024, from https://www.behaviouralsafetyservices.com/behavioural-science-for-leadership-in-safety.

Safety4sea (2019). Herald of Free Enterprise: A wake-up call for ro-ro safety. Safety4sea. https://safety4sea.com/cm-herald-of-free-enterprise-a-wake-up-call-for-ro-ro-safety/

Safety4sea. (2021). *Sewol sinking: South Korea's Ferry Disaster*. SAFETY4SEA. https://safety4sea.com/cm-Sewol-sinking-south-koreas-ferry-disaster/

Sánchez-Beaskoetxea, J., Basterretxea-Iribar, I., Sotés, I., & Machado, M. de. (2021). Human error in marine accidents: Is the crew normally to blame? Maritime Transport Research, 2, 100016. https://doi.org/10.1016/j.martra.2021.100016

Sawacha, E., Naoum, S., and Fong, D. (1999). Factors affecting safety performance on construction sites. International Journal Of Project Management, 17(5), 309-315. https://doi.org/10.1016/s0263-7863(98)00042-8

Schwatka, N., and Rosecrance, J. (2016). Safety climate and safety behaviours in the construction industry: The importance of Â co-workers commitment to safety. Work, 54(2), 401-413. https://doi.org/10.3233/wor-162341

Seafarers International Research Centre (SIRC), Cardiff University. (2018). The causes of maritime accidents in the period 2002-2016. Cardiff: Cardiff University, UK.

Retrieved from https://orca.cardiff.ac.uk/id/eprint/117481/1/Sampson_The%20causes%20of%20maritime%20accidents%20in%20the%20period%202002-2016.pdf

Secretariat Paris Memorandum of Understanding on Port State Control (2020). Paris MoU Blacklist 2020. [image] Available at: https://www.parismou.org/sites/default/files/TBB_Jaarverslag%20Paris%20MoU%202020_totaal_HRlos.pdf [accessed 21 December 2021].

Sheffield, U., (2021). Beirut explosion was one of the largest non-nuclear blasts in history, new analysis shows–Archive-News archive-The University of Sheffield. [online] Sheffield.ac.uk. Retrieved from: https://www.sheffield.ac.uk/news/nr/beirut-explosion-what-happened-impact-force-analysis-investigation-engineering-blast-study-1.916971

Shi, Y., Du, J., Ahn, C. R., & Ragan, E. (2019). Impact assessment of reinforced learning methods on construction workers' fall risk behavior using virtual reality. Automation in Construction, 104, 197–214. https://doi.org/10.1016/j.autcon.2019.04.015

Ship Technology, Beirut Explosion: Tracing the timeline of the disaster, retrieved on 20 October 2020, https://www.ship-technology.com/features/beirut-explosion-timeline/

Safety and Shipping Review Insights. Allianz Commercial. (2023). https://commercial.allianz.com/news-and-insights/reports/shipping-safety.html

Skinner, B. F. (1950). Are theories of learning necessary? Psychological Review, 57(4), 193–216. https://doi.org/10.1037/h0054367

Skinner. B., F. (1953). Science and Human Behavior. Pearson Education Inc. Library of Congress Catalog Card Number: 53-7045, p415-421

Speight, J. G. (2017). Chapter One - Inorganic Chemicals in the Environment. In *Environmental Inorganic Chemistry for Engineers* (pp. 1–49). essay, Butterworth-Heinemann.

Statista Research Department. (2023). Causes of ship losses by type - worldwide 2022. Statista. https://www.statista.com/statistics/419055/causes-of-losses-of-ships-worldwide/

STCW code - table A-II-1 - Edumaritime. Edumaritime.net. (2010). https://www.edumaritime.net/images/docs/stcw-table-a-ii-1.pdf

STCW code - table A-II-2 - Edumaritime. Edumaritime.net. (2010). https://www.edumaritime.net/images/docs/stcw-table-a-ii-1.pdf

STCW code - table A-III-2 - Edumaritime. Edumaritime.net. (2010). https://www.edumaritime.net/images/docs/stcw-table-a-ii-1.pdf

STCW regulations explained. Australian Maritime Safety Authority. https://www.amsa.gov.au/qualifications-training/international-qualifications/stcw-regulations-explained

Subramanyam, S. S., & Dhankher, D. D. (2022). The impact of behavioral-based safety among the seafarers. International Journal for Research in Applied Science and Engineering Technology, 10(12), 1297–1313. https://doi.org/10.22214/ijraset.2022.48189

Sun, B. (2015). Tianjin Port Explosions. Process Safety Progress, 34(4), p.315. https://doi.org/10.1002/prs.11790

Teoh, P. (2021). Beirut Port Tragedy: Ports and Dangerous Chemicals. Retrieved from: https://www.maritime-executive.com/editorials/beirut-port-tragedy-ports-and-dangerous-chemicals

The Senate. (2017). Rural and Regional Affairs and Transport References Committee: Increasing use of so-called Flag of Convenience shipping in Australia (pp. 3-15). Canberra, ACT: Commonwealth of Australia

Thomson, R. (2020). Ship that delivered explosive material to Beirut Port was never supposed to stop there, says Captain. Retrieved 12 October 2020, https://www.cbc.ca/news/world/rhosus-ammonium-nitrate-beirut-Captain-1.5678444

Training and certification. International Maritime Organization. https://www.imo.org/en/OurWork/HumanElement/Pages/TrainingCertification-Default.aspx

THUONG, L. T. (1987). From Flags of Convenience to Captive Ship Registries. Transportation Journal, Vol. 27(No. 2), 22–24.

UNCTAD. (2018). International seaborne trade development in selected years (millions of tons loaded) [Image]. Retrieved 2 July 2022, from https://unctad.org/system/files/official-document/dtl2018d1_en.pdf.

UNCTAD. (2022). 50 Years of Review of Maritime Transport, 1968-2018: Reflecting on the past, exploring the future (p. 14). UN New York: United Nations. Retrieved from https://unctad.org/system/files/official-document/dtl2018d1_en.pdf

Van Fossen, A. (2016). Flags of Convenience and Global Capitalism. International Critical Thought, 6(3), 359-377. Doi: 1080/21598282.2016.1198001

VERA-RUIZ, E. (2020). The powerful explosions in Beirut and Tianjin: 5 years apart; both caused by improper storage of Hazardous Chemicals. Manila Bulletin. https://mb.com.ph/2020/08/06/the-powerful-explosions-in-beirut-and-tianjin-5-years-apart-both-caused-by-improper-storage-of-hazardous-chemicals/

Vogel, P. (1982). The Last Wave from Port Chicago, The Black Scholar, 13:2-3, pp.30-47, DOI: 10.1080/00064246.1982.11414238

Wang, C. (2015). A Reflection on the Tianjin Explosions. Toxic News. Retrieved 3 July 2022, from https://toxicnews.org/2019/05/28/a-reflection-on-the-tianjin-explosions-2/.

Wang, Q., Zhang, L., Wang, L., & Bu, L. (2023). A practical method for predicting and analyzing the consequences of ammonium nitrate explosion accidents adjacent to densely populated areas. Heliyon, 9(5). https://doi.org/10.1016/j.heliyon.2023.e15616

Watt, E., Coles, R. (2009). Ship Registration: Law and Practice (2nd ed., pp.1-46). London: Informa Law from Routledge.

What Went Wrong in the Sewol Ferry Disaster? (2019). The New Yorker. Retrieved January 9, 2024, from https://www.newyorker.com/video/watch/what-went-wrong-in-the-Sewol-ferry-disaster.

Whiteman, H. (2015). *Tianjin blasts: Another of China's "profound lessons."* CNN. https://edition.cnn.com/2015/08/17/asia/china-tianjin-industrial-accidents/index.html

Wilson, H. A., (1989). Organizational behavior and safety management in the construction industry. Construction Management and Economics Ed-7, p303-309

Wu, T.-C., Chen, C.-H., andamp; Li, C.-C. (2008). A correlation among safety leadership, safety climate and Safety Performance. Journal of Loss Prevention in the Process Industries, 21(3), 307–318. https://doi.org/10.1016/j.jlp.2007.11.001

Wu, Y., Fu, G., Wu, Z., Wang, Y., Xie, X., Han, M., and Lyu, Q. (2023). A popular systemic accident model in China: Theory and applications of 24model. *Safety Science*, *159*, 106013. https://doi.org/10.1016/j.ssci.2022.106013

Xia, N., Xie, Q., Griffin, M., Ye, G., and Yuan, J. (2020). Antecedents of safety behaviour in construction: A literature review and an integrated conceptual framework. Accident Analysis and Prevention, 148, 105834. https://doi.org/10.1016/j.aap.2020.105834

Xin, K., and Pelled, L. (2003). Supervisorâ€"subordinate conflict and perceptions of leadership behaviour: a field study. The Leadership Quarterly, 14(1), 25-40. https://doi.org/10.1016/s1048-9843(02)00185-6

Yang, Q., Tian, J., and Zhao, T. (2017). Safety is an emergent property: Illustrating functional resonance in air traffic management with formal verification. *Safety Science*, *93*, 162–177. https://doi.org/10.1016/j.ssci.2016.12.006

Yu, G., Duh, Y.-S., Yang, X., Li, Y., Chen, Y., Li, Y., Li, J., Chen, R., Gong, L., Yang, B., & Huang, J. (2022). Holistic case study on the explosion of ammonium nitrate in Tianjin port. Sustainability, 14(6), 3429. https://doi.org/10.3390/su14063429

Zenger, J., Folkman, J., and Edinger, s. (2009). The inspiring leader: Unlocking the secrets of how extraordinary leaders motivate. Retrieved 11 October 2021, from https://www.behavioural-safety.com/articles/effective_leadership_cooper_0215.pdf.

Zhang, L., Liu, Q., Wu, X., and Skibniewski, M. (2016). Perceiving Interactions on Construction Safety Behaviours: Workersâ€™ Perspective. Journal Of Management In Engineering, 32(5), 04016012. https://doi.org/10.1061/(asce)me.1943-5479.0000454

Zhang, Q., Wen, Y., Zhou, C., Long, H., Han, D., Zhang, F., and Xiao, C. (2019). Construction of Knowledge Graphs for Maritime Dangerous Goods. Sustainability, 11(10), 2849. https://doi.org/10.3390/su11102849

Zhang, S., and Wang, J. (2015). Analysis of south korea Sewol sunken ferry accident based on Behavioral Safety. *Journal of Coastal Research*, *73*, 611–613. https://doi.org/10.2112/si73-106.1

Zhang, W.-X., Gao, S.-T., Zhang, X.-N., Zhen, W.-F., Zhu, Wang, Y. N. (2015). Successful treatment of a severely injured victim from 8.12 Tianjin Port Explosion, China." Chinese Journal of Traumatology 18(6): 320-322.

Zhao, B. (2016). Facts and lessons related to the explosion accident in Tianjin Port, China. Natural Hazards 84, 707–713. https://doi.org/10.1007/s11069-016-2403-0

Zhou, L., Fu, G. and Xue, Y. (2018). Human and organizational factors in Chinese hazardous chemical accidents: a case study of the '8.12' Tianjin Port fire and explosion using the HFACS-HC, International Journal of Occupational Safety and Ergonomics, 24:3, 329-340, DOI: 10.1080/10803548.2017.1372943

Zhao, L., Qian, Y., Hu, Q.-M., Jiang, R., Li, M., and Wang, X. (2018). An analysis of hazardous chemical accidents in China between 2006 and 2017. *Sustainability*, *10*(8), 2935. https://doi.org/10.3390/su10082935

Zohar, D. (2002). Modifying supervisory practices to improve subunit safety: A leadership-based intervention model. Journal Of Applied Psychology, 87(1), 156-163. https://doi.org/10.1037/0021-9010.87.1.156