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The Human Element in Maritime Industry Safety: Modeling the Critical Success Factors

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Abstract

This thesis investigates the integration of human factors within the maritime industry, focusing on Critical Success Factors (CSFs) through a safety approach. Given the industry's increasing emphasis on safety and human performance, this study aims to identify and analyze key CSFs that enhance safety outcomes in maritime operations. Utilizing the Decision Making Trial and Evaluation Laboratory – DEMATEL – process, the research examines the cause-effect relationships among various critical success factors, based on insights from the maritime industry experts and seafarers. The findings highlight that enhanced training, leadership and teamwork, clear communication, safety culture, and crisis management are pivotal in improving safety performance. Managerial implications include the need for ongoing professional development, competence validation, and innovative training methods such as virtual and augmented reality simulations. Lastly, the study underscores the importance of incorporating crew feedback into safety policies and leveraging advanced technologies like artificial intelligence for predictive analytics.

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Chapter 1 - Introduction

The maritime industry is a keystone of global commerce, yet it is fraught with numerous safety challenges that must be meticulously managed. The dynamic and often unpredictable nature of the sea, combined with complex vessel operations, such as navigation, cargo handling, vessel maintenance and diverse cargo types, underscores the critical need for robust safety protocols. Safety in the maritime sector is not merely a regulatory requirement but a fundamental operational priority that ensures the protection of human life, the marine environment, and valuable assets (Hetherington et al., 2006). The importance of safety is magnified by the potential consequences of maritime accidents, which can result in catastrophic loss of life, significant environmental damage, and substantial economic costs (Chauvin et al., 2013). Therefore, the industry places a strong emphasis on comprehensive safety management systems that integrate rigorous training programs, regular safety drills, and continuous monitoring and evaluation of safety practices (Macrae, 2009). Human factors significantly impact maritime safety, with human error identified as a leading cause of accidents (Hetherington et al., 2006).

Safety in the maritime industry was mainly shaped by historical incidents and evolving regulatory frameworks aimed at mitigating risks and improving operational standards. The sinking of the Titanic in 1912, for instance, highlighted significant deficiencies in maritime safety practices, prompting the establishment of international regulations to enhance vessel safety and passenger protection, named International Convention for the Safety of Life at Sea (SOLAS) in 1914 (IMO, 2023). The Exxon Valdez oil spill in 1989, caused by the grounding of the oil tanker, led to the implementation of the Oil Pollution Act of 1990, enforcing stricter regulations on oil spill prevention and response (Miller, 1990). The Deepwater Horizon oil spill in 2010, the largest marine oil spill in history, led to reforms in offshore drilling regulations and a renewed focus on safety culture and risk management in the oil and gas industry (Boesch, 2010). Those are only a few examples of historical incidents that enhance safety awareness in the maritime industry. Over the decades, the International Maritime Organization (IMO) has emerged as a pivotal regulatory body, spearheading efforts to establish and enforce global standards through conventions such as the SOLAS convention, already mentioned, the Maritime Labour Convention (MLC) and the International Safety Management (ISM) Code (IMO, 2023; ILO, 2021).

These conventions mandate rigorous safety protocols onboard vessels, encompassing everything from structural integrity and fire safety to operational procedures and crew competency. Central to these protocols is the recognition of human factors—defined as the interaction between individuals, their behavior, and their environment—as critical determinants of safety outcomes in maritime operations (IMO, 2023)

Central to this regulatory landscape is the Total Marine Safety Assessment (TMSA), developed by the Oil Companies International Marine Forum (OCIMF). Initially introduced to assess and enhance safety management systems within the oil tanker industry, TMSA has evolved into a comprehensive framework applicable across various sectors of the maritime industry. Recently, TMSA has undergone significant updates to integrate a more holistic approach to safety management, placing increased emphasis on the human element. This shift acknowledges that human factors, including crew competence, fatigue management, and organizational culture, are critical determinants of operational success and safety (OCIMF, 2022).

In parallel, the Ship Inspection Report Programme (SIRE) 2.0 has been instrumental in complementing TMSA by providing detailed assessments of vessel operations and management practices. With its latest iteration, SIRE 2.0 now includes a more nuanced evaluation of human factors, aligning closely with TMSA's updated guidelines. These developments reflect a broader recognition within the industry of the need to systematically address human performance issues to improve safety outcomes and operational efficiencies (OCIMF, 2022).

Additionally, the Safety Management System (SMS) framework, as outlined by the IMO's ISM Code, remains a cornerstone for effective safety practices onboard vessels. SMS requires maritime companies to establish, implement, and maintain procedures that incorporate risk management and emphasize the human element. This systematic approach ensures that safety protocols not only comply with international standards but also actively involve crew members in identifying and mitigating risks (IMO, 2023).

As the maritime industry continues to navigate complex global challenges—from environmental sustainability to technological advancements—the integration of human factors into safety management systems remains a cornerstone for ensuring both regulatory compliance and operational efficiency. Understanding the intricacies of human behavior and its impact on safety outcomes is therefore essential for advancing maritime safety standards and fostering a culture of continuous improvement.

Over the years, numerous studies have concentrated on the human element and human factors concerning safety within the maritime industry. Prior research has identified several Critical Success Factors (CSFs) that significantly impact the effectiveness of safety standards, thereby fostering a safety culture among maritime personnel. However, this study's literature review revealed that existing research tends to analyze these CSFs in isolation, drawing from multiple case studies and historical accidents that underscore human factors in safety incidents. Among the reviewed studies, it became apparent that methodologies employed often include theoretical frameworks (Baumler et al., 2021; Coraddu et al., 2020) and case study analyses (Cheng et al., 2023; Lee and Chung, 2018; Chen, 2020). Furthermore, methods such as HFACS (Human Factors Analysis and Classification System), which focuses on analyzing human factors in maritime accidents (Hasanspahic et al., 2021; Yildirim et al., 2019; Wrobel et al. 2021), CREAM (Cognitive Reliability Error Analysis Method), used to assess human reliability in scenarios like abandonship (Aydin et al. 2021; Akhtar and Utne, 2014) , and SLIM (Success Likelihood Index Method), employed to evaluate human errors in diverse maritime contexts (Akyuz, 2016; Akyuz and Celik, 2018; Kayisoglu et al., 2022), were prevalent. Nevertheless, there remains a research gap concerning the interconnectedness of these CSFs, particularly in employing methodologies like DEMATEL (Decision Making Trial and Evaluation Laboratory). Therefore, there is a need for further research that explores the relationships among these Critical Success Factors comprehensively, utilizing advanced methodologies such as DEMATEL.

For this specific reason, this thesis aims to fill this gap by identifying and analyzing the cause-effect relationships among CSFs related to human factor under a safety approach and the maritime industry, using the DEMATEL methodology. The primary research question guiding this study is: "Which are the Critical Success Factors on the human element and how do they influence each other?". By doing so, the study seeks to determine the areas that require focused improvement to enhance overall safety and efficiency and provide actionable insights that can help maritime organizations prioritize their effort and resources effectively.

This thesis is structured into four main sections. Chapter 1 ("Introduction") the introduction sets the stage for the research by outlining the scope, objectives, and significance of investigating the Critical Success Factors (CSFs) influencing the human element within the maritime industry. Chapter 2 ("Literature Review") provides a comprehensive and systematic review of the literature on human factors in maritime safety, highlighting key theoretical frameworks and empirical studies. Chapter 3 ("Research Methodology" describes the DEMATEL methodology employed in this study, including data collection process. Chapter 4 ("Results and Research Discussion") discusses on detail the results, presents the empirical findings and their implications. This thesis offers conclusions drawn from the research, recommendations for industry practice and avenues for future research.

Chapter 2 - Literature review

This section explores the critical human success factors that ensure maritime safety by reviewing relevant literature. By synthesizing various studies, it aims to provide a comprehensive understanding of the essential elements that contribute to safe maritime operations. The analytical methodology used for the systematic literature review that was used will be described on Chapter 3 of this thesis.

1. Enhanced Training, Education, and Competence Validation

The importance of comprehensive training, education, and competence validation in maritime safety cannot be overstated. Effective training programs not only equip crew members with essential technical skills but also enhance their non-technical skills, ensuring a holistic approach to maritime operations. Akyuz (2016) underscores the necessity of both theoretical and practical training for maritime crew members. This includes specific training on sending distress messages and using control panels, as well as stress management courses before embarking on a ship. These measures aim to speed up processes during emergencies and ensure the crew is well-prepared to handle various operational challenges effectively.

Non-technical skills, such as communication, teamwork, situation awareness, and leadership, are integral to maritime safety. Hetherington et al. (2006) argue that deficiencies in these skills often lead to incidents. They advocate for Crew Resource Management (CRM) training, which encompasses these core non-technical skills. CRM training has proven effective in other industries, such as aviation, and is increasingly being adopted in maritime operations to enhance overall safety performance. Furthermore, the work by Ernstsen and Nazir (2018) on team communication skills reiterates that effective communication is a critical component of safety knowledge. Training programs should focus on improving these skills to enhance team performance and reduce human error in maritime operations.

Competence validation through regular assessments is crucial in maintaining high proficiency levels among crew members. Akyuz et al. (2018) suggest implementing structured checklists and interim audits to ensure that crew members consistently practice distress message procedures and other critical operations during drills. This approach helps in reinforcing theoretical knowledge through practical application, thereby reducing human error probabilities. With the increasing automation in maritime operations, there is a growing need for crew members to be adept at using sophisticated technological equipment. Alan and Söğüt (2020) emphasize the necessity of familiarizing officers with new technologies and integrating these systems into their training programs. This ensures that officers can effectively manage both normal and abnormal situations, leveraging the strengths of both human and automated systems.

Lin and Cheng (2021) highlight the administrative challenges in maritime education and training, particularly the disconnect between education departments and transportation management. They advocate for a unified training system that integrates educational resources to improve crew abilities and reduce maritime accidents. This approach not only streamlines the training process but also enhances the overall quality of maritime education. A robust safety culture is essential in maritime operations. Zaib et al. (2022) stress the importance of safety management and risk assessment training to foster better communication and safety practices among crew members. Proper monitoring of these measures can significantly minimize the loss of cargo, ships, and lives, thereby promoting a culture of safety and vigilance.

The use of simulators for training is increasingly recognized as an effective method to enhance maritime safety. Simulators can replicate complex ship operations, allowing crew members to gain practical experience in a controlled environment. This method is particularly beneficial for training in bunkering operations, as it helps in eliminating human errors through realistic practice scenarios (Kayisoglu et al., 2022). Continuous professional development is vital for adapting to the evolving demands of maritime operations. Uğurlu et al. (2015) suggest that competency training should include team management, communication, effective use of navigation equipment, and risk assessment. Regular training updates and refresher courses ensure that crew members stay proficient in the latest safety practices and technological advancements.

The findings by Tore Relling et al. (2020) on the importance of experience highlight how nautical and VTS (Vessel Traffic Service) experience influences the ability of operators to handle complex situations. Experienced operators develop a mental maritime picture that aids in timely and effective decision-making. This underscores the need for targeted training programs that enhance both technical and non-technical skills through practical exposure and experience-sharing. Moreover, the study by Fan and Yang (2023) on the dynamic human-machine system highlights the evolving nature of maritime operations. They stress the importance of seafarer competencies in interacting with advanced technological systems, suggesting that training programs must be updated to include these new competencies to ensure effective human-machine interactions.

Chen (2020) identifies common latent conditions causing maritime accidents, such as lack of ECDIS (Electronic Chart Display and Information System) training and the absence of man overboard training. These deficiencies underscore the need for comprehensive training programs that address both standard and emergency procedures. Macrae (2009) further emphasizes that training should enable crew members to recognize and respond swiftly to failure modes and unsafe acts, enhancing overall maritime safety. In addition, the research by Gundić et al. (2021) shows that the rapid development of technology necessitates continuous professional development programs. Formal education often cannot keep pace with technological advancements, making additional education programs essential for acquiring new competencies. These programs should focus not only on professional skills but also on generic competences that reduce the impact of human factors on maritime accidents.

Lastly, Vinagre-Ríos and Iglesias-Baniela (2013) discuss the concept of risk homeostasis, where improvements in technology and crew qualifications can lead to more efficient risk management but also a perceived acceptable level of risk, potentially maintaining accident rates. This highlights the importance of a balanced approach to training and technology implementation.

2. Safety Culture

The cultivation of a robust safety culture within the maritime industry is essential to ensure that safety is prioritized above all else and that individuals feel a collective responsibility for their safety and that of their peers. The International Maritime Organization (IMO) highlighted the necessity of a safety culture for safer shipping, emphasizing that such a culture is critical for maritime operations (Hetherington et al., 2006).

In the maritime industry, Bridge Resource Management (BRM) is a critical component of safety culture, focusing on situational awareness and decision-making. Failures in BRM, such as incorrect instructions and insufficient manning, often lead to accidents like groundings, underscoring the importance of comprehensive training and adherence to BRM principles (Alan & Söğüt, 2020). Additionally, Alan and Söğüt (2020) emphasize the dangers of over-reliance on a single system, advocating for the correct use of all available information sources to maintain ship safety.

The management system, including shore and onboard management, plays a significant role in influencing human factors related to maritime safety. Ineffective supervision and inadequate safety culture are often linked to dangerous behaviors and accidents such as collisions and groundings (Fan et al., 2020). Regular training and certification of inspectors are crucial to maintaining maritime seaworthiness and ensuring competent inspection practices (Lin & Cheng, 2021). This is particularly important given that non-compliance with certified systems and infrequent inspections can lead to increased risks (Kasyk et al., 2023).

Developing safety checklists that include all identified risks and potential hazards is another key strategy to enhance safety culture. Continuous monitoring and implementation of these checklists by both onboard personnel and shore-based supervisors can ensure that safety measures are consistently applied (Qiao et al., 2020). Moreover, the analysis of human and organizational factors in maritime accidents underscores the importance of improving situation awareness, reducing attention deficits, and enhancing knowledge through targeted training programs (Chauvin et al., 2013). The dynamic network-based approach proposed by Adumene et al. (2022) offers a framework for understanding how human factors contribute to maritime accidents and how these interactions can be monitored and managed to improve safety outcomes.

The establishment of a common mental model and effective communication through resource management training and drills is vital for maintaining safety during navigation and operational tasks (Yıldırım et al., 2019). Additionally, ensuring adequate manning levels and appropriate work-rest hours can mitigate fatigue-related human errors, which are a major concern for maritime safety (Uğurlu et al., 2015). The integration of prescriptive and descriptive procedures in Vessel Traffic Service (VTS) operations allows operators to apply expert judgment while having clear criteria for action, thus enhancing safety measures (Relling et al., 2020). High levels of health and safety awareness among maritime personnel, supported by adequate training and resources, further contribute to a positive safety culture (Corrigan et al., 2019).

Safety climate, a subset of safety culture, serves as a snapshot of an organization’s safety culture at a specific point in time, reflecting employees' attitudes and perceptions towards safety (Hetherington et al., 2006). Research indicates that a strong safety climate can predict safety performance, with management values and practices significantly influencing this climate. Studies by Griffin and Neal (2000) propose that the antecedents of safety climate, such as management commitment to safety, translate into improved safety performance through enhanced worker knowledge, skills, and motivation.

A strong organizational safety climate can also mitigate the pressures faced by maritime crews due to commercial demands, such as the immediate completion of fuel operations. Uflaz et al. (2022) highlight the necessity of rigorously applying standard checklists and reviewing them at specified intervals to ensure safety compliance. The development of trust in autonomous systems, achieved through common regulatory frameworks and shared expectations, is essential for future maritime operations. This trust is built on awareness and understanding of the systems and their decision-making processes, as discussed by Mallam et al. (2020).

3. Use of Technology

The integration of technology in maritime operations is pivotal for enhancing safety and reducing human errors. While human factors remain crucial, leveraging modern technology such as navigation aids, safety equipment, and communication tools significantly assists in maintaining safety. The maritime industry has witnessed a cultural shift towards increased automation, particularly in navigation systems, in response to reduced manning levels (Hetherington et al., 2006). This shift has altered the role of seafarers, introducing new attentional demands as operators must track numerous systems and their operational modes, a concept termed "mode awareness" (Sarter & Woods, 1995). However, this increased reliance on automation can lead to cognitive complacency, where operators may overly trust automated systems and overlook critical errors, as evidenced by the Royal Majesty grounding incident (Lützhöft & Dekker, 2002).

Maritime Autonomous Surface Ships (MASS) represent a significant advancement in reducing human error by shifting operational control from onboard to shore-based centers, thereby decreasing the direct involvement of seafarers in navigation tasks (Liu et al., 2021). This evolution progresses through stages of enhanced, assisted, remote, and fully autonomous navigation, gradually reducing the human element in operational processes. Nevertheless, remote operations do not eliminate human factors entirely; operators still need to maintain situational awareness and effectively control vessels from shore control centers, which introduces challenges such as communication latency and increased workload (Mallam et al., 2020).

Furthermore, autonomous ship operations present new dimensions of trust and interaction between human operators and automated systems. Trust in these systems is built on their predictability and reliability, though adaptive algorithms can sometimes lead to unexpected responses, known as "automation surprises" (Sarter et al., 1997). Ensuring seafarers are familiar with the capabilities and limitations of these systems is essential for maintaining trust and effective operation (Mallam et al., 2020).

The use of additional innovative technologies like drones and the Internet of Things (IoT) can further enhance maritime safety. Drones can conduct surveys in hazardous environments, reducing the need for seafarers to enter dangerous spaces, while IoT can continuously monitor atmospheric conditions in enclosed spaces, thereby reducing associated risks (Soner & Celik, 2020). These technologies also facilitate the development of electronic permitting systems that automate safety checks and approvals, minimizing human error in complex procedures.

Other advanced technologies like Electronic Chart Display and Information System (ECDIS) have also become essential for ensuring navigational safety. The STCW 2010 Manila Amendments emphasize the importance of ECDIS training for watchkeeping officers to prevent errors related to position-fixing, chart use, and route selection (Uğurlu et al., 2015). ECDIS integrates crucial navigational information on a single screen, enhancing the bridge team's ability to interpret and respond to current circumstances effectively.

The design and functionality of ship bridge systems also play a crucial role in enhancing safety. Modern bridge designs incorporate high-definition monitors, adjustable consoles, and centralized information displays to improve operator focus and efficiency (Alan & Söğüt, 2020). Additionally, adaptive systems allow for task-specific configurations, such as emergency maneuvers or harbor operations, further aiding operators in maintaining safety under varying conditions.

However, the introduction of new technologies also necessitates comprehensive training and familiarization to ensure that operators can effectively utilize these systems. For instance, in the context of pilotage operations, the complexity and multitasking requirements demand high levels of skill and concentration from maritime pilots (Oraith et al., 2021). To mitigate errors, it is crucial to provide targeted training and develop countermeasures that address identified causal factors.

4. Comprehensive Fatigue and Well-being Management

Proper fatigue and well-being management in the maritime industry is crucial for ensuring the crew's alertness and overall safety. Research has demonstrated that fatigue can lead to poor health and diminished performance, contributing to maritime accidents. The Exxon Valdez grounding incident in 1989, where the watchkeeper had only 5-6 hours of sleep in the 24 hours prior, exemplifies how fatigue can result in catastrophic outcomes (Hetherington et al., 2006). Despite regulatory efforts, such as the IMO's work-rest mandates, instances where crew members must work extended hours remain prevalent, exacerbating fatigue (NTSB, 1990; Raby & McCallum, 1997).

The demanding conditions of modern seafaring—shorter sea passages, higher traffic levels, reduced manning, and rapid turnarounds—intensify the risk of fatigue. Studies have shown that extended hours on duty and high workloads are significant contributors to marine accidents attributable to fatigue (Raby & McCallum, 1997). For instance, Australian seafarers reported poor sleep quality, with 70% indicating poor to very poor sleep (Parker et al., 2002). Furthermore, research indicates that fatigue-related accidents are more common at the beginning of a tour, in the first four hours of a shift, and in calm conditions (Smith, 2001; Smith et al., 2003).

The impact of fatigue is not limited to performance but extends to broader health issues. Studies have shown that seafarers experience higher levels of stress compared to other occupational groups, with significant health implications. For example, Australian seafarers reported high levels of stress and poor health behaviors, such as excessive alcohol consumption and smoking, which further exacerbate fatigue and health issues (Parker et al., 2002; Cooper et al., 2001). Additionally, cultural and linguistic incompatibilities among multicultural crews can lead to increased stress and fatigue, affecting overall performance (Corović & Djurović, 2013).

In addition to stress, physical factors such as noise, vibration, and harsh environmental conditions can significantly impact fatigue levels. These factors contribute to poor sleep quality and increased workload, further complicating the management of fatigue (Endrina et al., 2019). Effective fatigue management must consider these environmental factors and implement strategies to mitigate their impact.

Maintaining adequate manning levels is crucial for effective fatigue management. Inadequate manning increases the likelihood of fatigue, as crew members are unable to get sufficient rest and must work longer hours. Research suggests that improving manning levels can significantly reduce the probability of fatigue and associated accidents (Akhtar & Utne, 2014). Additionally, ensuring regular meals, sufficient sleep, reduced administrative tasks, and adequate rest periods are essential measures for managing fatigue (Akhtar & Utne, 2014).

Stress management is also a vital component of comprehensive well-being management. Chronic stress can lead to negative mental and physical health outcomes, reducing overall performance and safety (Quick et al., 1997). Implementing stress management programs, promoting a positive safety climate, and fostering good communication among crew members can help mitigate the effects of stress (Mednikarov, Lutzkanova, & Vaptsarov, 2021).

Effective communication is another critical factor in managing fatigue and ensuring safety. Poor communication can lead to misunderstandings and errors, particularly in high-stress situations. Ensuring clear communication and proper coordination among crew members can help prevent accidents related to fatigue and stress (Akhtar & Utne, 2015).

5. Leadership and Teamwork

Leadership and teamwork are crucial for ensuring a safe working environment on ships, as emphasized by numerous studies. Effective teamwork and strong leadership from ship officers are integral to maritime safety, promoting coordination and cooperation among crew members and fostering a culture of safety.

Leadership on board, especially by the chief officer, is pivotal in ensuring that crew members adhere to protocols, rules, and regulations safely. Effective supervision, regular monitoring of cargo operations, and proper task allocation are essential to prevent misunderstandings and mishaps. For instance, during loading operations on tanker ships, supervision is critical to avoid environmental risks like oil or chemical spills (Aydin et al., 2021). Similarly, during LNG bunkering operations, the assignment of specific roles and responsibilities, along with continuous monitoring, ensures the operation's safety (Uflaz et al., 2022).

Leadership in maritime operations extends beyond the ship to include supervisors located ashore, who provide orders and resources to the master. However, accidents often highlight unsafe supervision linked to inappropriate planning and decision-making by the master, emphasizing the need for adherence to safety management systems and proper motivation of crew members (Chauvin et al., 2013).

Research has demonstrated the significant role of teamwork in maritime safety. In a study conducted by the Canadian Transportation Safety Board (CTSB), it was found that a high percentage of maritime professionals, including 96% of masters, 100% of bridge officers, and 85% of pilots, recognized the importance of teamwork alongside technical proficiency. However, only a smaller portion, 51% of masters, 46% of bridge officers, and 38% of pilots, reported that they always worked as a cohesive team. This disparity highlights the need for improved teamwork practices, particularly among pilots, to establish effective working relationships with the master and officers of the watch (Hetherington et al., 2006).

Effective teamwork is particularly important during high-risk operations such as mooring and pilotage. Cooperation between pilots, ship's crew, and assisting parties is crucial for maintaining situational awareness and executing maneuvers safely, especially in challenging conditions like poor visibility (Oraith et al., 2021). The interaction between different maritime professionals, such as pilots, bridge teams, and tugboat masters, should be seamless to ensure safe navigation and port operations (Abreu et al., 2022).

In vessel traffic services (VTS), cooperation among operators is essential for handling complex situations. VTS operators work in a shift setup, and their cooperation is critical, especially during high-stress periods. Experienced operators are paired with less experienced ones to standardize operations and facilitate knowledge sharing. The ability to call in extra operators during crises further underscores the importance of teamwork in maintaining maritime safety (Relling et al., 2020).

Trust is a critical component of leadership and teamwork in maritime operations. The development of trust in autonomous systems and among human operators is essential for the successful integration of technology in shipping. Trust in operations and decisions made by autonomous systems is necessary as human operators move away from direct control, requiring confidence in both human and technological systems to operate effectively in shared environments (Mallam et al., 2020).

Cultural differences also play a role in the effectiveness of leadership and teamwork on ships. Studies have shown that national culture influences human failures in shipping operations, with different perceptions of cultural dimensions among seafarers from various countries. Understanding these cultural dynamics is vital for improving teamwork and reducing human errors (Lua et al., 2012). Additionally, the management of multicultural crews is essential for maintaining long-term stability in relationships among crew members, with the ship's master needing to effectively manage cultural and linguistic diversity (Corović & Djurović, 2013).

6. Clear Communication

Effective communication among crew members and between the ship and shore is critical for safe operations and emergency situations in maritime environments. Research indicates that communication influences team situational awareness, teamwork, and decision-making, which are central to safe and efficient maritime operations.

In the maritime industry, there exists an essential teamwork relationship between the officer of the watch (OOW), master, and pilot, particularly in high-risk areas such as pilotage waters. A study by the Canadian Transportation and Safety Board (CTSB) reviewed 273 incidents and found that 42% involved misunderstandings or lack of communication between the pilot, master, and OOW. This highlights the need for clear communication protocols to prevent accidents. Subsequent surveys by the CTSB revealed that while a majority of pilots believed they ensured their orders were understood, a significant portion of Masters and OOWs disagreed, indicating discrepancies in communication perceptions (Hetherington et al., 2006).

Therefore, miscommunications can arise from inadequate environmental and operational information sharing. Zaib, Yin, and Khan (2022) suggest that crew members should be briefed on environmental conditions and verify information from third parties to prevent accidents. Effective pilotage depends on clear communication among the pilot, bridge team, and external parties, such as Vessel Traffic Service (VTS) operators. Remote operations introduce additional communication challenges, including latency and the need for updated data transmission via sensors and satellite communications. Effective decision-making in these contexts requires overcoming these barriers to maintain a clear sense of the ship's status (Corović & Djurović, 2013).

Language barriers are a significant challenge in the maritime industry, which is characterized by multinational crews. Poor communication and insufficient English language skills can lead to misunderstandings, impacting the safety of berthing and navigation operations (Oraith et al., 2021). The Seafarers International Research Centre (SIRC) found that communication difficulties were a primary drawback of mixed nationality crews, often leading to hazardous situations. This issue is exacerbated in emergency situations where cognitive demands are high. The loss of the M/V Green Lily, where cultural and language issues were implicated, underscores the critical role of clear communication in maintaining safety (Hetherington et al., 2006).

Standardized communication protocols, such as the International Maritime Organization's (IMO) Standard Marine Communication Phrases (SMCP), are designed to reduce language barriers and misunderstandings. However, their implementation varies, and challenges remain in ensuring consistent use of standardized terms and phrases. VTS operators emphasize the need for short, concise, and correct communication, using message markers to clarify intentions and instructions. Variations in communication practices among operators, influenced by their backgrounds and experiences, highlight the need for continuous training and adherence to standardized protocols (Relling et al., 2020).

In this respect, closed-loop communication, where instructions are confirmed and acknowledged, is crucial. Failures in communication, such as the absence of mutual performance monitoring and insufficient task allocation, can lead to increased workloads and accidents. Effective communication requires briefing and discussion of roles and responsibilities, particularly during handovers and critical operations (Chauvin et al., 2013).

The effectiveness of communication systems within port authorities also requires improvement. Safety messages need to be effectively filtered and tailored to operational needs, ensuring that all staff, including those less comfortable with IT, receive critical information. Consistent feedback from incident reports is essential to maintain a robust safety culture (Corrigan et al., 2019).

7. Decision-making Skills

Decision-making skills are critical in maritime safety, particularly under pressure, as they ensure crew members make the best choices in critical situations. Effective decision-making in emergencies, such as collisions, groundings, and fires, can significantly minimize hazards and prevent loss of life.

Improper decision-making has been identified as a contributing factor in several maritime accidents. For example, in the Thames accident, the third officer's decision to alter course for collision avoidance failed to consider the restricted waters. In Busan, the pilot's improper selection of the ARPA radar mode led to a collision. These incidents underline the importance of proper decision-making systems like Bridge Resource Management (BRM) and Engine Room Management (ERM), which could prevent such human error-related accidents (Chen, 2020).

Research highlights the importance of training crew members in decision-making during emergency procedures, such as abandoning ship. The use of simulation and virtual environments nowadays are considered important methods to support decision-making during emergencies, i.e. flooding. Park et al. (2015) and Wang et al. (2014) utilized computer simulations to validate passenger ship evacuation scenarios, providing substantial decision support for ship officers. The Safety of Life at Sea (SOLAS) convention mandates monthly abandon ship drills to ensure crew preparedness for evacuation, emphasizing the need for practical training to prevent tragedies during real emergencies (Akyuz, 2016).

With the advent of autonomous ships, human interference in operations is reduced, but human error recognition and prevention remain crucial for safe operations. Human elements play a pivotal role in the software development of autonomous ships. Algorithms and decision-making procedures must be thoroughly tested under normal and exceptional conditions to ensure reliable operations. This comprehensive testing ensures that autonomous systems can handle surprising situations effectively (Ahvenjärvi, 2016). Task Analysis (TA) and the cognitive model IDAC help identify tasks and potential failures in cognitive phases such as information gathering, decision, and action. This analysis is vital for designing Human-Machine Interfaces (HMI), shore control centers (SCC), and operational procedures that ensure operators can effectively supervise and respond to potential collisions (Ramos, Utne, & Mosleh, 2019). Trust in SCCs is a significant human factor. Operators must trust sensor information while avoiding skill degradation due to over-reliance on automation. Decision-making and teamwork are crucial in monitoring and controlling vessels remotely. High levels of trust over extended periods can negatively impact operators' skills, emphasizing the need for balanced training and regular practice (Kari & Steinert, 2020).

The collision avoidance model based on human fast-slow thinking frameworks combines rules and seamanship with analytical adjustments using social force models. This approach transforms human cognition into machine decision-making guidance, providing new solutions for collision avoidance in complex scenarios involving multiple ships. This model enhances practical efficiency and supports human-machine cooperation in intelligent ships (Lia, Pengb, & Zhengc, 2023).

8. Crisis Management and Emergency Preparedness

Crisis management and emergency preparedness are critical components of maritime safety, ensuring that crew members can respond effectively to incidents such as fires, collisions, groundings, and flooding. Preparedness through structured response mechanisms and regular drills can significantly mitigate the impact of such incidents.

The importance of comprehensive emergency planning, including both internal and external plans, cannot be overstated. Effective emergency plans encompass task distributions, alarm systems, communication channels, training, and awareness of potential dangers, such as those posed by LNG bunkering processes. High Human Error Probability (HEP) in these processes underscores the need for thorough review and implementation of safety checklists and information exchange (Uflaz et al., 2022).

Human resilience and adaptability are strengths in crisis situations, though they can also present challenges. Unlike autonomous systems, which lack the ability to adapt to unforeseen situations, human deck officers can leverage creativity and experience to manage emergencies. Thus, building resilience into autonomous ship control systems is essential for future marine transportation safety (Ahvenjärvi, 2016).

Studies on human factors influencing ship operators' perceived risk highlight the critical role of decision-making under pressure. For example, simulations measuring heart rate variability in ship operators demonstrate that perceived collision risk (PCR) increases significantly in crossing situations compared to head-on encounters. Such insights help identify key risk factors and inform strategies to improve marine navigation safety (Kim, 2020). The integration of human factors into ship collision risk models emphasizes the need for collision avoidance systems with intelligent decision-making capabilities. These systems, designed using Human-Centered Design frameworks, ensure usability and effectiveness in critical situations where time and distance to collision are limited (Sotiralis et al., 2016).

The OODA Loop theory (Observe, Orient, Decide, Act) contextualizes the time factor in decision-making. In emergencies, the decision time can vary from fractions of a second to several minutes, requiring rapid adaptation and maximum use of professional potential. This theory underscores the need for dynamic and responsive crisis management strategies to maintain safety under varying conditions (Mednikarov et al., 2021).

Evacuation analysis plays a crucial role in the ship design stage. The development of intelligent evacuation models, like IMEX, integrates human behavior and dynamics models to address complex configurations and motions of ships during emergencies. This model improves upon static calculations outlined by the International Maritime Organization (IMO) by incorporating physical interactions between evacuees and providing mechanisms to evaluate evacuation procedures (Park et al., 2004). Regular practice of emergency procedures, such as abandon ship drills mandated by the Safety of Life at Sea (SOLAS) convention, ensures crew readiness and minimizes hazards arising from human errors during actual emergencies (Akyuz, 2016).

Simulation-based studies, such as Park et al. (2015) and Wang et al. (2014) validated passenger ship evacuation scenarios through simulations, providing essential decision support for ship officers in charge of evacuation (Akyuz, 2016).

9. Feedback Mechanisms

Feedback mechanisms are crucial for maritime safety, providing a structured system for crew members to report near-misses, concerns, or suggestions for safety improvements. These mechanisms enable the identification and rectification of potential hazards, enhancing overall safety and operational efficiency.

Effective feedback systems begin with proper supervision and control mechanisms on board. The chief officer plays a pivotal role in coordinating the crew and ensuring adherence to protocols, rules, and regulations. A feedback loop is essential for observing duties, providing proper feedback, and allocating tasks appropriately to prevent undesired events (Aydin et al., 2021). Proper supervision can prevent misunderstandings and mishaps, particularly during complex operations such as cargo handling on oil/chemical tanker ships.

A robust reporting culture is fundamental to the success of feedback mechanisms. Research indicates that a positive response to incident reporting systems exists, with a significant majority agreeing that they have a good system for reporting incidents and that reported incidents are handled promptly. However, issues remain, such as a lack of trust in the reporting process and fear of repercussions, which can hinder effective reporting. Some staff members feel that their concerns are not adequately addressed, and corrective actions are not always communicated, indicating a need for improved communication channels to facilitate a necessary feedback loop (Corrigan et al., 2019).

The importance of including both shore management and shipboard crews in the feedback process cannot be overstated. Inadequate or inapplicable check-lists and procedures should be reported to the company by seafarers, with shore management responsible for creating ship-specific corrective documents. This collaborative approach can significantly reduce causal factors contributing to marine accidents, improving overall safety (Hasanspahic et al., 2021).

In the context of autonomous ships, the human element in remote control centers mirrors the role on manned ship bridges. User-centered design of the Human-Machine Interface (HMI) in these centers is critical to minimize user errors and maximize safety. Audible feedback can enhance the monitoring process carried out by operators, providing an additional layer of safety and ensuring timely responses to potential issues (Ahvenjärvi, 2016).

Moreover, fostering a culture of reporting and feedback is essential. Although a positive incident reporting system is often in place, the perception and utilization of these systems vary across management, supervisors, and operational staff. There is often a disparity in the belief that reported incidents will receive feedback, with management generally having a more optimistic view compared to operational staff. This highlights the importance of building trust and ensuring transparent communication throughout all levels of the organization (Corrigan et al., 2019).

10. Regulatory Compliance

Regulatory compliance in the maritime industry is crucial for ensuring standardized safety practices and mitigating risks associated with maritime operations. Adherence to international and local regulations, particularly those set by the International Maritime Organization (IMO), plays a significant role in maintaining high safety standards and promoting a culture of safety across the maritime sector.

The effectiveness and implementation of maritime laws and regulations are essential for controlling the behaviors of seafarers and maritime companies. Qiao et al. (2020) highlight that the safety standards for ships operating in domestic waters are often lower than those for ocean-going vessels. To address this disparity, the effectiveness of laws and regulations should be continuously assessed against their intended safety objectives. This includes evaluating the safety management levels of maritime companies to ensure they meet the required standards and contribute to overall maritime safety.

Furthermore, the role of Vessel Traffic Service (VTS) operators is particularly significant in ensuring regulatory compliance and managing complex traffic situations. They rely on multiple sources of information, including radar data, departure schedules, and CCTV footage, to create a comprehensive traffic picture and make informed decisions to maintain safe and efficient traffic flow in regulated areas. The operators also establish informal regulations, such as prioritizing passenger vessels, to manage traffic effectively. This practice, although not formally codified, reflects the adaptive measures taken by operators to enhance safety and efficiency in real-time traffic management (Relling et al., 2020).

11. Ethical Practices

Ensuring ethical practices on board ships, such as fair treatment, absence of harassment, and promotion of ethical behavior, is essential for a positive work environment and maritime safety. Managing multicultural human resources is crucial for achieving these objectives. Progoulaki and Theotokas (2016) propose a framework integrating Resource-Based View (RBV), strategic Human Resource Management (HRM), and cultural diversity management, thus providing a comprehensive approach to managing maritime human resources ethically and effectively.

The framework includes strategies such as developing cross-cultural competencies through training and using mediators or support groups. These measures enhance ethical treatment by reducing misunderstandings, fostering mutual respect, and providing safe platforms for reporting issues. Surveys among European maritime companies show a growing interest in progressive management practices, although widespread implementation remains limited (Sadjadi and Perkins, 2010). Nevertheless, the evolution of Integrated Management Systems in shipping towards achieving total quality management and corporate social responsibility goals underscores the importance of managing multicultural crews effectively.

On the following table a summary of the literature review and relevant brief description of Critical Success Factors is presented:

1. Enhanced Training, Education, and Competence Validation Enhanced training, education, and competence validation are critical success factors for maritime safety. Integrating theoretical knowledge with practical application, focusing on non-technical skills, and using advanced training methods such as simulations can significantly reduce human errors and enhance overall safety. Continuous assessment and professional development ensure that crew members remain competent and capable of handling the dynamic challenges of maritime operations. The collective insights from various studies underscore the importance of a comprehensive, well-structured training and education system in promoting maritime safety.	Akyuz (2016), Hetherington et al. (2006), Akyuz et al. (2018), Alan & Söğüt (2020), Lin & Cheng (2021), Zaib et al.(2022), Kayisoglu et al. (2022), Uğurlu et al. (2015), Tore Relling et al. (2020), Fan & Yang (2023), Chen (2020), Macrae (2009), Gundić et al. (2021), Vinagre-Ríos & Iglesias-Baniela (2013), Ernstsen & Nazir (2018)
2. Safety Culture Cultivating a strong safety culture in the maritime industry involves a multifaceted approach that includes effective management practices, comprehensive training programs, adherence to regulatory frameworks, and continuous monitoring and improvement of safety measures. By fostering a culture where safety is paramount and individuals are collectively responsible, the maritime industry can significantly reduce the occurrence of accidents and enhance overall safety.	Hetherington et al. (2006), Alan & Söğüt (2020), Fan et al. (2020), Lin & Cheng (2021), Kasyk et al. (2023), Qiao et al. (2020), Chauvin et al. (2013), Adumene et al. (2022), Yıldırım et al. (2019), Uğurlu et al. (2015), Relling et al. (2020), Corrigan et al. (2019), Griffin & Neal (2000), Uflaz et al. (2022), Mallam et al. (2020)
3. Use of Technology While human factors remain critical, the strategic use of technology in maritime operations significantly enhances safety and reduces human errors. Technologies like ECDIS, autonomous navigation systems, and IoT, along with proper training and familiarization, equip seafarers with the tools needed to maintain safety in increasingly automated environments. The ongoing development and integration of these technologies, combined with a focus on human factors, create a robust framework for improving maritime safety.	Hetherington et al. (2006), Sarter & Woods (1995), Lützhöft & Dekker (2002), Liu et al. (2021), Mallam et al. (2020), Sarter et al. (1997), Soner & Celik (2020), Uğurlu et al. (2015), Alan & Söğüt (2020), Oraith et al. (2021)
4. Comprehensive Fatigue and Well-being Management Comprehensive fatigue and well-being management in the maritime industry requires a multifaceted approach that includes adherence to work-rest hours, stress management, adequate manning levels, and effective communication. Addressing both physical and mental well-being is essential to prevent accidents and ensure the safety of the crew. Implementing these strategies can help mitigate the impact of fatigue and promote a safer working environment for seafarers.	Hetherington et al. (2006), NTSB (1990), Raby & McCallum (1997), Parker et al. (2002), Smith (2001), Smith et al. (2003), Cooper et al. (2001), Corović, Djurović (2013), Endrina et al. (2019), Akhtar & Utne (2014), Quick et al. (1997), Mednikarov et al. (2021), Akhtar & Utne (2015)
5. Leadership and Teamwork Strong leadership and effective teamwork are fundamental to promoting a safe working environment in maritime operations. The integration of trust, cultural awareness, and cooperation among maritime professionals enhances safety and operational efficiency, ultimately reducing the risk of accidents and ensuring the well-being of the crew.	Aydin et al. (2021), Uflaz et al. (2022), Chauvin et al. (2013), Hetherington et al. (2006), Oraith et al. (2021), Abreu et al. (2022), Relling et al. (2020), Mallam et al. (2020), Lua et al. (2012), Corović & Djurović (2013)
6. Clear Communication Clear communication is a fundamental human critical success factor for maritime safety. Overcoming language barriers, ensuring closed-loop communication, and adhering to	Hetherington et al. (2006), Zaib, Yin, & Khan (2022), Corović & Djurović (2013), Oraith et al. (2021), Relling et al. (2020), Chauvin et al. (2013), Corrigan et al. (2019)

standardized communication protocols are essential strategies to enhance safety and operational efficiency in maritime contexts.	
7. Decision-making Skills Training crew members in decision-making under pressure is essential for maritime safety. Practical training, simulation, and comprehensive testing of autonomous systems contribute to effective decision-making. Trust in automation, balanced with regular practice and proper decision-making frameworks, ensures that crew members can make informed and effective decisions in critical situations.	Chen (2020), Park et al. (2015), Wang et al. (2014), Akyuz (2016), Ahvenjärvi (2016), Ramos, Utne, & Mosleh (2019), Kari & Steinert (2020), Lia, Pengb, & Zhengc (2023)
8. Crisis Management and Emergency Preparedness Crisis management and emergency preparedness in maritime operations rely on structured response mechanisms, regular drills, and the integration of human factors into safety models. Ensuring crew readiness through continuous training and practice, coupled with advanced simulation tools and intelligent decision-making systems, is vital for mitigating the impact of maritime emergencies and enhancing overall safety.	Uflaz et al. (2022), Ahvenjärvi (2016), Kim (2020), Sotiralis et al. (2016), Mednikarov et al. (2021), Park et al. (2004), Hu et al. (2013), Park et al. (2015), Wang et al. (2014), Akyuz (2016)
9. Feedback Mechanisms Feedback mechanisms are vital for maintaining and improving maritime safety. By encouraging a robust reporting culture, ensuring proper supervision, and facilitating clear communication channels, maritime organizations can effectively mitigate risks and enhance safety. This approach not only addresses immediate safety concerns but also fosters an environment of continuous improvement and proactive safety management.	Aydin et al. (2021), Corrigan et al. (2019), Hasanspahic et al. (2021), Ahvenjärvi (2016)
10. Regulatory Compliance Regulatory compliance in maritime safety involves a multifaceted approach that includes continuous assessment and improvement of laws and regulations, effective traffic management systems, and the integration of regulatory information into navigational aids. Ensuring that seafarers are aware of and adhere to these regulations is paramount for achieving a standardized safety approach and minimizing the risks associated with maritime operations.	Qiao et al. (2020), Relling et al. (2020)
11. Ethical Practices The strategic management of multicultural maritime human resources can significantly contribute to ethical practices on board ships. By fostering fair treatment, eliminating harassment, and promoting ethical behavior, maritime companies can enhance the overall safety and well-being of their crew members.	Progoulaki and Theotokas (2016), Sadjadi and Perkins (2010)

Chapter 3 - Research Methodology

In this thesis and research the method that was chosen to analyze the results is Decision-Making Trial and Evaluation Laboratory (DEMATEL), originated from the Battelle Memorial Institute (Wu and Lee, 2007) . The DEMATEL method can be used to visually present the causal relationship and influence strength between factors. Particularly, the DEMATEL method could divide the contributing factors into the cause and effect group, in addition, the important aspect which distinguishes the DEMATEL method from other approaches is the ability to provide decision-makers with more valuable information, such as the influencing degree, influenced degree, centrality and causality of contributing factors hidden in the human element.

The following steps outline the DEMATEL method applied in this research (Fontela and Gabus 1976, Tzeng et al. 2007).:

1. Problem Definition and Factor Identification

In this thesis, the objective is to understand the causal relationships among factors influencing the human element in the maritime industry, by identifying the Critical Success factors (CSFs).

To begin with, a database associated with Critical Success Factors of the human element was built in order to illustrate the proposed methodology. The Critical Success Factors contributing to the human element into the maritime industry, through a safety approach, were identified through the systematic literature review that was performed, as described above. This entailed an initial search of articles within the "Web of Science Core Collection" database, utilizing specific keywords structured as follows:

1. Title: "Human"
2. All fields: "Ship" or "Shipping" or "Maritime" or "Marine"
3. All fields: "Safe" or "Safety"

This search yielded 956 results, of which 950 were in the English language. Subsequently, the gathered articles underwent an initial screening process based on their titles and relevant abstract descriptions. Each article was assigned a rating: 2 for those closely aligned with the thesis objectives, 1 for those tangentially related, and 0 for those lacking relevance.

This screening process identified 115 articles with a rating of 2 and 49 articles with a rating of 1. Following this, a comprehensive analysis was conducted on the 164 selected articles to extract the pertinent information required for the thesis objectives.

Review resulted to the following 11 Critical Success Factors which were used in this research:

1. **Enhanced Training, Education, and Competence Validation (CSF 1)**: Proper training of crew members, including both on-the-job training and formal maritime education, ensures they are equipped with the knowledge and skills to perform their tasks safely, complemented by regular competence assessments to maintain high levels of proficiency.
2. **Safety Culture (CSF 2):** Cultivating a strong safety culture where safety is prioritized above all else, and where individuals feel responsible for their safety and the safety of others.

3. **Use of Technology (CSF 3):** While human factors are crucial, leveraging technology like navigation aids, safety equipment, and modern communication tools can assist humans in maintaining safety.
4. **Comprehensive Fatigue and Well-being Management (CSF 4):** Proper fatigue management practices, including adherence to work-rest hours, ensure the crew is alert, while also addressing the broader aspects of physical and mental well-being to prevent accidents related to health issues or poor mental states.
5. **Leadership and Teamwork (CSF 5):** Strong leadership from the ship's officers, combined with effective teamwork, promotes a safe working environment.
6. **Clear Communication (CSF 6):** Effective communication among the crew members, and between the ship and the shore, is vital for safe operations and in emergency situations.
7. **Decision-making Skills (CSF 7):** Training crew members in decision-making under pressure ensures that they make the best choices in critical situations.
8. **Crisis Management and Emergency Preparedness (CSF 8)**: Preparedness for crisis situations through a structured response mechanism, complemented by regularly practicing emergency situations like fire or man-overboard drills, ensures the crew is well-prepared to mitigate the impact of any incident.
9. **Feedback Mechanisms (CSF 9):** Systems that allow crew members to report near-misses, concerns, or suggestions for safety improvements can provide invaluable insights.
10. **Regulatory Compliance (CSF 10):** Adherence to international and local maritime safety regulations, such as those set by the International Maritime Organization (IMO), ensures a standardized safety approach.
11. **Ethical Practices (CSF 11):** Ensuring fair treatment, no harassment, and ethical behavior on board contributes to a positive work environment, which indirectly promotes safety.

2. Construction of the Initial Direct-Relation Matrix

Upon the identification of Critical Success Factors, the next step was to determine the direct influence matrix *H* that can reflect the direct relationship between the factors.

The influence determination was performed by an expert panel which was selected, having relevant knowledge and experience.

Experts evaluated the influence of each Critical Success Factor (CSF) on every other factor using a predefined scale from 0 to 4. This results in an *n* x *n* initial direct-relation matrix *H [hij]*, where *hij* represents the direct influence of factor *CSFi* on factor *CSFj*.

$$H = \begin{bmatrix} 0 & \cdots & h_{1n} \\ \vdots & \ddots & \vdots \\ h_{n1} & \cdots & 0 \end{bmatrix} = \left[h_{ij}\right]_{n \times n} \tag{1}$$

In more detail, a questionnaire was developed which allowed experts to evaluate the influence of each factor on every other factor (please refer to Appendix No. I), to ensure a systematic evaluation process.
Level of influence was defined by a predefined scale, as per below:

- 0: No influence
- 1: Low influence
- 2: Moderate influence

- 3: High influence
- 4: Very high influence

Specific instructions were given that evaluation should not be mirror type i.e. If someone evaluated the influence of CSF1 to CSF2 with 3, this does not necessarily mean that the influence of CSF2 to CSF1 is the same (might be equal, less, or more).

Based on this approach, a questionnaire was distributed to participants employed in the maritime industry. A total of 96 completed questionnaires were collected for further analysis. The sample was categorized into the following sub-groups:

1. Various from Maritime Industry (18 participants): Sample included assistants and coordinators working in various departments of maritime companies, shipping brokers and officers & operators working at accounting, IT, purchasing and freight departments.
2. Mid experts (21 participants): Sample included Marine and Technical Superintendents, Crew operators, Operators and Training Officers.
3. Experts (36 participants): Sample included Technical Directors, Managers at HSQE/Marine/Vetting, Training, Operations, Crew, Technical, Chartering, HR and Legal departments, DPA/CSO/ADPAs, HSQE Officers, Quality Assurance Representatives, Deputy Managers and Class surveyors.
4. Vessel Feedbacks (21 participants): Sample included seafarers of top 4 officers onboard tanker and dry bulk vessels (Masters, Chief Officers, Chief Engineers and 2nd Engineers)

The participants were divided into these four categories to capture the perspectives of each group (participants' profile can be found on Appendix II of this thesis). This approach, along with the overall sample results, will be presented and discussed in the next chapter.

Collecting their answers, an *n x n* initial direct-relation matrix was constructed, as per DEMATEL process, for each participant.

All responses underwent a consistency check, which lead to 93 out of 96 valid participations (17 out of 18 from "Various from Maritime Industry – 20 out of 21 from "Mid experts" – 35 out of 36 from "Experts" – 21/21 from "Vessels Feedbacks")

An "average" initial direct-relation matrix was constructed for each sample category, incorporating the average score given by participants within each group. In addition to the four described categories, the DEMATEL method was applied to the entire sample (96 participants) and the combined group of experts and mid-experts (57 participants).

3. Normalization of the Direct-Relation Matrix

Next step was to normalize the initial direct-relation matrix to bring the values within a standardized range. The normalized matrix *E* is calculated as:

$$E = \frac{1}{\max\limits_{1 \le i \le n} \sum_{j=1}^{n} h_{ij}} H \qquad (2)$$

The normalized matrix ensures that all elements fall between 0 and 1.

4. Calculation of the Total-Relation Matrix

After obtaining the normalized direct influence matrix *E*, the total-relation matrix *T* was computed which captures both direct and indirect influenced among factors. The total-relation matrix is obtained as:

$$T = E(I - E)^{-1} \quad (3)$$

In this case, the *I* is the identity matrix of the same dimension as *E* and *-1* is the inverse matrix.

5. Causal Diagram Construction

At this stage total influences of each factor were summarized. The row sums (*ri*), representing the total influence given by factor *CSFi*, were calculated, as well as the column sums (*cj*), representing the total influence received by factor *CSFj*. Those were calculated as:

$$r_i = \sum_{j=1}^{n} T_{ij} \quad (4)$$

$$c_j = \sum_{i=1}^{n} T_{ij} \quad (5)$$

The centrality of factor *CSFi* reflects the degree of importance that factor *CSFi* has in the whole system. The prominence *fi* for each factor *CSFi* is defined as:

$$f_i = r_i + c_j \quad (6)$$

The causality of factor *CSFi* indicated the pure influence of factor *CSFi* has in the whole system. The net influence *ei* for each factor *CSFi* is defined as:

$$e_i = r_i - c_j \quad (7)$$

Factors were plotted in a causal diagram based on *fi* and *ei*, where *fi* indicates the significance of the factor and *ei* indicates whether the factor is a net influencer (positive *ei*, the factor *CSFi* has greater impact on other factors and can be clustered to the cause factor) or a net receiver (negative *ei*, the *CSFi* is more susceptible to other factors and can be clustered to the effect factors).

Basis this research methodology, the results are presented on the following Chapter, along with relevant research discussion.

Chapter 4 – Results and Research discussion

In this research, DEMATEL methodology, was followed as per steps described on Chapter 3, giving the results that follow on this part of the thesis.

After the collection of all questionnaire results and the construction of Initial Direct-Relation Matrixes (Step no. 2 of DEMATEL process), applying an "average" initial direct-relation matrix for each sample category as already described and after the normalization of Initial Direct-Relation Matrixes (Step no. 3 of DEMATEL process), the Step no. 4 was applied where the below Total-Relation Matrixes were created for each sample category of current research:

Table 1 Total Relation Matrix (Total Sample)

TOTAL RELATION MATRIX											
Factor \ Influence on →	CSF 1	CSF 2	CSF 3	CSF 4	CSF 5	CSF 6	CSF 7	CSF 8	CSF 9	CSF 10	CSF 11
CSF 1: Enhanced Traini	0,859006	1,092932	0,831068	0,956045	1,019441	1,023097	1,020912	1,106563	0,958823	0,9767	0,903066
CSF 2: Safety Culture	0,884222	0,928077	0,756636	0,909458	0,952476	0,957319	0,950548	1,040837	0,901025	0,913813	0,857356
CSF 3: Use of Technolo	0,792179	0,88389	0,603504	0,786121	0,819386	0,83645	0,825417	0,905636	0,797268	0,796764	0,723422
CSF 4: Comprehensive	0,812665	0,954788	0,696793	0,763143	0,891715	0,89226	0,895626	0,970762	0,833917	0,836904	0,79251
CSF 5: Leadership and T	0,92962	1,069575	0,783507	0,948127	0,913569	1,011382	1,016752	1,097972	0,945251	0,932813	0,893229
CSF 6: Clear Communic	0,879156	1,022859	0,757108	0,900704	0,968742	0,872722	0,9632	1,047064	0,909634	0,896532	0,848432
CSF 7: Decision—makii	0,864007	1,002613	0,741616	0,892698	0,95966	0,948849	0,856809	1,03335	0,88314	0,881987	0,830749
CSF 8: Crisis Managem	0,883097	1,030555	0,765068	0,902389	0,96587	0,965956	0,970507	0,946892	0,897913	0,903215	0,841221
CSF 9: Feedback Mech	0,847347	0,978313	0,737693	0,864492	0,914209	0,922337	0,914472	0,988667	0,782165	0,858273	0,810904
CSF 10: Regulatory Cor	0,873933	0,996026	0,750157	0,880533	0,921862	0,921257	0,923345	1,007718	0,869546	0,796348	0,827408
CSF 11: Ethical Practice	0,805095	0,934473	0,6832	0,834869	0,886807	0,875435	0,868288	0,942206	0,818054	0,823349	0,702784

Table 2 Total Relation Matrix (Experts & Mid Experts)

TOTAL RELATION MATRIX											
Factor \ Influence on →	CSF 1	CSF 2	CSF 3	CSF 4	CSF 5	CSF 6	CSF 7	CSF 8	CSF 9	CSF 10	CSF 11
CSF 1: Enhanced Traini	0,823092	1,066762	0,783797	0,914126	0,980219	0,980581	1,000087	1,084494	0,919237	0,924625	0,84104
CSF 2: Safety Culture	0,836932	0,887022	0,696979	0,857337	0,900672	0,905973	0,915911	1,003386	0,857861	0,854622	0,790197
CSF 3: Use of Technolo	0,763919	0,855316	0,564436	0,751165	0,787014	0,804286	0,808306	0,885116	0,770015	0,756529	0,674095
CSF 4: Comprehensive	0,782439	0,930252	0,650333	0,728186	0,858222	0,860366	0,882617	0,952156	0,801686	0,794058	0,741905
CSF 5: Leadership and T	0,906201	1,060574	0,746649	0,923193	0,889303	0,98539	1,013563	1,092621	0,927226	0,896907	0,850618
CSF 6: Clear Communic	0,868172	1,025281	0,731081	0,882008	0,95467	0,855305	0,96778	1,051201	0,900551	0,869438	0,811384
CSF 7: Decision—makii	0,841016	0,986434	0,702579	0,862792	0,9356	0,924034	0,845948	1,022903	0,86292	0,841647	0,783724
CSF 8: Crisis Managem	0,848619	1,00167	0,720011	0,859764	0,926362	0,923645	0,951132	0,920517	0,865182	0,852896	0,779711
CSF 9: Feedback Mech	0,80075	0,930955	0,680282	0,813078	0,858588	0,868168	0,876791	0,945546	0,735521	0,794762	0,740771
CSF 10: Regulatory Cor	0,815161	0,939247	0,681811	0,815514	0,85509	0,849406	0,873917	0,951958	0,809493	0,725773	0,745152
CSF 11: Ethical Practice	0,742153	0,874725	0,612119	0,766926	0,82021	0,799765	0,811946	0,879561	0,754577	0,748988	0,625789

Table 3 Total Relation Matrix (Various from Maritime Industry)

TOTAL RELATION MATRIX											
Factor \ Influence on →	CSF 1	CSF 2	CSF 3	CSF 4	CSF 5	CSF 6	CSF 7	CSF 8	CSF 9	CSF 10	CSF 11
CSF 1: Enhanced Traini	0,528136	0,728478	0,572094	0,643836	0,682516	0,705984	0,684031	0,793433	0,700532	0,676064	0,628599
CSF 2: Safety Culture	0,5334	0,559226	0,485461	0,58484	0,594401	0,619797	0,597345	0,710648	0,616596	0,59839	0,572441
CSF 3: Use of Technolo	0,500284	0,576168	0,373276	0,516464	0,517924	0,556596	0,528139	0,633716	0,564615	0,521227	0,472823
CSF 4: Comprehensive	0,469442	0,583183	0,425285	0,444493	0,539546	0,553222	0,536174	0,634743	0,553834	0,512923	0,500924
CSF 5: Leadership and T	0,554008	0,648014	0,473084	0,586423	0,540379	0,659453	0,635242	0,731824	0,6425	0,578893	0,572294
CSF 6: Clear Communic	0,505092	0,607762	0,458457	0,557504	0,605051	0,525411	0,59005	0,689876	0,614683	0,555513	0,539175
CSF 7: Decision—makii	0,511093	0,618172	0,459276	0,561607	0,60889	0,607663	0,506191	0,690851	0,584711	0,556853	0,533751
CSF 8: Crisis Managem	0,548169	0,673625	0,48454	0,579841	0,631472	0,648884	0,634163	0,629461	0,633714	0,606324	0,567375
CSF 9: Feedback Mech	0,532981	0,649722	0,496827	0,579895	0,60738	0,629817	0,602347	0,702957	0,537178	0,577015	0,55727
CSF 10: Regulatory Cor	0,585996	0,686249	0,520388	0,60476	0,621845	0,646838	0,626637	0,739652	0,638755	0,529909	0,593025
CSF 11: Ethical Practice	0,522285	0,627226	0,451324	0,568908	0,599889	0,61466	0,586343	0,682223	0,60321	0,560737	0,469358

Table 4 Total Relation Matrix (Mid Experts)

TOTAL RELATION MATRIX											
Factor \ Influence on →	CSF 1	CSF 2	CSF 3	CSF 4	CSF 5	CSF 6	CSF 7	CSF 8	CSF 9	CSF 10	CSF 11
CSF 1: Enhanced Traini	0,76022	0,962681	0,692876	0,824966	0,912099	0,919038	0,944387	0,999817	0,798616	0,844663	0,763419
CSF 2: Safety Culture	0,761896	0,787171	0,60393	0,775601	0,832498	0,836539	0,852998	0,918825	0,735564	0,771996	0,710364
CSF 3: Use of Technolo	0,719151	0,777705	0,496852	0,688576	0,742251	0,748579	0,761994	0,820031	0,672304	0,701988	0,615229
CSF 4: Comprehensive	0,747433	0,863622	0,584174	0,671999	0,813248	0,822936	0,841944	0,899622	0,713844	0,746863	0,688038
CSF 5: Leadership and T	0,844415	0,956708	0,653439	0,830879	0,814096	0,910934	0,940026	1,001549	0,806347	0,814304	0,760271
CSF 6: Clear Communic	0,815605	0,930426	0,647679	0,808817	0,8965	0,794534	0,912802	0,971827	0,790733	0,800724	0,741105
CSF 7: Decision—makin	0,761906	0,875189	0,598968	0,768516	0,845164	0,838404	0,762497	0,912036	0,732412	0,748011	0,69112
CSF 8: Crisis Manageme	0,799623	0,912573	0,644713	0,785492	0,865589	0,864699	0,89585	0,843009	0,761268	0,784109	0,699837
CSF 9: Feedback Mecha	0,689335	0,781717	0,553721	0,686086	0,737404	0,749315	0,750655	0,798501	0,584811	0,669752	0,615416
CSF 10: Regulatory Con	0,733564	0,819175	0,585552	0,716851	0,76609	0,75803	0,785949	0,837185	0,666123	0,631506	0,648182
CSF 11: Ethical Practice	0,694026	0,788077	0,543143	0,701203	0,766067	0,752146	0,755322	0,812193	0,660166	0,678344	0,560544

Table 5 Total Relation Matrix (Experts)

TOTAL RELATION MATRIX											
Factor \ Influence on →	CSF 1	CSF 2	CSF 3	CSF 4	CSF 5	CSF 6	CSF 7	CSF 8	CSF 9	CSF 10	CSF 11
CSF 1: Enhanced Traini	0,719112	0,996587	0,702235	0,850903	0,905354	0,885549	0,914554	1,014849	0,863561	0,847701	0,780305
CSF 2: Safety Culture	0,730809	0,80834	0,617215	0,785645	0,817984	0,806954	0,828929	0,930782	0,797435	0,774615	0,724331
CSF 3: Use of Technolo	0,661585	0,774805	0,485378	0,676495	0,702113	0,713704	0,719696	0,805896	0,706138	0,667253	0,604287
CSF 4: Comprehensive	0,65754	0,82832	0,552879	0,640555	0,766126	0,742689	0,780148	0,853708	0,715218	0,688301	0,661678
CSF 5: Leadership and T	0,796237	0,985518	0,661993	0,859802	0,814782	0,889147	0,933119	1,021092	0,871212	0,81613	0,795063
CSF 6: Clear Communic	0,74938	0,940044	0,64447	0,800947	0,867135	0,752852	0,872579	0,975395	0,831279	0,776311	0,739322
CSF 7: Decision—makin	0,727786	0,901306	0,615375	0,786818	0,858196	0,82468	0,75839	0,949315	0,793937	0,752979	0,714752
CSF 8: Crisis Manageme	0,735849	0,924106	0,632678	0,791625	0,849692	0,827532	0,866909	0,847208	0,804111	0,76946	0,721872
CSF 9: Feedback Mecha	0,741103	0,901597	0,635678	0,784527	0,82759	0,818132	0,84055	0,92479	0,71328	0,752868	0,72265
CSF 10: Regulatory Con	0,733345	0,890359	0,616505	0,769503	0,802798	0,781297	0,816701	0,909309	0,779123	0,667517	0,708934
CSF 11: Ethical Practice	0,633518	0,795875	0,526977	0,695251	0,742657	0,699381	0,729854	0,803264	0,689512	0,672634	0,563001

Table 6 Total Relation Matrix (Vessels Feedback)

TOTAL RELATION MATRIX											
Factor \ Influence on →	CSF 1	CSF 2	CSF 3	CSF 4	CSF 5	CSF 6	CSF 7	CSF 8	CSF 9	CSF 10	CSF 11
CSF 1: Enhanced Traini	1,513661	1,756203	1,420734	1,596011	1,690607	1,672136	1,62128	1,667463	1,498141	1,641516	1,559097
CSF 2: Safety Culture	1,618832	1,670278	1,419464	1,620502	1,708387	1,68007	1,631517	1,685049	1,499872	1,645335	1,571166
CSF 3: Use of Technolo	1,361642	1,472732	1,119695	1,34242	1,410097	1,396869	1,353051	1,400979	1,259172	1,377952	1,296072
CSF 4: Comprehensive	1,48034	1,639079	1,308905	1,409187	1,578993	1,549852	1,512059	1,55835	1,387463	1,514394	1,450405
CSF 5: Leadership and T	1,608489	1,757028	1,403413	1,60447	1,598466	1,667074	1,629753	1,678079	1,483345	1,618261	1,555346
CSF 6: Clear Communic	1,506125	1,65692	1,323022	1,507751	1,59976	1,48433	1,53211	1,580087	1,403608	1,529655	1,467258
CSF 7: Decision—makin	1,512623	1,667003	1,335487	1,526401	1,614098	1,582191	1,4539	1,597952	1,414074	1,544668	1,474582
CSF 8: Crisis Manageme	1,544231	1,702271	1,372105	1,559048	1,643438	1,621878	1,574113	1,528958	1,431697	1,568411	1,502748
CSF 9: Feedback Mecha	1,518785	1,668963	1,342973	1,511422	1,606476	1,585562	1,539582	1,583119	1,333073	1,541201	1,476841
CSF 10: Regulatory Con	1,556657	1,696674	1,376307	1,555524	1,637676	1,615158	1,56579	1,619906	1,442913	1,488861	1,5115
CSF 11: Ethical Practice	1,492453	1,638787	1,316483	1,508628	1,591528	1,567137	1,514729	1,56362	1,38702	1,520617	1,373871

Afterwards, Step no. 5 (Causal Diagram Construction) was applied where the following Cause – Effect factors are presented for each sample category of current research, based on Causal Diagram Construction:

Table 7 Cause/Effect factors (Total Sample)

	Ri	Ci		Ri+Ci	Ri-Ci		
CSF 1: Enhanced Training, Education, and Competence Validation	10,74765	9,430328		20,17798	1,317326		CAUSE
CSF 2: Safety Culture	10,05177	10,8941		20,94587	-0,84234		EFFECT
CSF 3: Use of Technology	8,770036	8,10635		16,87639	0,663686		CAUSE
CSF 4: Comprehensive Fatigue and Well—being Management	9,341082	9,638581		18,97966	-0,2975		EFFECT
CSF 5: Leadership and Teamwork	10,5418	10,21374		20,75553	0,328059		CAUSE
CSF 6: Clear Communication	10,06615	10,22706		20,29322	-0,16091		EFFECT
CSF 7: Decision—making Skills	9,895479	10,20587		20,10135	-0,3104		EFFECT
CSF 8: Crisis Management and Emergency Preparedness	10,07268	11,08767		21,16035	-1,01498		EFFECT
CSF 9: Feedback Mechanisms	9,618871	9,596735		19,21561	0,022136		EFFECT
CSF 10: Regulatory Compliance	9,768134	9,616697		19,38483	0,151437		CAUSE
CSF 11: Ethical Practices	9,17456	9,031082		18,20564	0,143478		CAUSE

Table 8 Cause/Effect factors (Experts and Mid Experts)

	Ri	Ci	Ri+Ci	Ri-Ci	
CSF 1: Enhanced Training, Education, and Competence Validation	10,31806	9,028452	19,34651	1,289608	CAUSE
CSF 2: Safety Culture	9,506893	10,55824	20,06513	-1,05134	EFFECT
CSF 3: Use of Technology	8,420196	7,570076	15,99027	0,85012	CAUSE
CSF 4: Comprehensive Fatigue and Well—being Management	8,982219	9,17409	18,15631	-0,19187	EFFECT
CSF 5: Leadership and Teamwork	10,29224	9,765948	20,05819	0,526295	CAUSE
CSF 6: Clear Communication	9,916871	9,75692	19,67379	0,159951	EFFECT
CSF 7: Decision—making Skills	9,609596	9,947998	19,55759	-0,3384	EFFECT
CSF 8: Crisis Management and Emergency Preparedness	9,649508	10,78946	20,43897	-1,13995	EFFECT
CSF 9: Feedback Mechanisms	9,045212	9,204269	18,24948	-0,15906	EFFECT
CSF 10: Regulatory Compliance	9,062523	9,060245	18,12277	0,002278	CAUSE
CSF 11: Ethical Practices	8,436758	8,384386	16,82114	0,052372	CAUSE

Table 9 Cause/Effect factors (Various from Maritime Industry)

	Ri	Ci	Ri+Ci	Ri-Ci	
CSF 1: Enhanced Training, Education, and Competence Validation	7,343703	5,790884	13,13459	1,552819	CAUSE
CSF 2: Safety Culture	6,472545	6,957823	13,43037	-0,48528	EFFECT
CSF 3: Use of Technology	5,761234	5,200012	10,96125	0,561222	CAUSE
CSF 4: Comprehensive Fatigue and Well—being Management	5,75377	6,228571	11,98234	-0,4748	EFFECT
CSF 5: Leadership and Teamwork	6,622114	6,549292	13,17141	0,072822	CAUSE
CSF 6: Clear Communication	6,248573	6,768324	13,0169	-0,51975	EFFECT
CSF 7: Decision—making Skills	6,239057	6,526662	12,76572	-0,2876	EFFECT
CSF 8: Crisis Management and Emergency Preparedness	6,637567	7,639386	14,27695	-1,00182	EFFECT
CSF 9: Feedback Mechanisms	6,473388	6,690329	13,16372	-0,21694	EFFECT
CSF 10: Regulatory Compliance	6,794054	6,27385	13,0679	0,520204	CAUSE
CSF 11: Ethical Practices	6,286163	6,007035	12,2932	0,279128	CAUSE

Table 10 Cause/Effect factors (Mid Experts)

	Ri	Ci	Ri+Ci	Ri-Ci	
CSF 1: Enhanced Training, Education, and Competence Validation	9,422784	8,327175	17,74996	1,095609	CAUSE
CSF 2: Safety Culture	8,587382	9,455044	18,04243	-0,86766	EFFECT
CSF 3: Use of Technology	7,74466	6,605046	14,34971	1,139614	CAUSE
CSF 4: Comprehensive Fatigue and Well—being Management	8,393723	8,258987	16,65271	0,134736	EFFECT
CSF 5: Leadership and Teamwork	9,332969	8,991005	18,32397	0,341964	CAUSE
CSF 6: Clear Communication	9,110751	8,995154	18,10591	0,115597	EFFECT
CSF 7: Decision—making Skills	8,534223	9,204425	17,73865	-0,6702	EFFECT
CSF 8: Crisis Management and Emergency Preparedness	8,856761	9,814595	18,67136	-0,95783	EFFECT
CSF 9: Feedback Mechanisms	7,616712	7,922187	15,5389	-0,30547	EFFECT
CSF 10: Regulatory Compliance	7,948206	8,192258	16,14046	-0,24405	CAUSE
CSF 11: Ethical Practices	7,711232	7,493527	15,20476	0,217705	CAUSE

Table 11 Cause/Effect factors (Experts)

	Ri	Ci	Ri+Ci	Ri-Ci	
CSF 1: Enhanced Training, Education, and Competence Validation	9,480708	7,886265	17,36697	1,594443	CAUSE
CSF 2: Safety Culture	8,623039	9,746858	18,3699	-1,12382	EFFECT
CSF 3: Use of Technology	7,51735	6,691383	14,20873	0,825967	CAUSE
CSF 4: Comprehensive Fatigue and Well—being Management	7,887162	8,442071	16,32923	-0,55491	EFFECT
CSF 5: Leadership and Teamwork	9,444097	8,954428	18,39852	0,489669	CAUSE
CSF 6: Clear Communication	8,949715	8,741917	17,69163	0,207798	EFFECT
CSF 7: Decision—making Skills	8,683533	9,061429	17,74496	-0,3779	EFFECT
CSF 8: Crisis Management and Emergency Preparedness	8,771042	10,03561	18,80665	-1,26457	EFFECT
CSF 9: Feedback Mechanisms	8,662764	8,564806	17,22757	0,097958	EFFECT
CSF 10: Regulatory Compliance	8,475391	8,185769	16,66116	0,289622	CAUSE
CSF 11: Ethical Practices	7,551925	7,736194	15,28812	-0,18427	CAUSE

Table 12 Cause/Effect factors (Vessels Feedbacks)

	Ri	Ci	Ri+Ci	Ri-Ci	
CSF 1: Enhanced Training, Education, and Competence Validation	17,63685	16,71384	34,35069	0,923011	CAUSE
CSF 2: Safety Culture	17,75047	18,32594	36,07641	-0,57547	EFFECT
CSF 3: Use of Technology	14,79068	14,73859	29,52927	0,052093	CAUSE
CSF 4: Comprehensive Fatigue and Well—being Management	16,38903	16,74136	33,13039	-0,35234	EFFECT
CSF 5: Leadership and Teamwork	17,60373	17,67953	35,28325	-0,0758	CAUSE
CSF 6: Clear Communication	16,59063	17,42226	34,01288	-0,83163	EFFECT
CSF 7: Decision—making Skills	16,72298	16,92789	33,65086	-0,20491	EFFECT
CSF 8: Crisis Management and Emergency Preparedness	17,0489	17,46356	34,51246	-0,41466	EFFECT
CSF 9: Feedback Mechanisms	16,708	15,54038	32,24837	1,16762	EFFECT
CSF 10: Regulatory Compliance	17,06697	16,99087	34,05784	0,076095	CAUSE
CSF 11: Ethical Practices	16,47487	16,23889	32,71376	0,235988	CAUSE

The causal diagram indicating the strongest relationships between the Critical Success Factors was constructed by specifying the Threshold (alpha) Value, to indicate research results. This value was determined by calculating the percentile of all values in the Total Relation Matrix for each research category, getting the top 10% of results. If the cell value of each Total Relation Matrix exceeded the Threshold Value, it indicated a strong relationship between the two Critical Success Factors.

Following this process, the values greater than the Threshold Value were retained, and the results are presented here below through six different diagrams. All the diagrams, have three different colors: light blue represents the CSFs that influence other factors (causes), dark blue represents the CSFs that get influenced (effects) and medium blue represents the CSFs that influence and get influenced by various factors, working as mediators. Arrows are used to indicate the flow of influence or causation between factors.

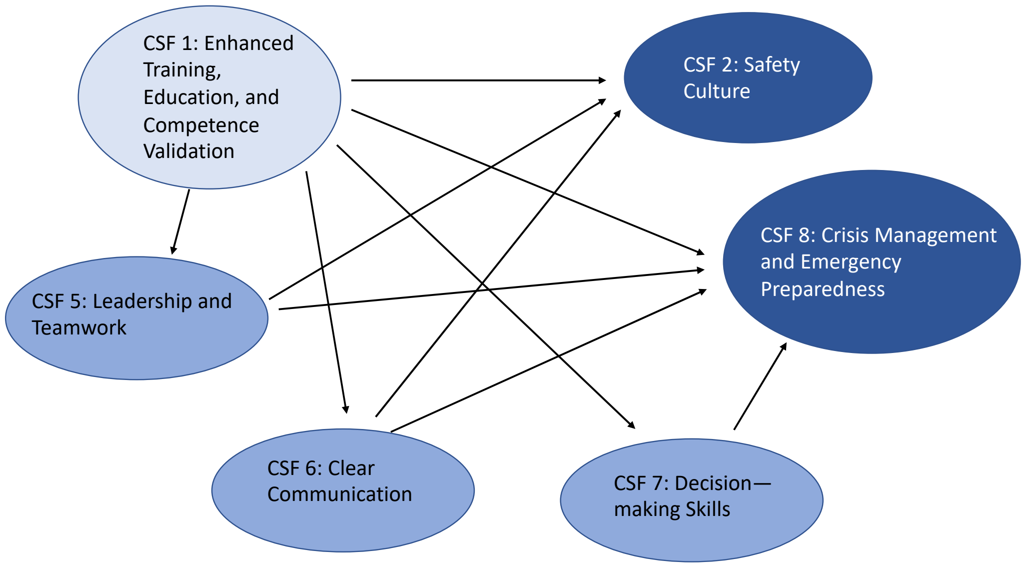

Diagram 1 Total Sample process results

In above diagram which includes the total sample results, we can conclude that CSF 1 constitutes as the main factor that influences all other critical success factors. CSF 2 and CSF 8 operate as passive factors that get influenced by mainly all others presented. It goes without saying that CSF 5, CSF6 & CSF7, not only are both active and passive but, also, operate as mediators, since CSF1 affects CSF 2 & CSF 8, either directly or through the mediators.

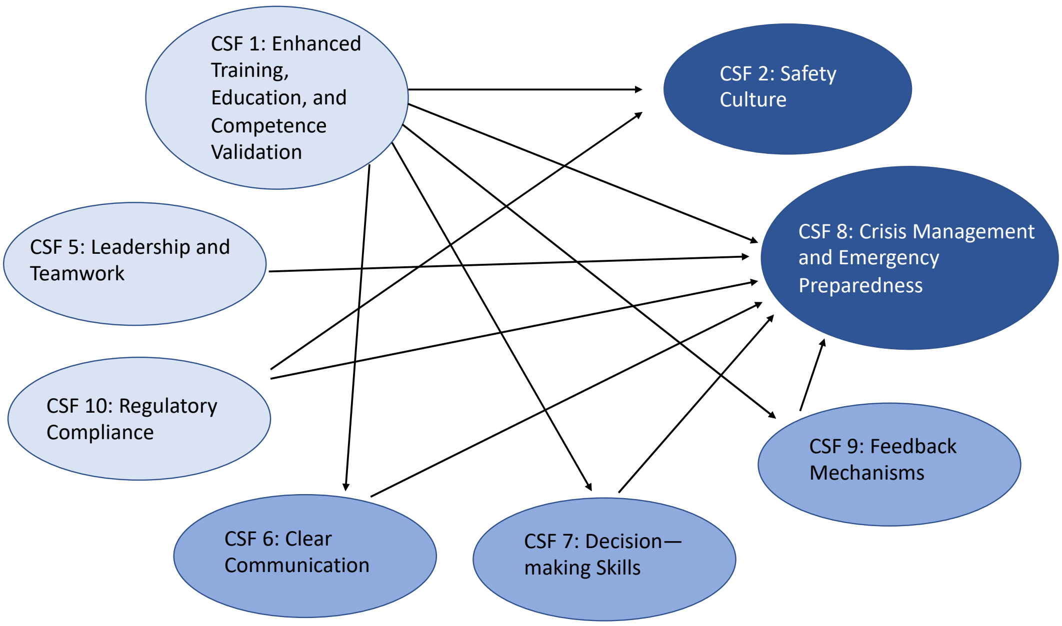

Diagram 2 Various participants from maritime industry process results

In Diagram no. 2, representing the results of the participation of various maritime industry stakeholders, we can see a similar trend with diagraph no. 1, while CSF 1, CSF 5 and CSF 10 are the most active influencers to CSF 2 and CSF 8, which are the most passive factors.

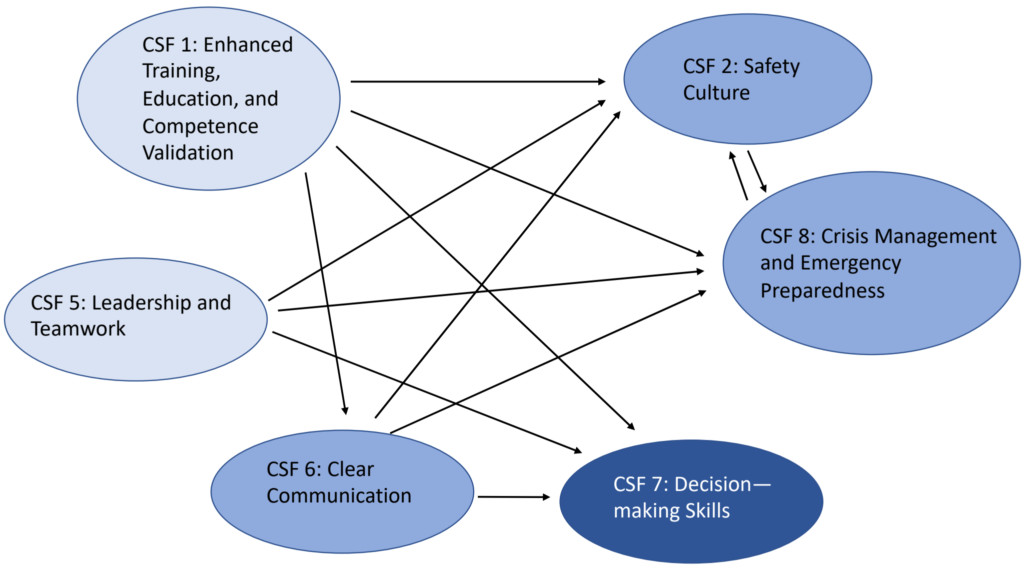

Diagram 3 Mid experts process results

In Diagram no. 3, which includes the results on Mid Experts answers to the research, we see a slight change to the passive factor which now is CS7, however, CSF 2 and CSF8 remain as main factors that get influenced by many of the factors presented above. It stands out, that according to Mid Experts opinion, Safety Culture and Crisis Management & Emergency preparedness, influence each other and have a vice versa strong relationship. Lastly, the most important mediator is CSF 6, through which training affects CSF 2 and CSF 8.

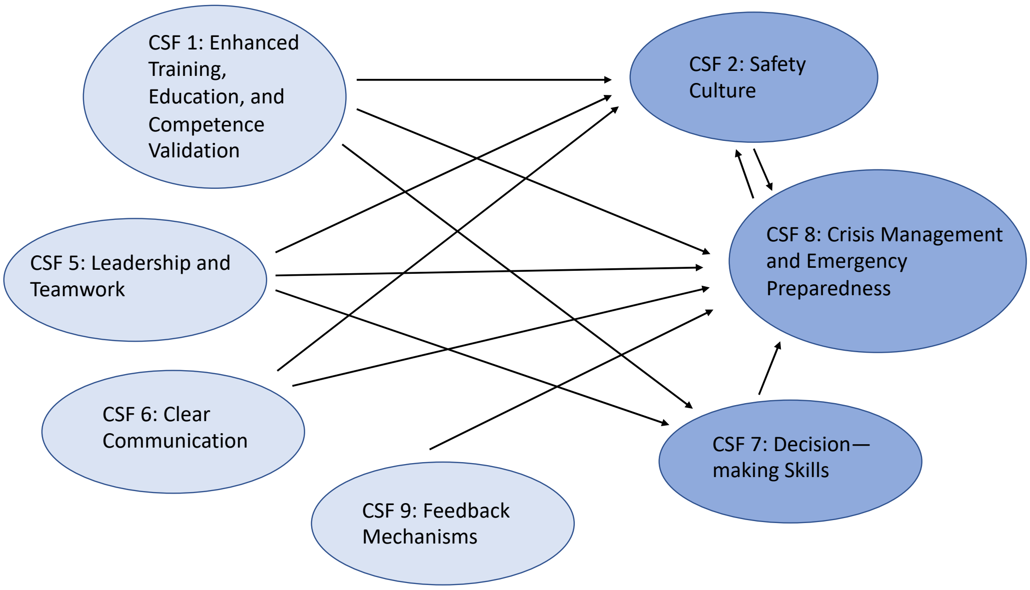

Diagram 4 Experts process results

On Diagram no. 4, results of Experts participation are presented. In this occasion, there is not any stand-alone passive factor. There are four active factors, CSF 1, CSF 5 CSF 6 and CSF 9, and three factors that affect and get affected, which are CSF 2, CSF 8 and CSF 7. It should be mentioned though, that CSF 2 and CSF 8 keep the same trend as mid experts' opinion and influence only each other keeping their strong relationship. CSF 7 becomes the mediator between training - leadership/teamwork and crisis management - emergency preparedness.

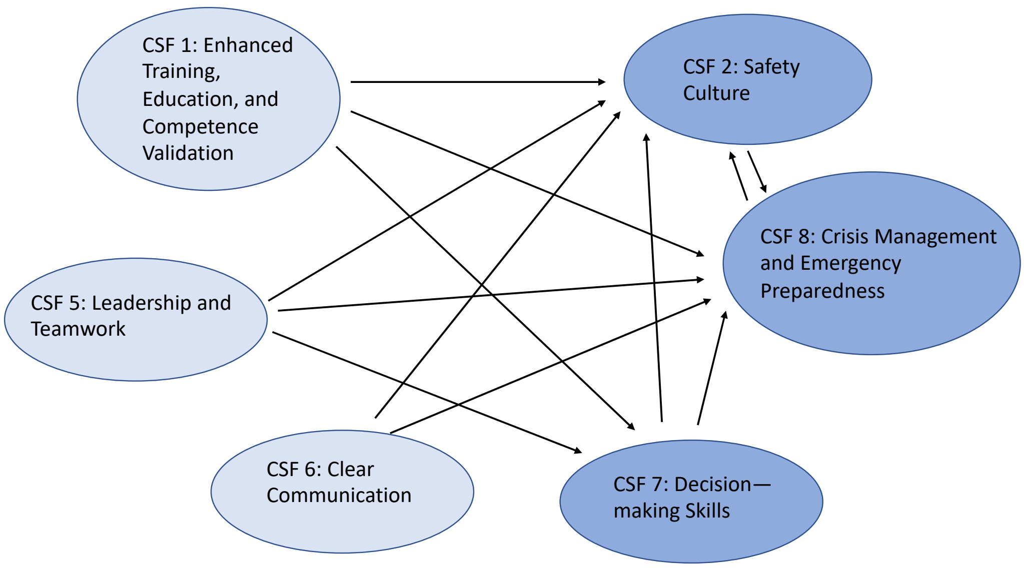

Diagram 5 Experts & Mid Experts process results

Due to the importance of mid experts and experts' participation in this study, their results were merged for a clear view of their opinion trend. It goes without saying, that Diagram no. 5 is very similar to diagram no. 4 (Experts results process), while CSF 9 now does not exist as an active influencer. However, other relationships remain in the same way and strong. This mean that mid experts have very similar opinion to the experts sample on the matter of Critical Success Factors on the human element.

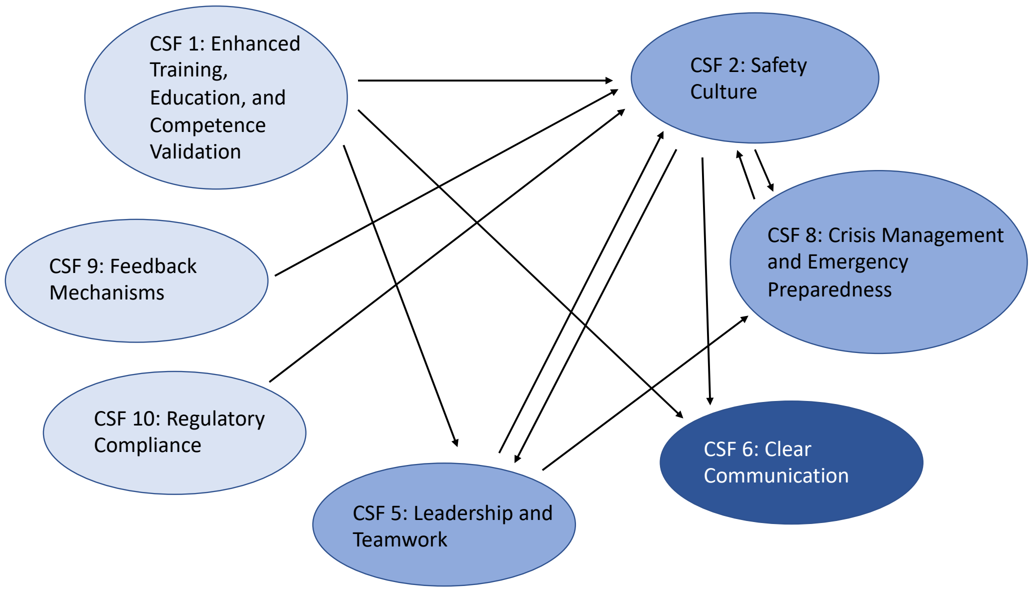

Diagram 6 Vessels' officers (top 4) process results

Due to the complexity of the maritime industry and the numerous stakeholders getting involved in the human element, it was very important to include and ask the opinion of seafarers (top 4 officers – Master/Chief Officer/Chief Engineer/2nd Engineer), who actively participate in day to day vessels' operations and get involved in all accidents/incidents that lead to nowadays human element analysis. Their participation could not be absent from this study, in order to get holistic results in the analysis.

In view of the above, in Diagram no. 6 there is a slight change to the trend that all other diagraphs had. Of course, CSF 1 remains one of the most important influencers. CSF 2 remains as the most passive one, but we can see that CSF 6 – Clear communication – in the case of officers' opinion is affected, though according to office staff and experts' opinion we saw that CSF 6 was an active influencer. Also, CSF 10 shows up for the first time as an influencer. Last but not least, we can also conclude to two vice versa relationships, between CSF 2 & CSF 8 and CSF 5 & CSF 2.

According to the research and the results both in whole sample and in each participant's category respectively, as analyzed above, we can conclude to some main issues for further discussion and analysis:

1. CSF 1 – Enhanced training, education and competence validation – is the most obvious critical success factor that affects many other factors (both in office and seafarers' sample)
2. CSF 5 – Leadership and teamwork – stands as one of the most important influencers.
3. CSF 6 – Clear communication – stands as one of the most important influencers.
4. CSF 2 – Safety culture – is the most obvious critical success factor that gets influenced by many other factors.
5. CSF 8 – Crisis management and emergency preparedness – stands as one of the most important passive factors.
6. The interrelationship of CSF 2 and CSF 8
7. CSF 7 – Decision making skills – stands as the most important mediator.
8. The different view of seafarers.

Given the aforementioned considerations, it is imperative to thoroughly examine the eight identified issues, their interconnectedness, and their critical role in the maritime industry, particularly concerning the human element. These highlighted factors represent focal points for companies seeking further progress and the development of the human factor, both onshore and offshore. As revealed in the literature review analysis, office operators play a pivotal role within companies and in maintaining smooth office-ship relationships. The handling of emergency situations is crucial in demonstrating the maturity of the human element, directly linked to CSF 8, a topic for deeper discussion. The question remains: how do we navigate towards these goals?

The exploration should commence with one of the most crucial critical success factors that emerged prominently from this research—enhanced training, education, and competence validation. This factor has been identified as a significant influencer across various aspects of this research, as confirmed by samples from both office executives and seafarers. This underscores the profound impact of this factor on enhancing the human element within maritime companies, ensuring high standards for office staff and onboard crew. In today's landscape, it is widely acknowledged that many companies, particularly those operating long-range voyages, allocate working hours and financial resources to developing comprehensive training plans for their employees. This can be achieved through outsourcing to consulting or specialized training companies or through insourcing with dedicated training centers for onshore and offshore personnel.

The maritime industry is highly regulated, with specific training and competence standards, not only mandated by international conventions and national regulations (for example the STCW – Standards of Training, Certification and Watchkeeping for Seafarers), but, also, indirectly imposed by i.e. TMSA and its stages and the standards that promotes. Meeting these standards through training and competence validation is essential for compliance. Throughout the years and the history of maritime industry, many accidents and incidents of paramount importance, such as the accident of Exxon Valdez, were the key reason that led to strict regulatory framework in this industry. Analyzing various accidents have shown the main root cause is the human error. However, through appropriate training and education individuals gain a deeper understanding of potential sources of error and learn effective strategies to mitigate them. Moreover, personnel are better equipped to manage risks and respond effectively to incidents. Competence validation ensures that crew members maintain a high standard of performance. For this reason, well trained personnel are more efficient in carrying out their duties, leading to improved operational performance. This includes tasks related to navigation, machinery operation, cargo handling and communication. Those mentioned operational tasks are under continuous technological evolvement with advancements, including automation and digitalization. In this rapid technological evolution, training and education programs help maritime professional to adapt in changes, ensuring they can effectively operate and maintain modern vessel systems. It is of vital role that both sides, onshore and ashore, to be well trained on the above case, in order maintain a clear communication. In the case of seafarers, investing in training and education demonstrates a commitment to crew development, which can boost morale, job satisfaction and motivation to their roles. Overall, training and education programs provide maritime professionals with the necessary skills, knowledge, and understanding of their roles, tasks, and responsibilities. This enhanced competence leads to better decision-making and performance onboard ships.

Considering the above, it is evident that training, education, and competence validation significantly impact the safety culture established within a maritime company, as also revealed from the literature review. These elements influence various key aspects of safety culture, including heightened awareness and comprehension, skill enhancement and competence, promotion of safety-oriented behaviors, empowerment and accountability, procedural standardization, leadership, role modeling, and regulatory compliance. Crew members who possess confidence in their skills and knowledge are more inclined to voice safety concerns, report near misses, and actively engage in safety initiatives, thus fostering a culture of accountability. Furthermore, standardized training fosters consistency in safety practices, reducing the risk of errors and misunderstandings that could compromise safety. Lastly, training initiatives for supervisors and managers emphasize their critical role in championing safety. Effective leaders who prioritize safety in their decision-making and actions serve as positive examples to their teams, reinforcing a robust safety culture both within the organization and onboard ships.

Undoubtedly, training not only influences the safety culture of an organization but also significantly contributes to the crisis management and emergency preparedness of the company's employees and seafarers aboard vessels. Training equips maritime personnel with the necessary tools and skills to respond effectively to various crisis scenarios and emergencies at sea, with drills being a primary method for imparting this knowledge. Onboard drills are conducted regularly—monthly, quarterly, or annually—depending on the type of drill, crew rotations, and relevant regulations. For instance, a man overboard drill provides critical knowledge on crew response protocols in such situations, with each seafarer assigned specific responsibilities based on their rank. Familiarity with these protocols enables seafarers to effectively handle emergencies, mitigating the risk of worst-case outcomes, such as fatalities.

Emergency drills and simulations enhance crisis management techniques, ensuring that crew members are well-prepared to navigate challenging situations as they arise. Furthermore, these exercises foster critical thinking and decision-making skills among individuals. Well-trained personnel are adept at making informed decisions swiftly during emergencies, thereby minimizing crisis impacts and ensuring the safety of both personnel and vessels. Effective communication is another critical aspect emphasized in training programs, promoting clear communication protocols that facilitate coordinated responses and actions during emergencies. Clear and efficient communication fosters effective team coordination, contributing to safer operations and optimal performance onboard ships.

Moreover, training and education cultivate a culture of teamwork, directly and indirectly impacting accurate communication—a cornerstone of crisis management. Additionally, training promotes risk mitigation strategies through proactive measures such as risk assessments, reducing the likelihood of crisis situations. Lastly, by adapting to evolving threats through specialized training and adhering to best practices and regulatory requirements, maritime personnel remain prepared to address emerging risks effectively. Competence validation ensures that crews can adapt and respond to challenges in the dynamic maritime environment, reinforcing safety and operational excellence throughout the organization.

It should be mentioned that all of the above can only be achieved through continuous training, education and competence validation. Since training is considered a critical success factor on the human element, success can never be achieved without continuous improvement. The maritime industry and its human element are dynamic. Changes and development are the core of the contemporary industry. Therefore, training should and must be continuous, otherwise the company's competitive position in the industry is discredited and the human factor withers instead of developing.

At this stage, a question arises. Does this critical success factor influence the soft skill gap?
In the recent years we have seen that discussions arise and efforts turn to soft skills of the human element in the maritime industry. The main problem associated with training and developing soft skills, such as leadership, teamwork and communication, in the maritime industry can be the challenge of assessing and measuring the effectiveness and impact of these programs. Unlike

technical skills that can be more quantitatively assessed through tests and evaluations, soft skills are often more subjective and difficult to measure objectively. To address these challenges, maritime organizations may need to invest in robust assessment methods, incorporate soft skills development into holistic training approaches, provide opportunities for continuous feedback and improvement, and prioritize a culture that values and encourages the development of soft skills alongside technical competencies. By addressing these challenges, the maritime industry can maximize the benefits of soft skills training and enhance overall safety, efficiency, and teamwork onboard ships.

Leadership and teamwork, a crucial component of soft skills, have played an important role to this research, resulting as one of the top influencing critical success factors in the maritime industry.

It has been determined that effective leadership plays a crucial role in fostering a robust safety culture within the company, extending its influence to employees and seafarers alike. Under such leadership, safety is prioritized in all communications and tasks, encouraging the implementation of safety protocols, hazard reporting, and active participation in safety initiatives by the crew. This proactive approach ultimately leads to a reduction in accidents and incidents. Similarly, strong teamwork relies on open and efficient communication among all company employees, crew members, and between the office and vessel for day-to-day reporting. Clear communication facilitates the sharing of accurate information, effective task coordination, and timely resolution of issues, enhancing overall efficiency and performance in both onshore and offshore operations. Maintaining high standards of leadership and communication effectiveness can prevent conflicts and misunderstandings while providing strong guidance and fostering a positive work environment. As a result, crew motivation and morale are boosted, with team members becoming more engaged and committed to their respective roles.

Moreover, effective leadership and teamwork are pivotal not only in shaping a company's safety culture but also in crisis management and emergency preparedness. This critical success factor contributes significantly to improved risk management, with comprehensive risk assessments and safeguards becoming integral to daily operations and vessel tasks, thereby ensuring a safer working environment. Additionally, a cohesive team led by effective leadership can swiftly adapt to changing conditions and emergency situations, ensuring preparedness for unforeseen challenges at all times.

It is evident that strong leadership and teamwork promote sound decision-making skills through effective communication, clear instructions, and consistent procedures and policies throughout the organization.

The primary weaknesses in effectively applying this critical success factor within the maritime industry include:

- Traditional hierarchical structures prevalent in many Greek maritime companies, which may hinder open communication and limit the empowerment and autonomy of teams.
- Cultural and language barriers among seafarers and between office employees and seafarers pose significant challenges to building solid and effective teamwork. The multicultural workforce presents obstacles to seamless collaboration.
- High turnover rates can disrupt team dynamics and continuity, resulting in the loss of valuable knowledge and experience. This applies to both onshore and offshore teams. Employees and seafarers with long tenures in the company possess a deep understanding of company policies and procedures, are familiar with the organizational structure, and contribute to effective leadership and team performance.

- Poor communication channels, such as unclear communication, delayed feedback, and limited access to communication tools, can impede information flow and hinder collaboration within teams, between leaders, and between leaders and teams.

Communication emerges as a defining factor between an organization and its teams. Research revealed that clear communication mainly affects the safety culture and crisis management within a company.

At the core of safety culture lie shared values, beliefs, attitudes, and norms pertaining to safety within an organization. Clear communication plays a crucial role in ensuring that safety procedures and protocols are comprehended and adhered to by all personnel, including both office employees and seafarers. Clarity in communication transforms safety procedures and policies into a universal language among crew members. This bridging of linguistic and cultural barriers prevalent in many maritime companies facilitates a cohesive understanding rooted in the company's standardized procedures. Consequently, this fosters heightened risk awareness, facilitated through the effective transmission of critical information, and encourages reporting and feedback via clear communication channels. Moreover, clear communication promotes accountability for actions, facilitates enhanced collaboration by ensuring a common understanding of procedures, and supports the implementation of effective training programs on safety procedures, emergency protocols, and best practices. When safety information is conveyed clearly and comprehensively, crew members are better equipped to execute their duties safely and contribute to a culture of safety within the organization.

In this ongoing discussion, let's consider an example of crisis management and emergency preparedness, specifically focusing on a scenario involving a fire onboard a vessel. Firstly, to prevent such an incident, it is imperative for a company to cultivate a robust safety culture onboard, wherein crew members fully comprehend the gravity of fire hazards, are well-versed in relevant safety procedures, and adopt a proactive approach to their tasks. This necessitates the daily implementation of risk assessments by crew members, coupled with proactive mitigation measures and ongoing evaluations. Secondly, safety procedures encompass clearly defined crisis management and emergency preparedness protocols. These procedures are effectively communicated to all seafarers and office employees through comprehensive company manuals and continuous training initiatives. Once this safety culture is ingrained, training becomes pivotal in ensuring compliance and maintaining the preparedness of crew members. One such training example is conducting drills, during which crew preparedness is put to the test. Performance is meticulously evaluated, identified gaps are addressed, suggestions for improvement are solicited, and both exemplary practices and areas for improvement are reported. These outcomes are communicated back to the company for review and feedback to address any identified issues. Furthermore, crew members are thoroughly prepared and understand their roles through muster list procedures and the assignment of duties within emergency response teams, as outlined in company protocols. Consequently, the crew is well-equipped to confront a fire onboard, with clearly defined procedures known to all and each individual fully aware of their role within emergency teams.

This illustrative example highlights the interconnectedness of critical success factors. Training and education, leadership and teamwork, and clear communication serve to enhance, improve, establish, and define foundational elements of safety, which is safety culture and crisis management. Together, these elements pave the way for the effective utilization of the human factor and the establishment of standards through holistic and multifaceted safety performance measures.

What about fatigue? Can the example outlined above still be effectively implemented when fatigue presents a significant obstacle to optimal performance?
Fatigue has the potential to lead to errors, yet a robust safety culture prioritizes proactive measures aimed at accident prevention and risk reduction. However, should a breach occur despite these preventive measures, an enhanced crisis management and emergency response protocol becomes imperative to address the breach reactively. For instance, we discussed strategies for preventing fires onboard. If fatigue prevents the implementation of these preventive measures and a fire does occur, the crew, despite potential fatigue, can still respond effectively due to their familiarity with the company's protocols, their assigned duties, and their roles within emergency response teams.

Above mentioned case, explains the interrelation between safety culture and crisis management and emergency preparedness. Most of the research samples, showed that those factors influence each other. The interconnection is profound rooted in their shared dedication to accident prevention, risk mitigation and safeguarding personnel and assets. Safety culture actively promotes risk awareness, adherence to safety procedures and continuous improvement therefore fortifying the company's readiness to address crises with positive result. Key contents of strong safety culture, i.e. clear communication, training and education, effective teamwork etc., play pivotal roles in crisis management efforts. Conversely, crisis management activities, including emergency response, contingency planning and post-incident assessments, contribute to nurturing and reinforcing a positive safety culture. By promptly addressing safety concerns amid crises, a maritime company underscores its unwavering commitment to prioritizing safety and nurturing a culture of resilience. Ultimately safety culture and crisis management form symbiotic pillars of organizations safety management, mutually reinforcing each other to uphold the safety and well-being of crew members and vessels.

Throughout this discussion, it became evident that decision-making skills are paramount to overall safety performance, guiding the implementation of appropriate actions in alignment with company safety protocols. Training and education emerged as direct influencers of decision-making abilities, cultivating enhanced competence and fostering a critical thinking mindset among employees and seafarers. Moreover, research findings highlighted the pivotal role of decision-making skills as mediators between influencing factors and those affected. Notably, CSF 7 emerged as a primary mediator between training and education initiatives and crisis management and emergency preparedness efforts. For instance, continuous drills onboard serve to prepare crew members to make informed decisions amidst crisis scenarios, considering safety priorities, resource availability, and potential outcomes under pressure. Furthermore, effective leadership, which prioritizes safety in decision-making and actions, serves as a catalyst for reinforcing a robust safety culture within the organization and aboard ships. Therefore, given the mediating role of decision-making skills, maritime companies can strategically focus on developing this factor to indirectly enhance crisis management and emergency preparedness. By maintaining training programs and competency assessments focused on decision-making skills, companies can effectively mitigate the impact of incidents and facilitate the implementation of emergency response protocols. In essence, organizations should recognize the significance of mediators in achieving overall performance improvement, setting high safety standards, and fostering opportunities for continuous improvement and development.

Considering the aforementioned insights, the following training proposals are suggested to cultivate informed, decisive, and proficient decision-making among crew members, thereby enhancing crisis management capabilities and fostering the adoption of well-established norms and attitudes conducive to a robust safety culture:

- Bridge Resource Management (BRM), which focuses on enhancing decision-making, communication, leadership skills among bridge team members. The training includes simulations and case studies, through which crew members understand how to take effective decisions in a dynamic environment.
- Navigation and Collision Avoidance training, which explains route planning, collision avoidance and safe navigation practicing, leading to developing such decision-making skills to ensure safe passages.
- Crisis Management and Emergency Response training, which as revealed by above discussion sets standards on effective response in various crisis situations.
- Risk Assessment and Hazard Identification training, which help seafarers to recognize potential risks, take the right mitigation safeguards, safety measures, task prioritization and resource allocation.
- Human Factors and Crew Resource Management (CRM), which addresses human factors related to soft skills that influence decision-making, such as communication, situational awareness, workload management, stress management.
- Incident Investigation and Root Cause Analysis training, which enhances decision-making skills, by analyzing incidents, identifying contributing factors, assessing the effectiveness of existing procedures and implementing corrective action to prevent recurrence.
- Simulation-Based training or drills, which include realistic scenarios to practice decision-making in a controlled environment, according to various dynamic factors, i.e. adverse weather conditions, equipment failures, emergency situations.

Do seafarers have the same opinion and view, regarding the Critical Success Factors on the human element and the results that were produced throughout the research?
Crew members, in contrast to office employees, hold differing views, influenced by their distinct work environments and operational responsibilities. Working aboard a vessel entails isolation, physical demands, and exposure to challenging natural elements, contrasting with the more controlled and stable environment of office-based roles. Office employees establish standards, procedures, and protocols (typically guided by regulatory compliance), while seafarers are tasked with adhering to these protocols and ensuring the safe operation and navigation of vessels. Their roles necessitate strong leadership, teamwork, and clear communication, while office employees prioritize decision-making and strategic planning in alignment with their organizational roles.

For officers and crew members, training and education remain among the most crucial Critical Success Factors that influence their perspectives. However, clear communication is predominantly perceived as an affected factor rather than an influencing one, stemming from seafarers' firsthand experiences in an industry rife with communication challenges. At this juncture, it is important to note that seafarers, given the nature of their profession, are exposed to a wide array of information originating from multiple sources. Seafarers perceive training/education and safety culture as factors that impact their ability to communicate clearly, providing a foundation to overcome limitations such as adverse environmental conditions, technological constraints, cultural and language differences, hierarchy dynamics, and fatigue/stress. Overcoming these limitations requires establishing effective communication channels through enhanced training, such as Crew Resource Management (CRM), and fostering a robust safety culture where individuals feel empowered to report concerns and adhere to established procedures and protocols during challenging voyages. Thus, clear communication is not the means to achieve safety culture but rather a product thereof. Seafarers expect companies to establish safety standards facilitating improved communication and enabling effective reporting to office management.

Furthermore, in the research sample comprising seafarers, regulatory compliance emerged as a critical factor significantly impacting safety culture. Seafarers perceive regulatory compliance as pivotal in ensuring their safety and well-being aboard vessels. Regulations governing vessel construction, equipment standards, emergency procedures, operational practices, and seafarers' training, certification, and competency are designed to mitigate risks, prevent accidents at sea, and ensure personnel possess the necessary skills and qualifications to perform their duties. Compliance with these regulations provides seafarers with assurance that their employers prioritize maintaining a safe working environment and safeguarding their safety.

Conclusions

Throughout this thesis, research has delved into the Critical Success Factors (CSFs) influencing the human element within the maritime industry, shaping safety practices and operational efficiencies at sea. More specifically, the CSFs were identified through an extensive analysis and systematic literature review and their interrelationships were thoroughly explored using the DEMATEL process. This methodology has provided valuable insights into the relative influence of these factors, highlighting areas where strategic interventions can yield significant improvements. Key findings reveal that CSFs like training and competence, leadership and teamwork, clear communication are closely interconnected with factors like safety culture and emergency preparedness, while the decision-making skills, remain as one of the most important mediators. A detailed discussion elaborates on these findings derived from the DEMATEL methodology, which involved analyzing a sample of 93 participants, predominantly comprised of maritime industry experts. Based on the systematic literature review performed, this research not only underscores the significance of CSFs in the maritime sector but also illuminates how these factors interact with each other, identifying critical areas for organizations to focus, enhancing their human element and ensuring effective operational performance. As the maritime industry continues to evolve, addressing these CSFs remains essential for safeguarding human lives, protecting the environment, and maintaining operational excellence.

It was, also, revealed that safety culture is a pivotal critical success factor, heavily influenced by other factors in the cause-effect analysis. However, once a safety culture is established through factors such as training, leadership, teamwork, and communication, it becomes a comprehensive framework that permeates all aspects of an organization's operations, creating an effective safety behavioral environment both ashore and at sea.

Based on the key findings of this research, several managerial implications are crucial for enhancing safety and operational performance. Regular and comprehensive training programs that cover both technical and soft skills, as well as training in communication and decision-making skills, are essential. Developing robust safety culture policies, conducting emergency drills and simulations, and implementing detailed emergency response plans are also vital measures. While many companies already apply these standards to achieve the highest stages of TMSA, this thesis highlights the importance of recognizing and continually developing both technical and soft skills. Training should extend beyond initial programs to include ongoing professional development. Competence validation through assessments, certifications, and practical simulations is essential for both office staff and seafarers. Training programs should also enhance decision-making skills through scenario-based training, critical thinking exercises, and stress management techniques.

Companies should not overlook the importance of crew feedback. Establishing effective feedback mechanisms allows seafarers to express their views and concerns, providing valuable insights into their unique perspectives. Regular surveys and open forums can facilitate this. Additionally, seafarers' practical experience and firsthand knowledge should inform the development of safety policies and procedures, leading to more effective and realistic safety measures and addressing the differing views identified in the research.

In an era of rapid technological advancement, maritime companies should consider adopting innovative tools from other industries to enhance the development of Critical Success Factors. Virtual reality technologies can create immersive training simulations, making training more engaging and memorable. Gamifying these training programs can further enhance retention of safety protocols. Augmented reality for remote assistance allows shore-based personnel to guide seafarers in real-time through complex tasks, reducing downtime and enhancing problem-solving capabilities. Wearable technology can monitor the vital signs, fatigue levels, and overall health of crew members, using real-time data to prevent accidents or develop personalized fatigue management plans. Artificial intelligence (AI) can analyze data from shipboard systems to predict equipment failures before they occur and conduct real-time risk assessments, identifying potential safety hazards and implementing preventative measures. AI can also be integrated into Safety Management Systems to provide easy access for both shore-based personnel and seafarers, with user profiles tailored to their tasks and responsibilities. Finally, creating platforms for crowdsourced safety solutions can leverage the collective knowledge and experience of the crew, leading to innovative solutions and a sense of ownership over safety practices.

Integrating these innovative approaches can position the maritime industry as a leader in adopting forward-thinking solutions and expanding the development of critical success factors. Though not yet commonly used, these recommendations have the potential to address CSFs in unique and impactful ways, ultimately contributing to a safer and more efficient maritime operation.

Limitations and future research directions:

In employing the DEMATEL process to analyze the critical success factors and their cause-effect interrelationships, several limitations inherent to this method must be acknowledged. This research was primarily conducted within the Greek maritime industry, with the majority of participants being maritime company experts. While third-party experts (e.g., from flag administrations, class societies, suppliers, and brokers) also participated, their involvement was less extensive. The DEMATEL process itself has limitations, such as its reliance on expert judgment, which introduces subjectivity and potential bias. To mitigate this, seafarers' opinions were also sought as a different research sample. Lastly, the DEMATEL methodology provides a static snapshot of relationships at a single point in time and does not offer absolute measurements, making the interpretation of influence strengths somewhat ambiguous.

In order to mitigate the limitations of this research and to further develop this thesis recommendations the following are suggested for further research:

- Dynamic Modeling and Longitudinal Studies: To overcome DEMATEL limitations, future research could integrate dynamic modeling approaches or conduct longitudinal studies to capture temporal changes. Also, complementary methods can be employed in future studies to enhance the precision of quantitative assessments.
- Expanded Seafarer Participation: To validate seafarers' opinion, future research should expand the sample of seafarer participation, including crew members from various vessel types and different maritime operations.
- Global Research Scope: To strengthen the validity of the results, future research could be conducted on a worldwide basis, involving experts from other leading maritime nations, such as China.
- Innovation in Maritime Operations: Further research is strongly recommended on the development and use of Artificial Intelligence and Virtual Reality Technologies as an innovative tool on maritime operations and more specifically on Critical Success Factor enhancement.

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Appendix I – Questionnaire

Dear Participant,

Thank you for your willingness to contribute to the research for my Master's thesis, titled "***The Human Element in Maritime Industry Safety: Modeling the Critical Success Factors".*** Your expertise and insights are of immense value as we delve into the complexities of human performance within this pivotal sector.

Human factors pertain to the dynamics of interaction among individuals and the interplay with their environment, equipment, and assigned tasks within a workplace setting. Within the maritime industry, human factors cover an extensive array of components. These encompass crew behavior, decision-making processes, communication protocols, workload management, fatigue mitigation strategies, the efficacy of training programs, and the prevailing organizational culture.

For the purpose of this thesis, we will explore **11 Critical Success Factors**.
Definitions for each, provided below for your convenience, will aid in your comprehension and analysis as you complete the Matrix:

1. **Enhanced Training, Education, and Competence Validation:** Proper training of crew members, including both on-the-job training and formal maritime education, ensures they are equipped with the knowledge and skills to perform their tasks safely, complemented by regular competence assessments to maintain high levels of proficiency.

2. **Safety Culture**: Cultivating a strong safety culture where safety is prioritized above all else, and where individuals feel responsible for their safety and the safety of others.

3. **Use of Technology:** While human factors are crucial, leveraging technology like navigation aids, safety equipment, and modern communication tools can assist humans in maintaining safety.

4. **Comprehensive Fatigue and Well-being Management:** Proper fatigue management practices, including adherence to work-rest hours, ensure the crew is alert, while also addressing the broader aspects of physical and mental well-being to prevent accidents related to health issues or poor mental states.

5. **Leadership and Teamwork:** Strong leadership from the ship's officers, combined with effective teamwork, promotes a safe working environment.

6. **Clear Communication:** Effective communication among the crew members, and between the ship and the shore, is vital for safe operations and in emergency situations.

7. **Decision-making Skills:** Training crew members in decision-making under pressure ensures that they make the best choices in critical situations.

8. **Crisis Management and Emergency Preparedness:** Preparedness for crisis situations through a structured response mechanism, complemented by regularly practicing emergency situations like fire or man-overboard drills, ensures the crew is well-prepared to mitigate the impact of any incident.

9. **Feedback Mechanisms:** Systems that allow crew members to report near-misses, concerns, or suggestions for safety improvements can provide invaluable insights.

10. **Regulatory Compliance:** Adherence to international and local maritime safety regulations, such as those set by the International Maritime Organization (IMO), ensures a standardized safety approach.

11. **Ethical Practices:** Ensuring fair treatment, no harassment, and ethical behavior on board contributes to a positive work environment, which indirectly promotes safety.

Purpose of the Matrix:
The matrix is designed to gather expert opinions on the interrelationships among the above 11 Critical Success Factors. Your insights will contribute to a deeper understanding of how these factors influence each other.

Your Contribution:
Your input is crucial in shaping our understanding of the complex interplay between human factors and maritime operations. We kindly request that you provide thoughtful and detailed responses based on your expertise and experiences. Your insights will help inform future initiatives aimed at enhancing safety, efficiency, and overall performance within the maritime industry.

Confidentiality:
Please rest assured that your responses will be treated with the utmost confidentiality. All information provided will be anonymized and aggregated for analysis purposes only. Your identity will not be disclosed without your explicit consent.

Thank you once again for your participation. Your contribution to this research endeavor is greatly appreciated, and we look forward to receiving your valuable insights.

Nantia Veltsin,
Postgraduate student on
“MBA – Total Quality Management International” at University of Piraeus

Questionnaire

Participant's profile:

1. ***Age:***
   - ☐ 20-35
   - ☐ 36-50
   - ☐ 51-65
   - ☐ 65 +

2. ***Gender:***
   - ☐ Male
   - ☐ Female

3. ***Educational background:***

   - ☐ High school
   - ☐ University degree
   - ☐ Post graduate degree
   - ☐ PhD
   - ☐ Other: __________

4. ***Type of company / public body*** *that you are working (i.e. shipowner company, shipmanagement company, Class, Flag, Broker house, University etc.):*

5. ***Rank/Position*** *in the company / public body* ***and department*** *that you are working****:***

6. ***Working experience*** *in the maritime sector (in years):*

Questionnaire

Please evaluate the degree of influence each critical success factor exert on the others on a scale from 0 to 4, where:
0 = No influence 1 = Low influence 2 = Moderate influence 3 = High influence 4 = Very high influence

Note: Evaluation should not be mirror type i.e. If you evaluate the influence of CSF1 to CSF2 with 3, this does not necessarily mean that the influence of CSF2 to CSF1 is the same (might be equal, less, or more). Therefore, please evaluate/review each factor correlation independently.

Factor \ Influence on →	CSF 1	CSF 2	CSF 3	CSF 4	CSF 5	CSF 6	CSF 7	CSF 8	CSF 9	CSF 10	CSF 11
CSF 1: Enhanced Training, Education, and Competence Validation	—										
CSF 2: Safety Culture		—									
CSF 3: Use of Technology			—								
CSF 4: Comprehensive Fatigue and Well-being Management				—							
CSF 5: Leadership and Teamwork					—						
CSF 6: Clear Communication						—					
CSF 7: Decision-making Skills							—				
CSF 8: Crisis Management and Emergency Preparedness								—			
CSF 9: Feedback Mechanisms									—		
CSF 10: Regulatory Compliance										—	
CSF 11: Ethical Practices											—

Appendix II - Participants Profile

Category	Participants	Age	Gender	Degree	Company	Position	Years of experience
VARIOUS FROM MARITIME INDUSTRY	1	20—35	Female	University	Shipowning	Account officer	10
	2	20—35	Male	University	Shipmanagement	Mid—Senior Accountant	5
	3	36—50	Male	University	Shipowner	Master's General Account Officer	10
	4	20—35	Male	Post graduate	Broker House	Tanker Chartering broker	8
	5	20—35	Female	Post graduate	Broker house	Senior Tanker Chartering Broker	6
	6	20—35	Female	Post graduate	Shipowner	Comercial Assistant	5
	7	20—35	Female	Post graduate	Shipowner	Senior Chartering Broker	8
	8	20—35	Female	Post graduate	Shipmanagement	Accounting Assistant	7
	9	36—50	Female	University	Shipmanagement	Technical Coordinator	16
	10	20—35	Female	University	Shipmanagement	Crew Coordinator	6
	11	36—50	Female	Post graduate	Shipowner	Crew Admiinistrator	7
	12	36—50	Male	Post graduate	Shipowner	Information Technology Administrator	20
	13	20—35	Female	University	Marine ropes industry	Purchasing Assistant	5
	14	20—35	Female	Post graduate	Shipowner	Freight Operator	8
	15	36—50	Male	University	Shipowner	Purchasing Operator	11
	16	20—35	Male	Post graduate	Shipowner	Information Technology Engineer	7
	17	36—50	Female	Post graduate	Shipowner	Human Resources coordinator	13

Category	Participants	Age	Gender	Degree	Company	Position	Years of experience
MID EXPERTS	1	20—35	Female	University	Shipowner	Training Coordinator	7
	2	20—35	Female	University	Shipowner	Training Officer	8
	3	20—35	Female	University	Shipowner	Crew Operator	10
	4	20—35	Female	University	Shipowner	Crew Operator	10
	5	36—50	Male	Post graduate	Shipowner	Crew Operator	13
	6	36—50	Male	Post graduate	Shipowner	Marine Superintendent	30
	7	51—65	Male	University	Shipowner	Marine Superintendent	20
	8	51—65	Male	University	Shipmanagement	Marine Superintendent	25
	9	20—35	Male	University	Shipowner	Tanker Operator	15
	10	36—50	Male	Post graduate	Shipowner	Tanker Operator	28
	11	36—50	Male	Post graduate	Shipowner	Tanker Operator	20
	12	36—50	Male	Post graduate	Shipowner	Dry Operator	24
	13	20—35	Male	Post graduate	Shipowner	Operator	12
	14	20—35	Male	Post graduate	Shipowner	Dry Operator	9
	15	20—35	Male	Post graduate	Shipowner	Technical Superintendent	9
	16	20—35	Male	University	Shipmanagement	Technical Superintendent	8
	17	20—35	Female	University	Shipowner	Technical Superintendent	12
	18	36—50	Male	Post graduate	Shipmanagement	Technical Superintendent	18
	19	36—50	Male	University	Shipowner	Marine Superintendent	20
	20	51—65	Male	University	Shipowner	Marine Superintendent	30

Category	Participants	Age	Gender	Degree	Company	Position	Years of experience
EXPERTS	1	36—50	Male	Post graduate	Broker house	Tanker Chartering Manager	13
	2	20—35	Female	Post graduate	Shipowner	Quality Representantive	11
	3	20—35	Male	Post graduate	Shipmanagement	Deputy Person Ashore	9
	4	36—50	Male	Post graduate	Shipmanagement	Deputy Person Ashore / Safety Manager	19
	5	20—35	Female	University	Shipmanagement	Health, Safety, Environment & Quality Officer	9
	6	51—65	Male	Post graduate	Shipowner	Technical Fleet Manager	30
	7	51—65	Male	University	Shipowner	Chief Security Officer	42
	8	51—65	Male	University	Shipowner	Operations Manager	33
	9	20—35	Female	University	Shipmanagement	Chief Security Officer	9
	10	36—50	Male	University	Shipowner	Operations Manager	29
	11	51—65	Male	Post graduate	Shipowner	Technical Fleet Manager	31
	12	20—35	Male	Post graduate	Manning agency	Crew Manager	8
	13	20—35	Male	Post graduate	Class Society	Technical Specialist	7
	14	20—35	Female	Post graduate	Shipowner	Health, Safety, Environment & Quality Officer	9
	15	36—50	Male	University	Shipowner	Safety Manager	23
	16	36—50	Female	Post graduate	Shipmanagement	Training Manager	8
	17	36—50	Male	University	Shipmanagement	Marine/Vetting Manager	21
	18	36—50	Female	College	Shipowner	Health, Safety, Environment & Quality Officer	30
	19	51—65	Male	Master mariner	Shipowner	Crew Manager	42
	20	36—50	Female	Post graduate	Shiponwer	Health, Safety, Environment & Quality Officer	11
	21	36—50	Male	University	Shipowner	Crew Manager	12

Category	Participants	Age	Gender	Degree	Company	Position	Years of experience
EXPERTS	22	20—35	Female	Post graduate	Maritime Security	Deputy Operations Manager	7
	23	36—50	Male	Post graduate	Shipowner	Operations Manager	20
	24	51—65	Male	University	Shipmanagement	Training Manager	30
	25	36—50	Male	Post graduate	Shipowner	Technical Director	20
	26	36—50	Male	Post graduate	Shipowner	Health, Safety, Environment & Quality Officer	25
	27	20—35	Female	Post graduate	Shipowner	Legal Manager	10
	28	51—65	Male	Master mariner	Shipowner	Alternate Designated Person Ashore	28
	29	51—65	Female	Post graduate	Shipowner	Human Resources Manager	17
	30	36—50	Male	University	Shipowner	Alternate Designated Person Ashore	27
	31	36—50	Male	University	Shipowner	Deputy Safety, Quality & Environment Manager	20
	32	36—50	Male	Post graduate	Shipowner	Operations Manager	20
	33	36—50	Female	Post graduate	Shipowner	Quality Assurance Representative	13
	34	20—35	Female	Post graduate	Shipowner	Health, Safety, Environment & Quality Officer	7
	35	51—65	Male	University	Shipowner	Alternate Designated Person Ashore	24

Category	Participants	Age	Gender	Degree	Company	Position	Years of experience
VESSEL FEEDBACKS	1	20—35	Male	College	Shipowner	Second Engineer	14
	2	51—65	Male	University	Shipowner	Master	35
	3	36—50	Male	College	Shipowner	Chief Officer	25
	4	20—35	Male	College	Shipowner	Chief Engineer	14
	5	36—50	Male	Post graduate	Shipowner	Master	12
	6	36—50	Male	University	Shipowner	Master	29
	7	36—50	Male	College	Shipowner	Second Engineer	10
	8	20—35	Male	College	Shipowner	Second Officer	8
	9	36—50	Male	University	Shipowner	Chief Engineer	20
	10	20—35	Male	University	Shipowner	Chief Officer	14
	11	51—65	Male	University	Shipowner	Master	35
	12	36—50	Male	University	Shipowner	Master	24
	13	20—35	Male	College	Shipowner	Chief Officer	16
	14	36—50	Male	University	Shipowner	Second Engineer	23
	15	36—50	Male	College	Shipowner	Second Engineer	16
	16	51—65	Male	College	Shipowner	Chief Engineer	34
	17	20—35	Male	Post graduate	Shipowner	Chief Engineer	15
	18	36—50	Male	Post graduate	Shipowner	Chief Officer	20
	19	36—50	Male	University	Shipowner	Master	26
	20	51—65	Male	University	Shipowner	Master	30
	21	20—35	Male	University	Shipowner	Chief Officer	8