Transition towards autonomous shipping:

The behavioural and technical skills of the navigational officer of the watch.

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Abstract

The maritime industry is on the brink of one of the most influential technological breakthroughs of the 21st century, autonomous shipping. The benefits of autonomous shipping are clear, from environmental to economic, as the industry looks to capitalise on this revolutionary technology. However, in the event of autonomous system failure, the operator's response in safety critical circumstances could result in catastrophic ramifications for the crew, vessel and environment. Therefore, to have robust and reliable autonomous shipping, this transition should not be instantaneous and will result in a prolonged adjustment period for the industry and crew, in particular the navigational officer of the watch.

The research presented in this thesis utilises a mixed methods empirical approach, consisting of four independent studies. The preliminary work incorporates a survey study, using 100 participants, to establish the seafarers' perspective towards autonomous shipping. The opinions gained from the survey then served as a foundational understanding and rationale to justify the subsequent studies. An interview-based study, was conducted which distinguished key themes from 16 maritime professionals, providing clearer understanding of the concerns that seafarers have regarding onboard decision making processes alongside the development of legislation and suggestions for future officer training. Furthermore, two simulator studies were carried out, using 50 and 60 participants respectively, which highlighted the demographic variables that impact performance and that seafarers experienced difficulties in recognising and diagnosing automation-based faults.

The work conducted in this thesis has identified that, given the current education for seafarers, there is a lack of situational awareness when using highly sophisticated navigational systems. Moreover, this thesis has provided information towards the development and restructure of future officer curricula, in particular the recommended inclusion of a behavioural based training regime, which both the maritime industry and future researchers can use to harmonise the human automation relationship.

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Contents

List of Figures

List of Tables

List of Abbreviations

AAWA	Advanced Autonomous Waterborne Applications
AB	Automation Bias
ABS	American Bureau of Shipping
AHI	Throughout my time within the maritime industry the level of automation and autonomous systems has increased
AIS	Automatic Identification System
ANOVA	Analysis of Variance
AR	Augmented Reality
AUTOSHIP	Autonomous Shipping Initiative for European Waters
AWI	As I progress throughout my career, the level of autonomy within the maritime industry will increase too
BNWAS	Bridge Navigational Watch Alarm System
CCTV	Closed Circuit Television
COLREGS	The International Regulations for Preventing Collisions at Sea
DNV/GL	Det Norske Veritas Germanischer Lloyd
ECDIS	Electronic Chart Display and Information System
EDH	Efficient Deck Hand
ETA	Event Tree Analysis
FA	Fire Alarm
FAL	Facilitation Committee
FMEA	Failure Modes and Effects Analysis
FTA	Fault Tree Analysis
GDF	Gyro Drift Failure
GDPR	General Data Protection Regulation
GMDSS	Global Maritime Distress and Safety System
GPS	Global Positioning System
HASAWA	Health and Safety at Work Act
HAT	Human Autonomy Teaming
HELM	Human Element Leadership and Management
HITL	Humans in the Loop
HNC	Higher National Certificate
HND	Higher National Diploma
HSD	Honestly Significant Difference
HURID	Human Risk Informed Design
IACS	International Association of Classification Societies
IMO	International Maritime Organisation

ISO	International Organization for Standardization
LEG	Legal Committee
MARPOL	International Convention for the Prevention of Pollution from Ships
MASS	Maritime Autonomous Surface Ships
MCA	Maritime Coastguard Agency
MET	Maritime Education and Training
MGN	Marine Guidance Notice
MOQ	Maritime Officer Questionnaire
MR	Mixed Reality
MSC	Maritime Safety Committee
MSN	Merchant Shipping Notices
MUNIN	Maritime Unmanned Navigation through Intelligence in Networks
NAEST	Navigational Aids, Equipment and Simulator Training
NASA TLX	NASA Task Load Index
NGO	Non-Government Organisation
NTSB	National Transportation Safety Board
NYK	Nippon Yusen Kabushiki Kaisha
OOW	Officer of the Watch
PES	Post Exercise Survey
ROF	Rudder Offset Failure
RQ	Research Question
SA	Situational Awareness
SBA	Single Best Answer
SJQ	Situational Judgement Question
SMS	Safety Management System
SOLAS	Safety of Life at Sea
SQA	Scottish Qualification Authority
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers
TEU	Twenty-foot Equivalent Unit
ULCV	Ultra Large Container Vessel
VHF	Very High Frequency
VR	Virtual Reality
VTS	Vessel Traffic Services
XR	Extended Reality

List of Publications

Journal Publications:

- Jevon Philip Chan, Rosemary A. Norman, Kayvan Pazouki & David Golightly, (2022) Autonomous maritime operations and the influence of situational awareness within maritime navigation, WMU Journal of Maritime Affairs, 21, 121–140
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Chapter 1. Introduction

1.1 Background

The maritime industry is on the cusp of some of the most impactful technological advances in shipping since the introduction of the combustion engine. With developments being made in emissions regulations and autonomous system technology, the maritime industry will have to make adjustments to ensure a smooth transition to the digital age of shipping. However, this step forward will have an impact at every juncture, hence, from classification societies to seafarers every aspect must be treated with the utmost care to ensure success as the maritime industry progresses. Levels of automation have increased gradually since the turn of the 21st century with the standardisation of the electronic chart display and information system (ECDIS) and autopilot being installed onto the vast majority of merchant vessels. This has then given the maritime industry the platform to conduct research into various projects that will aid the development of autonomous shipping. Research projects such as Maritime Unmanned Navigations through Intelligence in Network (MUNIN) (MUNIN, 2017) and Advanced Autonomous Waterborne Applications (AAWA) (Jokioinen, 2016) have formed the backbone of knowledge for the maritime industry with regard to autonomous shipping. Furthermore, this research has contributed to additional studies into autonomous vessel operations through the development of autonomous regulations such as Autonomous Shipping Initiative for European Waters (AUTOSHIP) (Bolbot, et al., 2020) and the International Maritime Organisation (IMO) Maritime Safety Committee (MSC) scoping exercise on Maritime Autonomous Surface Ships (MASS) (MSC - IMO, 2018); and has aided the design and construction of autonomous ships and ship retrofit projects such as Yara Birkeland (Kongsberg, 2017) and the Nippon Yusen Kaisha (NYK) line crewless MASS trials (NYK Line, 2019).

With the increasing rate of commercialising MASS, seafarers must be capable of managing their own abilities and coping with this transition. With autonomous operations looking to be implemented in the foreseeable future, research conducted has shown that the benefits of implementing fully autonomous and crewless vessels are apparent through providing a higher level of safety and reduction in cost, providing the system operates efficiently and correctly (Staruch, 2017). However, the ethics and challenges have been made apparent in the literature. Due to the value of cargo, whether that be goods, oil, passengers etc, a fully autonomous and crewless vessel is susceptible to cyber-attacks (Kavallieratos, et al., 2019). Moreover, the complications between system communications, route plotting and following, interference and collision avoidance have all be highlighted as potential hurdles that the maritime industry needs to address and overcome prior to commercialising a fully autonomous crewless vessel (Felski & Zwolak, 2020). Beyond these potential issues, the maritime industry should also learn from other transportation sectors such as the aviation industry. Within modern airlines the levels of autonomy are far greater than what is expected onboard a standard merchant ship. However, the training that airline pilots receive places emphasis on subjects such as situational awareness (SA) in addition to their in-flight responsibilities being more of a supervisory role (Sarter & Woods, 1994). With research dating back to the 1990s it is possible for the maritime industry to learn from the errors made by the aviation sector to ensure a smoother transition to autonomous shipping. Additionally, there are still crew members located within the cockpit which may indicate that the maritime industry will have to evolve the navigational officer role onboard.

While the maritime industry is currently focusing on autonomous shipping, the direction of research must concurrently advance to strengthen the relationship between automation and human operator. This improvement in relationship can come about by increasing training requirements, modification of the system interface, updating operational procedures or a combination of these. Research undertaken has shown that with the correct training, humans can find and correct technical faults that occur in automated systems (Pazouki, et al., 2018).

The next foreseeable technological leap will be heading towards the autonomous ship or "smart ship". The advantages of heading toward full vessel automation, would be evident as ships would no longer require seafarers to be onboard. This can not only be viewed as an improvement from an economic perspective, but it may also improve safety aspects as there would no longer be accidents involving the damage or loss of human life occurring on board vessels, due to the absence of seafarers (Kim, et al., 2019).

With the maritime industry in the early stages of autonomous system development, it is critical for the industry to take the precautionary steps to ensure the success of the introduction of autonomy. Furthermore, there is a lack of research into the maritime human-automation relationship, specifically addressing the impact that autonomy will have on seafarers. This thesis aims to address the research gap in literature and provide both the maritime industry and seafarers the knowledge to limit the teething issues that may be associated with the introduction of autonomous systems.

1.2 Key Themes

Many key themes are discussed throughout this thesis. Each of these themes is aligned to the navigational aspect of the maritime human factors research field. Each of following themes is critical to the development of this thesis and influences the design of the studies and is subsequently affected by the outcome of the thesis:

- Maritime Human Factors

  Many maritime accidents are attributed to human factors and, as such, this theme is critical to the development of this thesis. Furthermore, aspects such as the situational awareness, bias, complacency and over reliance of an individual towards automation and autonomy are discussed in detail throughout this thesis.

- Navigational Watchkeeping

  The introduction of autonomous shipping will revolutionise the role of the officer of the watch (OOW), henceforth this thesis aims to address the intricacies of navigational watchkeeping. Topics such as navigational distractions, fatigue, stress, navigational system knowledge and cognitive behavioural traits of OOWs are discussed throughout the thesis. Additionally, the elements of watchkeeping performance, including both fault recognition and fault diagnosis, have a critical impact on the direction of this thesis.

- Officer of the Watch Education and Training

  Maritime autonomy has the potential to be the most impactful technological advancement for the maritime education and training (MET) sector in recent history, through the inclusion of new topics and removal of outdated subjects. Therefore, the topics of navigational curricula and syllabi are featured throughout the development of this thesis.

- Human Automation Relationship

  As systems increase in complexity and sophistication, autonomy may transition from a seafaring tool to a complex seafaring team member in vessel operations. Consequently, this thesis discusses the complexities of trust in automation, optimising autonomous systems to compliment the OOW and the development of the OOW role to act in a supervisory capacity for autonomous systems.

1.3 Aims and Objectives

With the introduction of autonomous shipping in the foreseeable future, the aim of this thesis is to identify whether current navigational officers and cadets are suitably equipped with the skill set for the introduction of autonomous navigation. Additionally, this thesis will aim to deliver recommendations for the maritime industry to introduce to navigational education to aid the evolution of the navigational OOW role. This is to be achieved through the following objectives:

1. Determine the level of knowledge and understanding that modern seafarers have regarding autonomy and digitised bridges.
2. Analyse the relationship between modern automated navigational systems and operators.
3. Analyse the seafarers' perspective of the current officer training regime and autonomous shipping.
4. Determine whether situational awareness is a concern among navigational seafarers.
5. Determine the environmental variables that negatively impact a seafarer's situational awareness.
6. Assess whether different training can influence the fault recognition and diagnosis skills of seafarers.

As previously stated, there is currently a gap in literature around the impact of autonomous shipping with respect to seafarers. Therefore, this has justified the exploration of this thesis and by addressing the aim and objectives, this thesis will provide the information to aid the maritime industry's understanding, particularly the MET sector, of the development of future training regimes for navigational officers. A mixed methods approach of both qualitative and quantitative studies was adopted for this thesis; this methodology is discussed in detail in Chapter 3.

1.4 Research Questions

Through the development of the aforementioned research objectives, it was possible to develop multiple research questions that will be answered in this thesis. Therefore, this thesis aims to address the following research questions (RQ):

RQ1. What is the perception among seafarers of the current training regime, the introduction of autonomous shipping and the human automation relationship?

RQ2. Are modern seafarers equipped with the fault awareness skills suited for supervising autonomous shipping?

RQ3. Do demographic variables such as age, education level, sea experience or rank have an impact on the seafarers' opinions of autonomous shipping?

RQ4. Do seafarers lack the concentration skills to maintain the safety of the vessel?

RQ5. Do demographic variables such as age, education level, sea experience or rank have an impact on the fault recognition and fault diagnostic skills of navigational officers?

RQ6. Can a different training method improve the fault recognition and fault diagnostic skills of seafarers?

1.5 Thesis Structure

The development of the research objectives stated in Section 1.3 has influenced the design of this thesis, and has structured the thesis into nine chapters. The thesis continues with the review of literature in the maritime human factors research field in Chapter 2. In the literature review topics are discussed, such as the impact that autonomous shipping will have on maritime legislation, the human automation relationship from a maritime perspective and the discussion of the impact that maritime autonomy may have on MET, in addition to education through simulation.

Chapter 3 then defines the rationale behind the methodologies utilised in this thesis. Chapters 4, 5, 6 and 7 present the individual studies conducted and their associated findings, while Chapter 8 examines the cross cutting themes of both the individual studies and the collective research. Chapter 9 then presents the conclusion of the research work and recommends the future direction that may be taken for this work.

Chapter 2. Literature Review

2.1 Chapter Summary

The following chapter presents the literature behind the key areas and important surrounding research topics that impact the human automation relationship in terms of maritime human factors. Rationales for the research conducted in this thesis are identified with this chapter.

The chapter commences with detailing the current research and work that is being conducted for the production of MASS and the direction of the maritime industry once autonomous systems have been introduced.

The chapter then details the daily life onboard vessels for seafarers, highlighting the intricacies of the OOW role. Subsequently the chapter then examines past maritime incidents that have been reported as a consequence of human factors and the current relationship that other transportation sectors have between their respective human operators and autonomous control systems. Furthermore, the chapter then details how MASS will impact the maritime industry and the current use of navigational simulators within the MET sector.

2.2 Autonomous Shipping and The Future for the Maritime Industry

2.2.1 Background

The relationship between human operator and technology has rapidly developed into a significant part of day-to-day life, within many industries beyond the maritime world (Ghazizadeh, et al., 2012). This has led to the development of automation and autonomous technology to aid human operators with a wide variety of tasks that have an expansive range in complexities which the technology can undertake (Skibniewski & Hendrickson, 1990). In recent years, the level of autonomy has seen a significant rise, globally, within many industries that require a high standard of safety. The benefits of leaning towards full automation and then remote autonomous operation are vast as they provide a level of safety and cost benefits that outweighs the use of humans, and when implemented appropriately one can expect the desired result (Staruch, 2017). Nevertheless, autonomous systems, like everything, can experience malfunctions or if operated erroneously then the automated systems can produce a level of danger to the operator, and environment.

Past research has identified multiple areas of concern with aspects such as over reliance, complacency, and bias in highly sophisticated automated systems (Parasuraman & Manzey, 2010). Furthermore, research has highlighted that as technology increases within the maritime industry, aspects such as over reliance on onboard automation acts as a critical symptom of human caused failure that can result in hazardous scenarios for the vessel (Demirel, 2019).

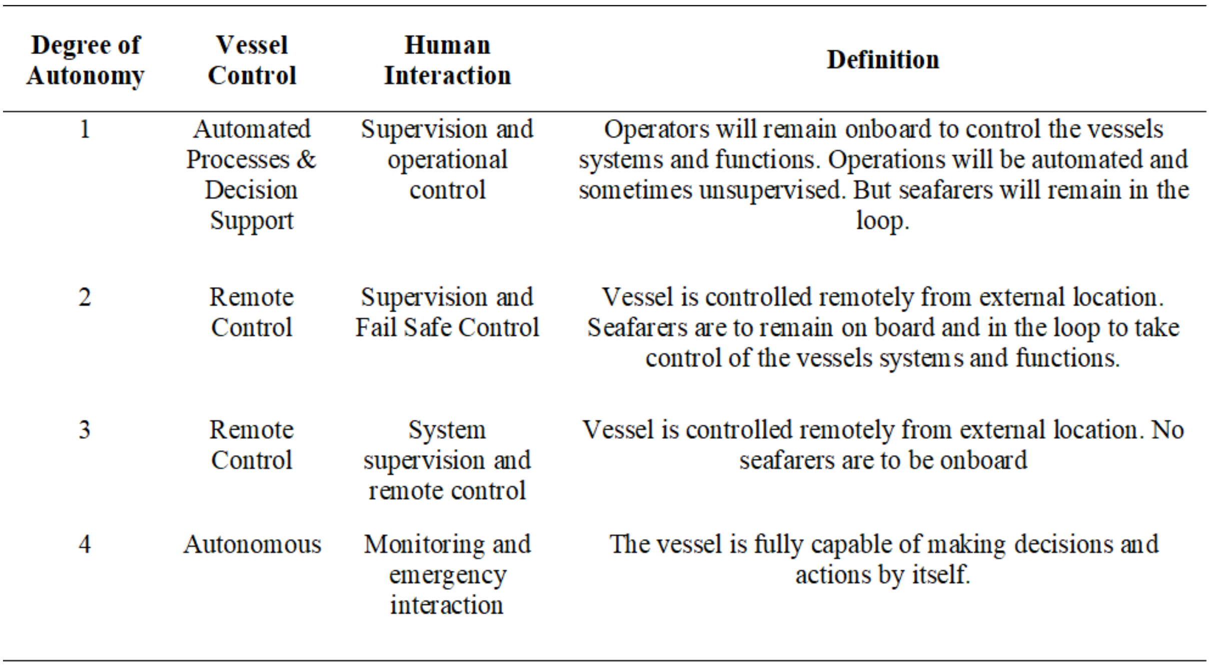
Furthermore, the history of maritime transportation and the occupation of seafaring has seen a long and illustrious history that can be dated as far back as the ancient era, and to date is responsible for around 90% of the world trade (OECD, 2018). However, the maritime industry is now at the brink of one of the most impactful technological advancements it has seen; autonomous navigation.

2.2.2 Legislation and the IMO

The advantages for the maritime industry of full vessel automation would be evident as the ships would no longer require seafarers to sail onboard. The removal of seafarers may be perceived to be an economical benefit, which may have a positive consequential effect on the onboard safety element as the absence of seafarers would result in minimal onboard accidents (Batalden, et al., 2017). The benefits of MASS have been widely documented from economic to environmental (Ziajka-Poznańska & Montewka, 2021), as such this has led to maritime regulatory bodies and classification societies to conduct research to develop guidance for the impending changes in technology (Yoo & Jo, 2023).

With the IMO looking to devise various methods to allow for the successful installation of autonomous technologies onboard, including regulatory scoping exercises and the creation of the joint MASS working group for the MSC, legal committee (LEG) and facilitation committee (FAL), as the maritime industry is preparing for the eventual introduction of autonomy (MSC - IMO, 2018). The introduction of the MSC resulted in the authorisation of the framework, through which a regulatory scoping exercise on MASS to be carried out. The exercise covered all work in progress for “Smart Ships”, initial definitions of MASS and the varying degrees of autonomy. Beyond the exercise, a methodology and plan of work were simultaneously created for the regulatory scoping exercise. The work conducted from the scoping exercise identified the varying levels of autonomy as shown in Table 2.1.

Table 2.1: IMO Degrees of autonomy (Kim, et al., 2019)



Degree of Autonomy	Vessel Control	Human Interaction	Definition
1	Automated Processes & Decision Support	Supervision and operational control	Operators will remain onboard to control the vessels systems and functions. Operations will be automated and sometimes unsupervised. But seafarers will remain in the loop.
2	Remote Control	Supervision and Fail Safe Control	Vessel is controlled remotely from external location. Seafarers are to remain on board and in the loop to take control of the vessels systems and functions.
3	Remote Control	System supervision and remote control	Vessel is controlled remotely from external location. No seafarers are to be onboard
4	Autonomous	Monitoring and emergency interaction	The vessel is fully capable of making decisions and actions by itself.

Research stemming from this scoping exercise has explored the concepts of designing a fully autonomous and unmanned vessel with the results identifying the need to keep seafarers onboard for the foreseeable future, despite the majority of incidents occurring from human interaction (Bratić, et al., 2019). Other research has also illustrated that the scoping exercise conducted by the IMO has defined multiple caveats for autonomous shipping and how to address various legal questions which may emerge alongside the development of autonomous technology (Klein, et al., 2020). Additionally, it was suggested that the IMO should not begin to simplify a highly complex design process and the objectives for MASS are outlined from statutory rules, with the main detail being derived by flag state and classification societies (Ringbom, 2019). Research has also identified that any autonomous system should be designed with a predictable thought process to allow human operators to understand the proceedings of the system (Porathe, 2019). Following the conclusion of the MASS scoping exercise, the discussion at IMO revealed that the shipping industry, from a technological perspective, is on the verge of readiness to move from current involvement of automation in operations to full automation and then autonomous ships. However, in this pathway seafarers are still critical for safe and secure ship operation.

Navigational officers and ships masters of the present will reach the assumed age of retirement, 62 years of age, within the next 10-15 years, with statistics showing that as of 2022, 61.3% of UK certificate of competency holders, of chief officer or higher, were over the age of 40 (Department for Transport, 2022). As such, age has been identified as an important variable in the discussion of trust in automation (Hoff & Bashir, 2015). The stigma of ageism with technology has been documented on multiple occasions, beyond the maritime industry, from the consumers' perspective in trusting older operators with the running of a vehicle or system (Winter, et al., 2014), or understanding the levels of trust displayed among age groups when using decision support aids (Pak, et al., 2012). Subsequently, studies have identified that older humans have more trust and reliance on decision aids than the younger cohort (Ho, et al., 2005; Mcbride, et al., 2010). This aging demographic shows that soon the entire maritime industry will be succeeded by crew members who have only ever experienced heavily automated operations. Reliance and dependency on automation could prove detrimental and worrisome for the maritime industry, with research highlighting the concerns from industrial experts towards autonomous shipping being the result of a cohort of seafarers losing key skills and operational knowledge (Mallam, et al., 2020).

Work conducted by the IMO has highlighted the concerns of the industry, including the uncertainties behind machine learning and smart shipping (Kim, et al., 2020). As such the IMO have directed their future goals to address these concerns through further research prior to allowing MASS to operate within global waters and to develop a two stage legislation system with the primary legislation to regulate vessels adhering to MASS and the secondary legislation being a code of practice for remotely operated unmanned vessels (IMO - Maritime Safety Committee, 2022). Furthermore, the outlook of a fully autonomous maritime industry has garnered interest among the regulatory bodies that develop the guidance and rules for the industry. Members of the International Association of Classification Societies (IACS) have begun development on various aspects of MASS, in particular cyber-resilience of MASS (IACS, 2022; IACS, 2022). IACS have identified the lack of standards that are currently instated for MASS, and they are looking to participate in the development of MASS (IACS, 2019). Furthermore, the individual members of IACS have begun to develop the foundations which will allow them to develop their own rule sets for MASS to adhere to (American Bureau of Shipping, 2022; Det Norske Veritas - Germanischer Lloyd, 2018; Bureau Veritas, 2019). Moreover, classification societies are also working together with various industrial bodies to conduct research into vessels and systems that will aid development of rules (Schiaretti, et al., 2017).

The development of autonomous systems and ships has created concerns within the maritime community regarding job security and has been a polarising topic among the industry (Kim, et al., 2020; Rødseth & Vagia, 2020). Moreover, research has shown that industry experts have many concerns regarding autonomous shipping including; that the reduction of crewing numbers, in addition to an increase in automation, will result in an over reliance on sensor technology; that the reduction of crewing numbers and the increase of automation will not result in a safe environment; and that the high levels of autonomy are not safe for human operation (Hannaford & Hassel, 2021). Such topics have subsequently complimented research regarding the manning requirements for vessels which has transitioned from minimum manning requirements to safe manning requirements, which denote the number of seafarers required to maintain both safety at sea and to determine the seaworthiness of the vessel (MacDonald, 2006). Furthermore, Carey (2017) suggested that the removal of crew from an autonomous vessel may render the ship unseaworthy, due to the vessel being unable to comply with COLREGs which will have a further effect on the industry from a legislation perspective. Vessels currently require a master onboard to act as the responsible human for the vessel and research into the removal of the master has highlighted that such actions require a deeper investigation to ascertain the appropriate answer (Stępien, 2023).

2.2.3 Maritime Projects and Industrial Developments

Beyond the regulatory sector of the maritime industry, many marine design and shipping companies are partnering with regulatory bodies to utilise current legislation and develop their own autonomous vessels. Various projects such as the Yara Birkeland (Kongsberg, 2017); NYK MASS trials (Lakshmi, 2018); MUNIN (MUNIN, 2017); AAWA (Jokioinen, 2016); AUTOSHIP (Bolbot, et al., 2020); and the ReVolt ship (Alfheim, et al., 2018), have developed the foundations, from an industrial perspective, to introduce autonomous systems onboard. These projects have theorised the wide range of benefits including financial and safety, that autonomous shipping will bring to the industry. Many projects within the field of autonomous ships are currently being completed, one of these is the EU Funded project AUTOSHIP. The development of the AUTOSHIP project aimed to provide the maritime industry with the knowledge of how to address: economic barriers; regulations; and societal issues faced by autonomous shipping (Bolbot, et al., 2020). While the project is still ongoing, it has established that for autonomy to successfully integrate with onboard operations, the operator must be able to trust the system in its operation. Thus, the operator should no longer need to pay attention to the system. Moreover, the findings have suggested that current taxonomy surrounding autonomous shipping has created confusion and the project aims to define clear descriptions of the operations for both the system and operator (Rødseth & Wennersberg, 2023).

Due to the wide scope of autonomous shipping, research projects have extended beyond the development of the autonomous ship and autonomous infrastructure and have assessed the requirements from a human factors perspective i.e., SAFEMODE project (Save, et al., 2021).

Furthermore, the SAFEMODE project identified that both the maritime and aviation industries do not currently have the framework to gather and analyse human factors information, which the project created the Human Risk Informed Design (HURID) platform to collate and analyse human factors data. Concurrently, the project has identified the criticality of enhanced taxonomy to provide further clarification to current terminology or the development and application of new taxonomy (Maya, et al., 2021).

As research looks to develop and promote various autonomous systems, there are equally studies that have identified concerns that the industry must address prior to installation. One study analysed the research that has been conducted into MASS and has categorised the risks associated with autonomous shipping into 4 distinct groups: system functional risks, organisational risks, human risks, and environmental risks. Additionally, Li, et al (2023) identified that aspects such as design fault, cyber-attack, inapplicable regulations, propulsion and steering system malfunction, shore control centre poor performance and autonomous navigation controller malfunction are all pivotal for the success of the entire autonomous maritime operation. Moreover, research has also identified that seafarers are somewhat opposed to the idea of MASS and that shipping owners and operators believe that autonomous shipping will benefit the industry and cover up the navigational deficiencies of seafarers (Theotokatos, et al., 2023). Nevertheless, Hannaford, et al (2022) has suggested that seafarers are open to the idea of change. With such concerns and ambiguity arising from the topic of autonomous ships, it can be seen that the transition to MASS will not be an instantaneous or uncontroversial event. Consequently, as the industry begins to commercialise and produce complex autonomous technologies, the criticality of the inclusion of humans in the loop (HITL) operations must be better understood (Mallam, et al., 2020).

The development and continual improvement of the human automation relationship has been suggested to be a critical feature that autonomous technology must acknowledge (Tam, et al., 2021). As such a combination of improving operator training, in addition to optimising the user interface and overhauling the operational procedures has the potential to improve this relationship. Moreover, Pazouki, et al (2018) has shown that the creation of an optimal training method can result in an improvement in the fault recognition skills of individuals (Pazouki, et al., 2018). Therefore, as the industry gradually progresses towards the first degree of autonomy it is imperative that the human automation relationship is harmonious between system and operator to improve the safety onboard.

2.3 The Human Automation Relationship

Over the course of the next 30 years the maritime industry is aiming to devise legislation, digitised smart ports, and provide an infrastructure to develop autonomous shipping with the aim of improving the environmental impact of the maritime industry (Department for Transport, 2019). However, the design of the initial onboard autonomous systems may be developed from the foundational knowledge of current onboard automated systems such as the ECDIS which already pose issues such as incorrect operation and an overreliance in the system (MAIB DMAIB, 2021). Trust and overreliance in automated systems is not a novel concept and has been identified as a flaw of automation in research conducted prior to the turn of the millennium (Lee & Sanquist, 1996).

The human-automation relationship is key to the success of maritime autonomy. In various transportation sectors, it has been shown that, if correctly operated, automated systems have the potential to be beneficial for the human operator (Kaber & Endsley, 1999). However, despite the benefits automation brings, an over reliance on automation can prove to be detrimental to the infrastructure implementing it. Moreover, research in the field of human-automation factors has highlighted issues such as a degradation of SA, out-of-the-loop performance, mind wandering, and over reliance (Gouraud, et al., 2017).

A common issue that has frequently been identified with the overall rapid advancement in automation, is the continuous negative impact on job skills (Ra, et al., 2019). This issue has also plagued the maritime industry with one study identifying that as technology increases, fundamental shipping knowledge and training may be overlooked in future MET regimes for seafarers (Alop, 2019). Additionally, research has indicated that there is a need to improve the education and training standard among seafarers (Chae, et al., 2021). A combination of these issues could prove to be a significant problem for autonomous shipping.

In 1995 the grounding of the *Royal Majesty* occurred 10 miles from Nantucket Island. From this incident the National Transportation Safety Board (NTSB) found that the cause of the accident was due to an overreliance on the vessels automated systems, displayed by the OOW (National Transportation Safety Board, 1995). Due to the high profile of the incident, in 2002 research was conducted analysing the grounding of the *Royal Majesty*, from the perspective of a crew member. This study identified the limitations of maritime automation as well as how to better utilise automation to improve the navigational officer role rather than replace it. Additionally, the study highlighted that automation, if used incorrectly, does not remove human error but has the potential to exacerbate misunderstandings around the position and status of the vessel (Lützhöft & Dekker, 2002). A multitude of issues currently stand in the way of a harmonious transition towards autonomous shipping. Communication problems and an integration of MASS into the International Regulations for Preventing Collisions at Sea (COLREGs) have already been highlighted among seafarers as initial issues as there is confusion and uncertainty as to how to perceive MASS operated vessels in day-to-day shipping traffic (Miyoshi, et al., 2022).

Another common issue for seafarers is that they work in a real time environment with time-based alarms and distractions. Research has shown that this issue has resulted in a considerable amount of time being wasted on their watch due to unnecessary alerts on the bridge, with participants of the study believing that nearly half of the alerts received on the bridge contribute to a distraction whilst navigating the vessel (Maglić & Zec, 2019). Furthermore, the non-standardisation of systems among vessels has already introduced problems with maintaining a level of safety between vessels (Kurt, et al., 2015). A study has shown that 68% of participants surveyed have had experience with a variety of integrated bridge set ups. From this study 62% of participants felt that they required more than a day to become fully familiar with the systems onboard, whilst over half of the participants stated that their company gives them less than 10 hours of familiarization time before they are responsible for the safe passage of the vessel (Mišković, et al., 2018).

Overreliance and trust are a common theme for the future of shipping. Statistics have claimed that the leading cause of maritime incidents is due to human error, with an estimated 75% to 96% of all maritime accidents being attributed to human interaction with the system (Allianz Global Corporate & Specialty, 2022). However, technology is not infallible, and statistics do not highlight events where the human interaction has averted a course of disaster. Research has been conducted attempting to verify the human error figure through an extensive review of incidents, but this ultimately found that the rate of maritime human error could not be validated (Wróbel, 2021). Furthermore, it was discovered that while the human error can be attributed to the cause of an accident, most failures that occur are not a direct fault of the operator, with the cause of the human error failure being credited to the working environments, technologies, and organisational factors of the vessel (Galieriková, 2019).

The aspect of communication is critical in the role of a navigational OOW. In the infancy of maritime automation, research identified that increasing the level of automation to replace human work is not suitable for the maritime environment, and to promote automation as a team player, human operators should have an adequate knowledge of task delegation for the system (Lützhöft & Dekker, 2002). A study was conducted analysing various incidents caused by human interaction, which found that most accidents occurred due to a breakdown in communication or misjudgements when navigating through pilot waters (Sánchez-Beaskoetxea, et al., 2021). The breakdown of communication has frequently been highlighted within literature as a common theme for the cause of maritime incidents among seafarers (Mišković, et al., 2022; Hasanspahić, et al., 2021). Furthermore, another research study has identified the leading cause of human error failure to be the condition of the operator, with the recommendations being that the maritime industry should look to develop guidelines for crew members, onboard safety courses for officers and guidance to develop a safer working environment onboard (Hasanspahić, et al., 2021). Developing a system that can optimise human-automation teaming will prove to be a step in the right direction. Allowing the human operator to act as a supervisor and the autonomous systems to undertake tasks will promote harmony within the human-automation relationship. However, as the level of autonomy onboard is increased, the SA of the operator decreases (Endsley, 2017).

2.3.1 The Modern Day Seafarer

As highlighted, seafaring is one of the longest standing professions. It is believed that to be a successful OOW hard work, determination and perseverance are all traits that are required to conquer the challenges that will be encountered daily (Magramo & Gellada, 2009). As the role of the OOW has progressed into the 21st century, the required knowledge of navigation has expanded beyond chartwork and celestial navigation, to incorporate technology and navigational systems (Aylward, et al., 2022). As time has progressed the OOW has had to become adept in using systems such as ECDIS, autopilot and the bridge navigational watch and alarm system (BNWAS), all of which may be optimised to aid the development and installation of onboard autonomous navigational systems (Rylander & Man, 2016). Moreover, as autonomous technology develops into the latter stages of MASS, the training regime may increase in difficulty for OOW students by adding in more active training using simulation to replicate the daily operations onboard (Setiawan, et al., 2021).

Due to being a global industry, the seafaring career is not regulated and standardised between countries. Research has demonstrated that seafarers from South-East Asia on average spend a longer duration of their life at sea and that there are lower numbers of qualified officers in comparison to the seafarers from western countries (Jensen, et al., 2006). Moreover, as seafaring has evolved the number of crew members onboard has reduced, due to the redundancy of various roles onboard and the introduction of the minimum manning requirement, which has allowed shipping companies and shipowners to implement smaller crew numbers to maximise trade profits (Bateman, 2009; Maritime Coastguard Agency, 2015). Additionally, mental health and wellbeing has become increasingly important and highly publicised in current times, with the maritime industry being no exception. Furthermore, research has shown that seafarers are a high risk group due to the job demands and lack of social circle, among many other factors, thus suggesting that shipping companies and owners should provide greater access to support and increase crewing numbers to improve mental health onboard (Brooks & Greenberg, 2022).

As the development of autonomous technology progresses, there is the potential for seafarers to become competent and comfortable in using highly sophisticated systems. However, if it is compared to onboard systems that are perceived to be reliable, it can be seen from many incidents that a lack of training or system knowledge has been attributed to some of the maritime industry's worst accidents (Nazir, et al., 2015). With systems such as ECDIS being initially discussed in the 1980s, it could be expected that the maritime industry would have laid the foundations to safely develop and implement training requirements for the system (Greer, 1994). However, the 40 years since the early 80s have still resulted in multiple instances of maritime incidents occurring due to a lack of understanding or training with the system, with the ECDIS still being in its "Implementation Phase" despite over two decades of constant onboard use (MAIB DMAIB, 2021). Moreover, research has identified discrepancies with ECDIS training and how to improve the learning curve that students have with the ECDIS (Brčić, et al., 2017). Additionally, further research into ECDIS has identified that due to the multiple manufacturers responsible for the design and development of the systems, there is a lack of continuity that ultimately creates a lack of familiarity for the OOW (Žuškin, et al., 2023). Therefore, there may a longer "Implementation Phase", due to the complexities associated with autonomous systems, than what is currently expected.

2.3.2 Human Autonomy Teaming and Humans in the Loop

Human autonomy teaming (HAT) has been defined within research as the collaborative relationship between autonomous systems and the human operator with both parties acting as team mates to each other (McNeese, et al., 2017). HAT research has allowed multiple industries, beyond the maritime sector, to better understand the topic and that modern day technology has yet to be optimised to harmonise HAT (Rieth & Hagemann, 2022). Research by Ellwart & Schauffel (2023) has shown that HAT has identified that many aspects of the maritime operational sector could benefit from HAT, with aspects such as ship inspections being prevalent in literature . Conversely, it has been shown that autonomy must be used as a valued team member equal to the operator and not just used as a tool (Ellwart & Schauffel, 2023). Nevertheless, HAT studies have predicted that in the event of introducing control centres for autonomous vessels, human error will still be prevalent namely through complacency, psychological issues, lack of understanding and fatigue among many others (Zhang, et al., 2020). However, how successfully autonomy is introduced will fundamentally be defined by the relationship between the human operator and navigational systems, through HAT (O'Neill, et al., 2022). Moreover, research has identified HAT collaboration as the potential future for aviation control, with sophisticated systems being designed in a manner to deliver consolidated information to the human operator, and that HAT has the potential to improve the human operator’s SA (Demir, et al., 2017).

Research on HITL has become prevalent with regard to MASS due to the complexity of the system and the supervisory role of the OOW that has been defined by the IMO scoping exercise (Maritime Safety Committee - IMO, 2018). As the introduction of autonomous systems will be a gradual process, the degrees of autonomy, as outlined by IMO, will look to implement HITL to allow the human operator to take a supervisory position over the autonomous systems (Grønsund & Aanestad, 2020). Due to the importance of HITL, research has been conducted analysing the various phases of autonomy that MASS will implement and how to use modern technology to better understand how to maintain the HITL within the decision making process (Wu, et al., 2022).

The concept of MASS, as defined by the IMO, promotes a harmonious working relationship between the OOW and the autonomous navigational system for the foreseeable future. Additionally, the critical feature that MASS must include is the ethical safety of the vessel, crew, cargo, and environment (Xing & Zhu, 2023). Therefore, any autonomous systems that are designed, should be conducted in a manner that HAT will allow the human to take over control of the vessel to increase safety (Lützhöft, et al., 2019). Such systems must incorporate automation transparency to support the OOW, deliver consolidated advice to correct faults and aid their SA (Endsley, 2017). Subsequently as navigational systems become more sophisticated, the system must provide the OOW with a display interface that allows the human operator to safely understand the situation whilst simultaneously taking control of the vessel (Koen van de Merwe, et al., 2023).

2.3.3 Maritime Human Factors

Within the maritime industry, human factors are often referred to as the interaction between human and machines at sea, regardless of outcome (Schröder-Hinrichs, et al., 2013). With a significant number of accidents annually being attributed to human error, it is important to understand the main causes behind the accidents and how elements such as SA, automation bias (AB), complacency, and other human actions factor into the incident occurring. Research suggests that in the event of there being an excessive or insufficient amount of reliance in the automated system then complacency or AB would occur (Lee & See, 2004). A potential learning method to expedite the understanding of maritime autonomy and develop core navigational skills may be through the use of simulation training (Nakashima, et al., 2023). Research into human factors in the maritime industry has increased with studies having identified the twelve human factors, defined as the deadly dozen, that have acted as the most common precursor to human error which ultimately leads to maritime accident, as shown in Figure 2.1 (Martime Coastguard Agency, 2016; Singh, et al., 2023).

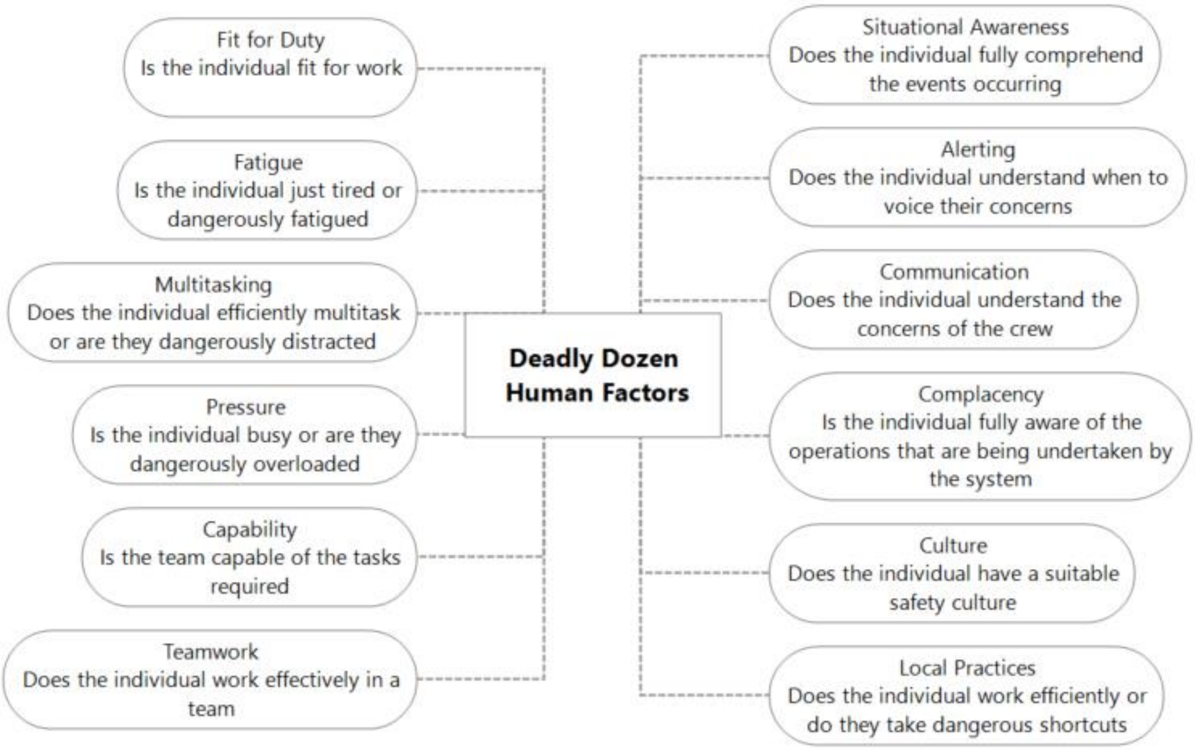


Figure 2.1: Deadly Dozen Human Factors (Singh, et al., 2023)

The term SA can be defined as how elements are viewed within their surroundings, which is relative to time and space, and how to foresee or predict the occurrence of events by understanding trends and patterns (Endsley, 1995). As the transition towards autonomous vessel operations begins to advance, the SA of the officer is key. Thus, as time constrained events, such as potential vessel incidents progress, it is imperative that the system operator has the knowledge and understanding to be able to assess and, if required, correct any malfunction or abnormal behaviour exhibited by the system. Due to the complexity that autonomous operations will bring, the SA of an individual will demand a high level of accuracy. Therefore, should the performance of the autonomous system degrade, then the officer’s SA should not be negatively affected and hence allow them to correct the fault. However, should an officer’s SA begin to degrade, it will result in a slower reaction time in fault detection which will have a resultant impact on the individual’s reorientation time with regard to their current situation and understanding of the systems operation (Gombolay, et al., 2017). Moreover, research has identified that SA is a critical aspect of the human automation relationship that is often overlooked in seafarers training regimes and as such the level of SA is significantly impacted due to the lack of focus within maritime education facilities (Melnyk, et al., 2022). As autonomous technology becomes a mainstay within the navigational wheelhouse, operator complacency and bias towards the system may result in the OOW SA being degraded to the point where minor technical faults are exacerbated to become major maritime incidents (Zhou, et al., 2019).

AB can occur due to the uncertainty displayed by the operator, resulting in the operator beginning to search for evidence to justify their decision making. Therefore, poor decision making can occur should the system malfunction to a level where the human operator begins to trust the system against their own knowledge, judgement and understanding of the situation (Parasuraman & Manzey, 2010). As autonomous operations become a mainstay within the maritime industry, human operators may begin to place too much trust in the system especially as it will be deemed reliable. As the addition of decision aiding systems has the potential to reduce human error, the level of trust displayed by an OOW may be so powerful that it overrides their sense of judgement and surrounding information, which can be defined as AB (Skitka, et al., 1999). This bias towards the system can create tendencies for the OOW to favour the decisions that are advised by the system resulting in a degradation of their navigational skills (Lou & Sun, 2021).

Automation complacency can be defined as a degradation in how an operator effectively observes the situation. With autonomous technology aiming to reduce the human error in incidents, the OOW may become accustomed to a much slower paced working environment than they are currently experiencing. Consequently, as the mundane and monotonous environment of the wheelhouse is not a recent discovery (Schuffel, et al., 1989), increasing the level of technology onboard has the potential for the risk of automation complacency. Consequently, the operator begins to make assumptions on the reliability of the system, thus degrading their own knowledge and expertise (Mosier, et al., 2013). Research has shown that complacency is a common trait exhibited by most OOW due to the levels of control taken by automation and mechanisation, complacency can also increase within individuals (Jo, et al., 2020).

2.3.4 The Human Factors Impact with Automation

Multiple factors can present themselves as an onboard distraction for the OOW maintaining a safe navigational watch, from external stressors such as home life and fatigue to the pressures associated with the seafaring profession (Lileikis, 2022). Moreover, the working life of the

OOW is a highly stressful role that requires a high level of data understanding that can result in an overload of mental workload for the OOW (Abdushkour, et al., 2018). The mental workload, in addition to fatigue, distraction and a degradation of SA, of an OOW has also attributed to some of the most impactful maritime accidents in history, including the wreck of the *Titanic*, the capsizing of the *Herald of Free Enterprise* and the grounding of *the Costa Concordia* (Labib & Read, 2013; Chen, et al., 2013; Bartolucci, et al., 2021). Therefore, as MASS becomes the focal point for future vessels, such systems should be designed in a manner to reduce the mental workload of the OOW without compromising the safety element of the vessel (Kari, et al., 2022). Conversely, research has determined that while technological advancements can benefit the OOW, they can contribute to being a root cause of fatigue (Rajapakse & Emad, 2023).

As highlighted, the working life onboard for an OOW is both highly stressful and arduous for an individual. As such, human error presents itself as a particularly complex topic due to the multitude of aspects that can also factor into a maritime incident (Dominguez-Péry, et al., 2021). Various elements of the human psyche can also impact the OOW's capability of successfully operating navigational systems. The topic of fatigue is widely discussed within the maritime industry, with research identifying that the industry must consider a multitude of factors to alleviate chronic fatigue amongst seafarers (Andrei, et al., 2020). It has been identified that the causes of maritime fatigue are due to various aspects of the working life, such as sleep disruption, overworking on tasks and insufficient sleep (Strauch, 2015). The grounding of the *Nathan E Stewart* is an example of one of many maritime incidents that has occurred due to the OOW being fatigued and falling asleep on watch (Transportation Safety Board of Canada, 2016). Another aspect that can significantly impact the performance of an individual onboard is misperception. Research has identified that misperception can result in the OOW misinterpreting the situation and can be caused by visual or motion-based illusions that influence what the individual perceives (Stroeve, et al., 2023). Misperception has been the cause of maritime accidents such as the collision between the *City of Rotterdam* and the *Primula Seaways* which transpired due to the onboard pilot being disorientated as a result of relative motion illusion (Marine Accident Investigation Branch - MAIB, 2017).

In the everchanging landscape of medical concerns for seafaring, mental health has increasingly become a critical aspect that is now promoted within the maritime industry, with the industry now encouraging seafarers to prioritise their mental health while at sea (Abila, et al., 2023). Research has identified that there are significant levels of stress and fatigue which negatively impact an officer's ability to maintain a safe lookout and that the preservation of the OOW's mental and physical health can result in a reduction in human error and benefit onboard safety

(Russo, et al., 2022). The global nature of the maritime industry sees seafarers spend a maximum period of 2 years at sea, but this is not standardised between countries. Many countries around the world have seafarers engaging in deep sea contracts varying from 3 to 4 months to 13 months with very little time being available for the OOW to enjoy their home life (Thomas, et al., 2003; Baylon & Santos, 2015). As a result, research has highlighted that the length of contract can detrimentally affect the mental and physical health of an individual due to the working life of a seafarer being carried out in isolation for prolonged periods, with the potential uncertainty of returning home (Slišković & Penezić, 2016). Additionally, throughout the COVID-19 pandemic seafarers experienced difficulties with crew changes which saw individuals being forced to extend their time onboard which allowed them little control over their lives and created the risk of distractions and fatigue whilst on watch (Pauksztat, et al., 2022). Studies into seafarers' mental health during the pandemic highlighted that seafarers had experienced concerns regarding future employment, loneliness and isolation and a lack of support from crewing management (Brooks & Greenberg, 2022).

With the introduction of autonomous systems, research has determined that a reduction in crew size is possible with a change in both how individuals are trained and the task assignment (Kooij & Hekkenberg, 2021). However, it has been suggested that despite digitalisation and automation having a significant impact on the psychological capital of the seafarer, seafaring individuals believe that the onboard social support network has a critical role in the daily life of a seafarer, thus complicating the potential of a reduction in crew size (Li, et al., 2022).

Onboard, the navigational bridge is not a silent working environment. Systems such as the BNWAS have been designed to aid the OOW by sounding an audible alarm to the bridge if no activity has been detected, thus encouraging the OOW to be active during their watch (Yu, et al., 2014). Such systems do promote the safety of the vessel, however there is the potential for the phenomenon known as alarm fatigue to manifest, which can occur when the OOW is inundated with multiple or regular alarms resulting in the individual neglecting alarms they deem unnecessary (Li, et al., 2020). However, research has identified that by varying the alarm types to the OOW, from speech output to abstract sounds, the individual will become more receptive to the alarm resulting in a reduction of alarm fatigue and an increase in SA (Kim, et al., 2020). Subsequently, further research into alarm fatigue has identified that the optimum method to reduce alarm fatigue is to introduce an audible voice alarm in favour of a conventional alarm method, alerting the OOW to any potential hazards that they must become aware of (Hwang, et al., 2022).

The personality of an individual, alongside both external stressors and pressure, can also impact the human operator's decision making, trust of a system and fault reactions (Abramowicz-Gerigk, et al., 2018). It can be expected that SA can be drastically impacted while under the influence of alcohol. Investigation into the grounding of the *Lysblink Seaways* identified that situations such as these can result in the event of operator malpractice and be avoided through additional personnel on the bridge assisting with lookout duties (Marine Accident Investigation Branch - MAIB, 2015). Moreover, personal technology such as mobile phones, tablets, and laptops in addition to paperwork have proven to be continuous distractions for seafarers (Fan, et al., 2023). It can be seen from the grounding of the *Ever Forward*, that personal devices can affect the individual's concentration and ability to maintain a high level of SA and can be the cause of poor bridge management (United States Coast Guard, 2022).

With autonomous technology looking to reduce the workload of the OOW (Li & Fung, 2019), it is critical that both ship owners and shipping companies do not view this as an opportunity to increase the already high workload of paperwork. Statistics have shown that seafarers currently believe that the demands of paperwork and administrative tasks have taken priority and have jeopardised the safety of the vessel (The Mission to Seafarers, 2021). Moreover, research has shown that seafarers believe that tasks such as reporting misconduct can result in a high volume of tedious paperwork that must be filled in and consequently, many seafarers do not report such inadequacies (Baumler, et al., 2020). Due to the multiple personnel involved with a vessel's trade route, seafarers believe that senior officers are unable to dedicate a suitable amount of time to educate and mentor navigational cadets and junior officers due to a reduction in crew size, vessel inspections and an increase in onboard paperwork (Baum-Talmor & Kitada, 2022).

2.3.5 Autonomous Technology Design

The maritime industry has benefitted through the various technology emerging throughout the 21st century, with the industry adopting and developing various technologies such as ECDIS and autopilots. Nevertheless, as technology is designed to improve reliability, such benefits can have a detrimental effect on the human operator, resulting in complacency, bias and many other human factors that negatively impact the safety of the crew, cargo, and vessel (Pazouki, et al., 2018). The vast majority of the world trade is conducted through maritime channels, with an estimated 90% of goods being transported by the maritime industry (Stanković, et al., 2021). As seen with the grounding of the *Ever Given*, in the event of a maritime incident occurring in a very busy channel such as the Suez canal, the incident can have a detrimental effect on the global economy, with an estimated $9.6 billion of trade being delayed due to the incident, in addition to the safety and environmental aspects that accompany maritime accidents (Forti, et al., 2022).

As MASS is gradually introduced to the maritime industry, it is vital that inter fleet management and communications are improved to increase the safety of vessels at sea (Jurdana, et al., 2021). Recent history has seen vessel incidents such the collision between the *APL Pusan* and *Shoutokumaru* being caused due to a lack of communication between vessels during vital manoeuvres. Reports of the incident have suggested that the probable cause of the collision was the operator of the *APL Pusan* failing to communicate their intentions to overtake the *Shoutokumaru* on the starboard. Due to the lack of communication, the OOW of the *Shoutokumaru* then proceeded to turn toward starboard not knowing of the manoeuvre resulting in the collision (Japan Transport Safety Board - JTSB, 2021). Breakdown of communications is not limited to vessel to vessel communications. Initially the grounding of the *Priscilla* was believed to have occurred due to a lack of SA. However, further findings have identified that despite the human operator being told to alter course by the vessel traffic services officer, the OOW did not adhere to the recommendations and thus ran the vessel aground (Marine Accident Investigation Branch - MAIB, 2019).

As autonomous systems develop to the latter stages of IMO’s levels of autonomy (IMO - MSC, 2018), it is imperative that both the human automation relationship and HITL is of a high level (MacKinnon, et al., 2015) The plan for the development for level 3 of autonomy and beyond will incorporate the shore command centre (SCC), which will revolutionise the seafaring role by introducing onshore responsibilities for the vessel. As such, this will introduce a new skill set for individuals to possess and a wide array of competencies which are yet to be finalised (Saha, 2023). The concept of the SCC has been widely researched within the industry, as shown from the MUNIN project and various research projects that have identified the framework for the design of the SCC (MUNIN, 2017; Alsos, et al., 2022). However, research has shown that industry experts believe that SA cannot be replicated from a shore-based role (Hannaford & Hassel, 2021). Nevertheless, while the development of the SCC is critical to the evolution of autonomous shipping, it is crucial for the maritime industry to fully optimise the initial stages of autonomous systems onboard to allow the industry to naturally progress to high level autonomy.

Onboard systems are designed and required by classification societies to be submitted for review with an appropriate Failure Modes and Effects Analysis (FMEA) to demonstrate the effects that system failures would have on the vessel (American Bureau of Shipping, 2023). Technology and onboard systems cannot be designed as completely infallible, despite being designed with a high degree of reliability (Łosiewicz, et al., 2019). Accidents have been attributed to system failure such as the grounding of the *Nova Cura* which occurred due to the vessel's ECDIS displaying a water depth of 112m in the location of the grounding, despite the water depth being 5.8m (Dutch Safety Board, 2017). Findings of the events preceding the grounding of the *Roebuck Bay* determined that while the system alerted the OOW to the shallow reef, the system had failed to store and apply the amended route for the vessel (Australian Transport Safety Bureau, 2017). Additionally, the grounding of the *Lauren Hansen* has been attributed to a malfunction with the vessel's autopilot, where the autopilot altered the vessel's course to port irrespective of the orders given by the OOW (Australian Transport Safety Bureau, 2018). Furthermore, with a vast quantity of literature and reports determining accidents being attributed to human error, research has identified that human error is symptomatic of a complex error that has arisen through a poor human system relationship (Rothblum, et al., 2002).

As autonomous technology is introduced to vessels, the design of the technology should incorporate a simple user interface and forgo the complexities that may accompany such technologies thus streamlining the information to the human operator (Alsos, et al., 2022). One of the more recent introductions of technology onboard was the ECDIS, which by 1995 had various classification societies and flag states developing rules for the use of the system due to the potential impact that it could have on the maritime industry (Riches, 1995). However, with over 25 years of use in the industry, incidents such as the grounding of the *Ovit* and the grounding of the *M.V. Universal Durban* have occurred due to the lack of understanding and incompetent use of the ECDIS (Marine Accident Investigation Branch - MAIB, 2013; Marine Safety Investigation Unit, 2018; Marine Accident Investigation Branch - MAIB, 2017). Moreover in the events surrounding the groundings of the *CFL Performer*, *Kea Trader* and *Muros* various OOW and masters were involved with the daily use of the ECDIS and it was found that the cause of the incidents stemmed from a lack of training, familiarity and understanding with the operational parameters and user interface display of the ECDIS (Marine Accident Investigation Branch - MAIB, 2008; Marine Safety Investigation Unit, 2017; Marine Accident Investigation Branch - MAIB, 2017). With many global incidents occurring through the use of ECDIS, a study was commissioned to investigate the operators use and understanding of the ECDIS. From this study it was found that while the ECDIS does have evident benefits there are many challenges such as alarm distractions, complex user interfaces increasing cognitive workload and an inundation of information for the OOW (MAIB DMAIB, 2021).

As previously suggested the criticality of the success of autonomous systems is not solely limited to the human operator's interaction but also the design of the system. The development of new technology relies on various vendors producing new systems. Therefore, to ensure that the maritime industry does not take a step in the wrong direction similarly to the introduction of ECDIS, the industry must develop systems to compliment the human operator (Vu & Lützhöft, 2020). Subsequently, as the maritime industry approaches the initial stages of autonomous vessels with humans onboard, research has shown that the development of autonomous systems and sensor technology has the opportunity to aid and improve seafarers SA (Thombre, et al., 2022). Moreover, as the maritime industry progresses towards autonomous shipping, various studies have identified that the operator's SA is critical to the design as developing systems to enhance the operator's SA will ultimately increase safety onboard (Rostek & Baldauf, 2024; Ottesen, 2014).

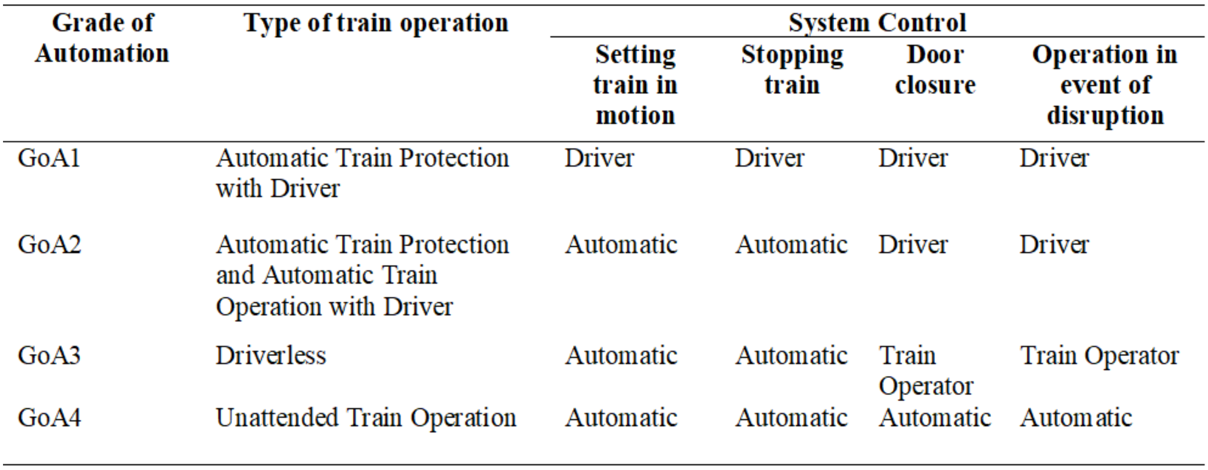
2.4 Autonomy Within the Transportation Industry

As the maritime industry moves closer to the installation of autonomous systems, the industry itself can utilise past experiences that other cargo transportation industries have encountered, such as the rail and aviation sectors, and modify their approach to efficiently instate MASS to the global maritime fleet (Johnsen, et al., 2019).

2.4.1 Rail

The railway industry has seen their drive for autonomous trains increase from the initial fully automated train, with no onboard staff, conducting its first transit in Kobe, Japan in 1981 (Mizuma, 2018), to the development of the first fleet of urban driverless trains (Boysen, et al., 2023). Due to the success of autonomous rail travel, the railway industry has seen the inclusion of the varying stages of railway autonomy adopted to the current fleet, as seen in Table 2.2 (Union Internationale des Transports Publics, 2019).

Table 2.2: Grades of Automation for the Rail Industry (Union Internationale des Transports Publics, 2019)



Grade of Automation	Type of train operation	System Control			
		Setting train in motion	Stopping train	Door closure	Operation in event of disruption
GoA1	Automatic Train Protection with Driver	Driver	Driver	Driver	Driver
GoA2	Automatic Train Protection and Automatic Train Operation with Driver	Automatic	Automatic	Driver	Driver
GoA3	Driverless	Automatic	Automatic	Train Operator	Train Operator
GoA4	Unattended Train Operation	Automatic	Automatic	Automatic	Automatic

Within the rail industry the inclusion of autonomous systems has yet to report a significant accident that has resulted in the loss of life or any long-lasting harm (Johnsen, et al., 2019).

Stene (2018) suggested that railway autonomy has the potential to improve safety, however, the inclusion of HITL is necessary due to the nature of railway transportation, with recommendations being to improve the complexity of the system and remove the financial constraints toward risk management activities

Despite both being part of the global trade fleet, there are limited similarities between railway and maritime autonomy. Research into autonomous rail travel primarily focuses on aspects such as the development of sensors for obstacle detection (Mahtani, et al., 2020) and track maintenance systems to detect faults (Vithanage, et al., 2019). However, certain aspects of autonomy in the rail industry can be adapted and restructured to improve the operations of the maritime OOW. Research into railway signalling and control has identified that by understanding the complexities of SA, the rail industry can strengthen its knowledge of the development of various systems installed (Golightly, et al., 2010).

2.4.2 Aviation

Research has frequently highlighted that in terms of emerging technology the aviation sector leads the maritime industry, including automation and legislation development, in their respective control stations i.e., cockpit and bridge (Schager, 2007; Lützhöft & Dekker, 2002). Moreover, both industries, while operating in different environments, conduct their operations in isolated environments, are subjected to various weather restrictions and forces acting on the craft and both industry craft types are of a high financial outlay to their respective industries (Johnson & Holloway, 2007). Therefore, the maritime industry can learn from the failures and successes of the aviation sector regarding safety and their experiences with the technological advances that have been introduced from automation (Turan, et al., 2016).

Research into the aviation human-automation relationship has identified that as pilots get older, they become more susceptible to external stressors such as family, health etc, this results in an imbalance between operator and system (Tang, et al., 2020). Furthermore, it has been identified that while technology is a possible issue with the older generation, interfaces have been adapted and configured to suit all age ranges within the aviation industry (Kaminani, 2011). As such this can benefit the maritime industry as statistics show that the average age of mariners is continually increasing (Department for Transport, 2022)

As autonomous technology in the aviation industry has developed, research has defined the framework to develop the varying levels of automation for the sector detailing the control of the aircraft and identifying the roles of both the pilot and automated system at each level, as shown in Table 2.3 (Anderson, et al., 2018). With technology progressing SA has become a critical focal point for the aviation industry in both flying the craft and within air traffic control centres, with research identifying that it is possible to improve the SA of the individual through improving both system design and human operator training (Nguyen, et al., 2019). Moreover, with the aid of autonomous technology, the complexities of aircraft control can be delegated, and HAT can be promoted with the systems helping the pilot with their workload and increasing the individual's SA (Roth, et al., 2019). Additionally, research has identified that with additional care in system design pilots are willing to show autonomous systems trust to promote HAT (Brandt, et al., 2017).

Table 2.3: Levels of Aviation Automation (Anderson, et al., 2018)

Level of Automation	Denotation	Aircraft Control	Description
0	Manual	Human Operator	Human is the operator for all onboard tasks, systems to inform and alert the human operator may be present
1	Task Assistance	Human Operator	Human operator can delegate the execution of the specific task limiting the responsibility to the system, the human monitors all systems
2	Partial Automation	Human Operator	Human operator can delegate the execution of multiple aspects of tasks increasing the responsibility to multiple systems, the human monitors all systems
3	Highly Automated	Human Operator	Human operator can delegate the execution of various aspects of the flight phase to an automated system, the human remains in the decision making loop and can intervene if required
4	Fully Automated	Automation	Human operator delegates all aspects of the flight phase to an automated system, automated is capable of managing all tasks and can make sound decisions for the safety of the craft. However, the human has the final decision and complete authority over the system
5	Autonomous	Automation	Entire flight phase is conducted by the autonomous system, the human manages the system in operation

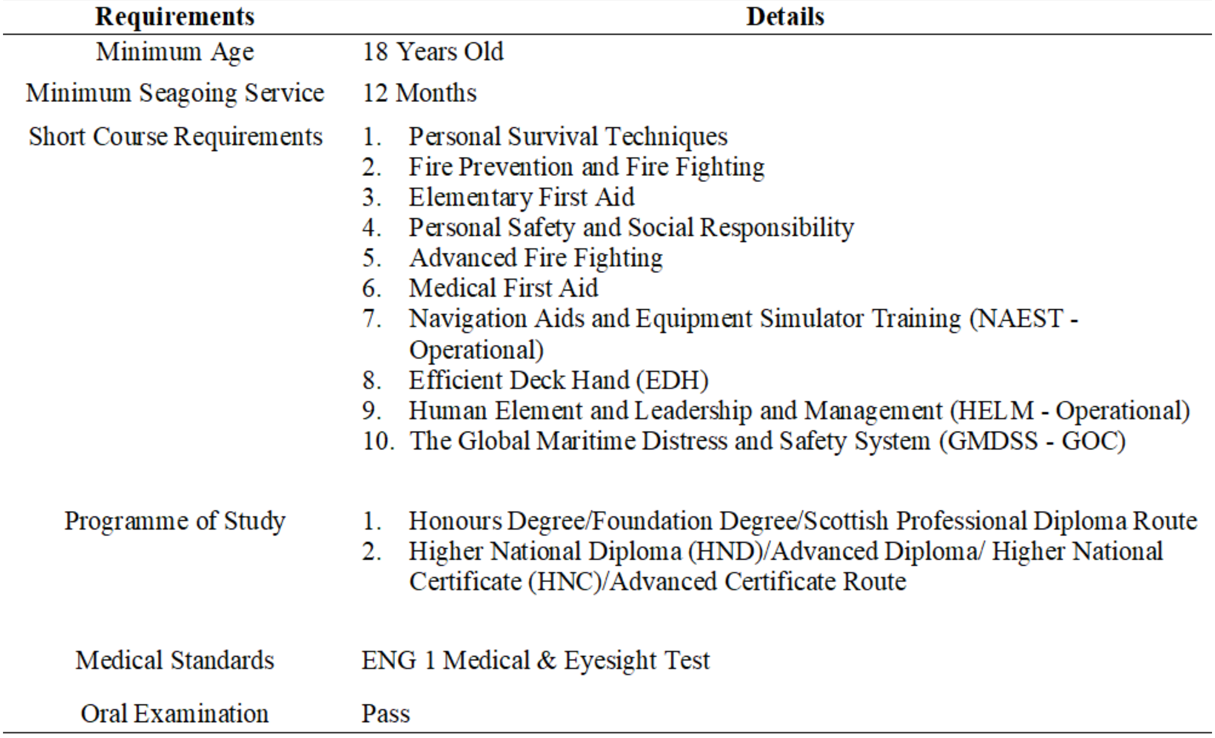
2.5 Maritime Education and Training

Prior to the further development of autonomous shipping systems, it is key that the MET sector fully understands the various rules and guides that will be implemented alongside MASS. Initial research into the requirements for seafarers has shown that maritime professionals require an enhanced skillset to cope with MASS and that the industry must incorporate subjects such as critical thinking, fault diagnosis and autonomous navigation to aid seafarers operating autonomous vessels (Aboul-Dahab, 2021).

2.5.1 The Development of Officer Training in MET

The standard route for British seafarers to become a fully qualified OOW and gain their unlimited, certificate of competency (CoC) has been laid out within merchant shipping notice (MSN) 1856 (M+F) Amendment 1 (Maritime and Coastguard Agency, 2022), and is summarised in Table 2.4. Research has shown that there are deficiencies with the training programme with individuals identifying a skill gap in the understanding of rules and misinterpreting the COLREGs (Mohovic, et al., 2016).

Table 2.4: Requirements for OOW unlimited Certificate of Competency (Maritime and Coastguard Agency, 2022)



Requirements	Details
Minimum Age	18 Years Old
Minimum Seagoing Service	12 Months
Short Course Requirements	1. Personal Survival Techniques 2. Fire Prevention and Fire Fighting 3. Elementary First Aid 4. Personal Safety and Social Responsibility 5. Advanced Fire Fighting 6. Medical First Aid 7. Navigation Aids and Equipment Simulator Training (NAEST - Operational) 8. Efficient Deck Hand (EDH) 9. Human Element and Leadership and Management (HELM - Operational) 10. The Global Maritime Distress and Safety System (GMDSS - GOC)
Programme of Study	1. Honours Degree/Foundation Degree/Scottish Professional Diploma Route 2. Higher National Diploma (HND)/Advanced Diploma/ Higher National Certificate (HNC)/Advanced Certificate Route
Medical Standards	ENG 1 Medical & Eyesight Test
Oral Examination	Pass

With autonomous systems still being viewed as a future technology, it is critical that the MET sector looks to implement the initial phases to introduce autonomous technology training before commercialisation of the technology (Aboul-Dahab, 2021). Research within the maritime industry has identified that maritime professionals do not believe that the modern International Convention on Standards of Training, Certification and Watchkeeping (STCW) framework, for training the OOW, is suitable to incorporate MASS and that, as MASS progresses towards unmanned remotely operated vessels, critical skills such as SA and leadership require more focus in seafarer training (Mallam, et al., 2020). Subsequently, as the MASS are introduced, MET will have an obligation to support and ensure that the knowledge and competencies of the OOW training programme are not rendered obsolete for shipboard operations by emerging autonomous technology (Narayanan, et al., 2023). Beyond the scope of seafaring, the vessel traffic services (VTS) will also be impacted by MASS with research identifying that individuals involved with the VTS believe that ship handling training thoroughly benefits the VTS operator in their daily operations and the inclusion of MASS training to MET will have a consequential effect on the training regime of VTS operators (Janssen, et al., 2023).

The current maritime training regime identifies 10 short courses as the minimum requirement for an individual to qualify as an OOW, as shown in Table 2.4. Beyond these requirements the

STCW have developed many additional short courses to improve an individual's skills in maritime operations such as Bridge Resource Management, Maritime Crew Resource Management and Leadership and Teamwork (STCW, 2024). However, many of the short courses offered are limited in number of spaces, diluted in information, optional and often costly for an individual to undertake (Haughton, 2011). Moreover, research has shown that while short courses are beneficial for cadets to develop initial SA skills, many experts believe that further development of such skills are gained from onboard experience (Evidente, et al., 2022).

The current curriculum for the navigational OOW mandates that to obtain an OOW unlimited CoC, individuals must pass OOW written examinations from the Scottish Qualification Agency (SQA) at an approved SQA facility qualifying in both navigation and stability and operations (Maritime and Coastguard Agency, 2022). Due to the current OOW syllabus only creating two essential subjects, this presents an opportunity for MASS to be incorporated into the future curriculum. Yet with maritime institutions being limited by the approval of STCW legislation, institutions are unwilling to invest in training equipment for emerging technology (Emad & Ghosh, 2023). Nevertheless, future training can include subjects beyond the technical aspect of onboard systems and the training and education of seafarers in subjects such as human factors, with emphasis on SA, could benefit maritime professionals (Balyan & Dhankher, 2023). Moreover, research has shown that training in certain systems, such as the ECDIS, can have a positive effect on the SA of an individual, which may result in fewer maritime incidents occurring (Baric, et al., 2023).

The role of the maritime cadet is critical to the daily operations as not only do they offer shipping companies future workforce security with officer retention, but they also create a tonnage tax relief for shipping companies and ship owners (Gekara, 2020). However, the maritime industry, over the course of the past two decades, has experienced a high turnover of maritime cadets whose training has been termed "wasted" due to a loss of a skillset among young people and in turn has been attributed of the leading factors towards the shortage of maritime officers (Gekara, 2009). However, with emerging technology being at the forefront of the maritime industry, autonomous shipping may reduce the number of jobs onboard yet increase the range of prospective maritime careers, providing MET can develop a timely response to design a future training regime (Lušić, et al., 2019). Furthermore, through research it has been identified that by adopting a maritime academy approach towards maritime institutions, in comparison to the outdated concept of learning at sea and necessitating having a qualified OOW to teach cadets, the MET is able to diversify their faculty to improve the education delivered to cadets (Abercrombie, 2021). Nevertheless, the introduction of autonomous systems has the potential to revolutionise the maritime industry, with research highlighting that young professionals in the industry while having concerns about future systems, remain optimistic and excited at the prospect of utilising autonomous technology (Bogusławski, et al., 2022).

2.5.2 Education Through Simulation

As a result of the COVID-19 pandemic, the world of education has seen rapid development in innovation to teach and educate young people by increasing the use of technology offering an interactive experience virtually (Ratten, 2023). Historically, the MET sector has been a body that adopts an on-scene form of education, with seafaring cadets learning predominantly at sea, yet due to the COVID-19 pandemic MET has adopted various techniques to develop new methods to educate maritime cadets, such as laboratory workshops and watchkeeping simulator work (Johansen, 2023). Furthermore, the use of simulators has allowed the maritime industry to recreate various shipping accidents to analyse the events that lead to disaster and how to improve team training to increase the safety and security of the vessel (Bauldauf, et al., 2016).Subsequently, research has identified that in a post COVID-19 landscape, the MET sector should introduce an indirect method of training that incorporate interactive practical watchkeeping training methods, including both extended reality (XR) and virtual reality (VR) in a simulator environment (Kim, et al., 2023).

Research has identified that simulation is a beneficial tool for training in the maritime industry (Hjelmervik, et al., 2018), offering pedagogical value. The idea of increasing simulator usage has frequently been a topic within research, with studies identifying that the introduction of more direct, high fidelity, simulator experiences can improve the performance in both basic seamanship and complex seafaring tasks including port manoeuvring operations and dynamic positioning operations (Oliveira, et al., 2022; Wahl, 2020). Moreover, beyond the potential benefits to standard seafaring and navigation, the use of simulators also offers individuals the environment to practice and hone their skills in situations, within a controlled safe area, that seafarers have limited opportunities of whilst at sea, for example Arctic navigation (Røds & Gudmestad, 2019). With the endless possibilities that bridge navigational watchkeeping simulator suites offer, it can be understood that the direction of research is to utilise such simulators to aid the development of autonomous navigational systems and simulators offer the possibilities to analyse the varying degrees of MASS prior to commercialisation (Brandsæter & Osen, 2023). Furthermore, research has promoted the use of simulators to investigate autonomous technology with HITL, to further the knowledge of the OOW and the industry (Vagale, et al., 2022).

The current primary use of bridge watchkeeping simulators, within MET, is to enable the education of OOW and cadets in complex ship handling and STCW approved short courses including Navigation Aids, Equipment and Simulator Training (NAEST). However current STCW guidance regulates the time spent in a bridge watchkeeping simulator to a maximum of 2 months for the OOW (Maritime and Coastguard Agency, 2022).

As the maritime industry looks to take the necessary steps towards MASS, research has identified that the MET sector can look to increasing the use of simulators within future OOW training programmes by delivering an authentic and practical education method to improve the training for individuals in aspects of the role of the OOW beyond vessel navigation (Tusher, et al., 2023; Vidan, et al., 2019). Moreover, further research has concluded that an immersive experience will accommodate the demands of the maritime industry and allow development of skills that are unable to be taught in a classroom setting (Dewan, et al., 2023). The concept of utilising simulator training to replace sea going experience has already taken place in certain countries, with the Netherlands opting to allowing Dutch OOW students to obtain their CoC by completing 300 days of active seagoing experience and the remaining 60 days to be replaced by 15 days of bridge watchkeeping simulator training (Uitterhoeve & Leunen, 2021). Despite simulators offering the OOW an environment to familiarise themselves with systems, research has shown that the seafarer’s believe that the possibility of simulator work replacing first hand sea experience is not beneficial to the development of the OOW (Evidente, et al., 2022).

2.6 Chapter Conclusion

By understanding the literature that is available regarding seafarer knowledge of MASS, it is apparent that there is a potential disconnect between the navigational OOW and the bridge watch navigational system. However, this relationship between the OOW and the navigational bridge systems is the foundation for future HAT systems, which will include the navigational watchkeeping officers within the decision making loop of autonomy. Furthermore, with the introduction of autonomous shipping on the horizon it is key that the relationship between navigational OOW and modern on board navigational systems is as harmonious as possible to ensure a smooth and successful introduction of autonomous shipping. Nevertheless, machinery systems are not infallible and the transition from manned to fully unmanned autonomous ships will not occur over night therefore it is imperative that navigational officers are equipped with the behavioural and psychological skills, in addition to the technical navigation skills, to ensure that the navigation system is fully operational and in the event of danger, the OOW can act appropriately to avert a course of disaster.

The overall structure aims to address multiple research questions, arising from the work presented within Chapter 2. However, by understanding the reviewed literature, it is evident that there is not one singular method to apply to understand the maritime human automation relationship. As such, multiple studies are to be conducted to gain a greater understanding of the human automation relationship. Moreover, it is critical to identify if psychological navigational skills such as SA can be influenced through the means of controlled variables, for example the training programme received by the individual or the quantity of time the individual has accumulated in a bridge watchkeeping simulator/direct bridge watchkeeping experience. Conversely, if such psychological navigational skills can be affected by the individuals uncontrollable variable, including nationality and age.

Chapter 2 has explored the wide range of areas of seafaring that will be impacted with the introduction autonomous shipping. Literature detailing the projected influence that autonomous shipping may have on the maritime industry and the modern relationship between the OOW, and sophisticated automated systems has been reviewed, with the intention to develop the initial research direction. The introduction of autonomous shipping also brings the possibility of a reduction in crewing numbers onboard that will affect the mental wellbeing of seafarers. Additionally, with the introduction of autonomous shipping, navigational officers will have to develop a higher level of awareness while conducting a watch and not allowing themselves to slip into the pitfalls of AB and complacency. All of these factors of autonomous shipping will impact the current issues associated with navigational seafaring. Conducting research into the available literature has identified a critical aspect that has yet to be addressed for the maritime industry and that is “do current OOW have the skillset to compliment future sophisticated systems and how can this skillset be improved?” which once analysed has allowed the research questions of this thesis to be defined.

Within this chapter various maritime incidents, with the root cause being human factors, have been identified. However, with further research highlighting that human error is part of a larger problem with the human psyche, it is understood that strengthening the knowledge and understanding of both the technical and psychological aspects of navigation are critical for the OOW to successfully integrate themselves in an autonomous maritime industry. The next chapter will discuss, in detail, the rationale behind the methodological procedures undertaken for the subsequent qualitative and quantitative studies conducted as part of this thesis.

Chapter 3. Methodology

3.1 Introduction

The following chapter details the various methodological approaches applied in this research. This chapter will address the various research challenges faced; the importance of the opinions of seafarers regarding autonomy, how simulation impacts seafarers' training regimes; and the rationale behind the methodological avenues that were explored.

The use of a multimethod approach allowed various accepted methods from a wide variety of maritime research areas, including education, training, safety performance, bias, complacency, workload and fatigue, to be introduced to this thesis. To address these research areas, interviews were conducted to produce qualitative data and a survey was conducted to produce quantitative data, whereas the use of human simulator testing was used to gain both qualitative and quantitative data sets. The selection of methodologies outlined for each individual research study are identified and justified within this chapter, which concludes by directly linking the research methodologies to the research questions posed within Chapter 1 of the thesis.

3.2 Background

Chapter 2 analysed the various aspects of the working environment and what is expected of navigational officers beyond the safe navigation of the vessel. Due to these dangers to navigation, further literature research was conducted into various aspects of the working life of a navigational officer including fatigue, work based stressors and the secondary tasks expected of them onboard.

A navigational officer must be on call for emergency response situations 24 hours a day, conducting 8 hours of watchkeeping, completing paperwork, and living away from family and friends, and therefore, the mental health of a navigational officer will undoubtedly be tested throughout their career. By constantly working, both physically and mentally, adverse effects that may impact the vessel could occur due to the navigational officer not having sufficient recovery time from fatigue.

This thesis contains multiple research objectives, which have been identified within Chapter 1 and allocated to various chapters and studies, as shown in Table 3.1. Additionally, Table 3.1 shows a summarised form of the methodological procedures taken for each research objective and subsequently how the study addresses the research questions as outlined in Chapter 1.

Table 3.1 – Summary of Methodological Procedures

Aim of Research	Research Objectives	Research Question	Methods Introduced	Chapter (Study)
To investigate the human automation relationship within the maritime industry and identify the potential navigational human factors that will impact the introduction of autonomous shipping.	Determine the level of knowledge and understanding that modern seafarers have regarding autonomy and digitised bridges. Analyse the seafarers perspective of the current officer training regime and autonomous shipping.	RQ1 – What is the perception among seafarers of the current training regime, the introduction of autonomous shipping and the human automation relationship? RQ3 – Do demographic variables such as age, education level, sea experience or rank have an impact on the seafarers’ opinions of autonomous shipping?	- Gaining data through the use of a survey - Conducting quantitative data analysis using various statistical analysis techniques	Chapter 4 (Survey Study)
	Analyse the seafarers perspective of the current officer training regime and autonomous shipping. Analyse the relationship between modern automated navigational systems and operator.	RQ1 – What is the perception among seafarers of the current training regime, the introduction of autonomous shipping and the human automation relationship? RQ2 – Are modern seafarers equipped with the fault awareness skills suited for supervising autonomous shipping?	- Gaining data through the use of virtual interviewing - Conducting qualitative data analysis through the means of coding and thematic analysis	Chapter 5 (Interview Study)
	Determine whether situational awareness is a concern among navigational seafarers. Determine the environmental variables that negatively impact a seafarers situational awareness.	RQ4 – Do seafarers lack the concentration skills to maintain the safety of the vessel? RQ5 – Do demographic variables such as age, education level, sea experience or rank have an impact on the fault recognition and fault diagnostic skills of navigational officers?	Primary study - Gaining data through the use of bridge watchkeeping simulator surveillance - Conducting qualitative data analysis using statistics and event tree analysis Secondary study - Gaining data through the use of a survey - Conducting quantitative data analysis using simple statistics	Chapter 6 (Pilot Study)
	Assess whether different training can influence the situational awareness of seafarers. Determine whether situational awareness is a concern among navigational seafarers.	RQ4 – Do seafarers lack the concentration skills to maintain the safety of the vessel? RQ6 – Can a different training method improve the fault recognition and fault diagnostic skills of seafarers?	Primary study - Designing the simulation using fault tree analysis - Gaining data through the use of bridge watchkeeping simulator surveillance - Conducting qualitative data analysis using statistics and event tree analysis Secondary study - Gaining data through the use of a survey - Conducting quantitative data analysis using simple statistics	Chapter 7 (Final Study)

3.3 Overall methodology

As the current state of autonomous shipping is primarily focused on system design, the methodology of the research conducted for this thesis was presented with multiple challenges. A crucial aspect for this research was to design studies that allowed both qualitative and quantitative data to be recorded from navigational officers. Capturing quantitative data from individuals would provide a rationale for subsequent studies that would allow a richer qualitative data set to be captured. The direction of this research was to document both the views of navigational officers towards MASS and the actions of navigational officers when presented with a navigational fault on the bridge. It is not possible to fully recreate a navigational bridge, nevertheless, the use of navigational simulators provided a suitable substitute, allowing the individual to replicate their actions in an environment that can be observed while slightly reducing the realism factor of the exercise. Beyond the fidelity of the exercise, another difficulty to replicate is the duration of a navigational watch. The majority of seafarers will be accustomed to conducting two, 4 or 6 hour watches within a 24 hour period (MCA, 2006). To simulate a watchkeeping pattern such as this is possible as has been shown through research into seafaring fatigue (MCA, 2012). Whilst a simulation can aid the identification of various operator errors, research has shown that throughout the course of a 30 minute simulator session the participant is more likely to recognise a fault in the first 10 minutes rather than the last 10 minutes (Molloy & Parasuraman, 1996)

Research has identified four types of data triangulation (Patton, 1999): method triangulation, the examination and analysis of findings from various data collection methods; investigator triangulation, the use of multiple investigators in one study to identify findings across the various investigators; theory triangulation, the examination and analysis of multiple theories or hypotheses in the examination of a phenomenon or situation; and data source triangulation, the examination and use of various data sources (Carter, et al., 2014). To satisfy the various research questions that are presented within this thesis, a multimethod approach is utilised. The multimethod approach is defined as a research approach that utilises multiple separate studies to answer the same research questions. Moreover, multiple studies within this thesis have adopted a mixed method approach, which can be defined as a combination of methods to address one study. Subsequently the results are then triangulated to form a complete study (Esteves & Pastor, 2003). Further research has identified that multimethod work would allow for the research data and results to be validated by utilising a combination of methods, this would then be defined as triangulation (Tashakkori & Teddlie, 2003). Triangulation of the research allowed for a variety of studies to be conducted with the intention to eliminate the deficiencies of a lone research strategy, resulting in increased confidence in the interpretation of the findings. Furthermore, utilising a mixed methods approach allows for various complimentary qualitative and quantitative research studies to be conducted and then the data from the research is combined to consolidate and strengthen the research topic (Bryman, et al., 2021). Therefore, for this thesis, method triangulation and data collection triangulation are used extensively to strengthen the arguments between the individual studies.

Due to the complexities and ethical issues of human testing and data collection for this field of research, it was imperative to gain the approval of the Newcastle University Ethics Committee. Therefore, before the detailed design of each study was undertaken, an ethical approval application was submitted and approved by the Newcastle University Ethics Committee. Prior to each study, all participants were told that their participation was entirely voluntary and in the event of them wishing to withdraw, either at the time of their participation or following the study, they would receive the details of how to do this. Additionally, all participants were informed that the data collected would be kept in accordance with the General Data Protection Regulations (GDPR) and the Data Protection Act 2018, as enforced by the data protection policy of Newcastle University. Therefore, all electronic data files were stored in an encrypted database with password protection and all paper and hard data files were kept in a locked cabinet. Additionally, all data was anonymised and uploaded to a password protected database prior to its use in any academic writing.

Due to the novel concept of autonomous shipping, various aspects of maritime autonomy are undergoing significant levels of research. However, in regard to the human automation relationship there is a lack of current studies which provide a depth of knowledge on the subject. Therefore, the aim of this thesis was to devise a series of studies in which each served as a foundation to supplement the design of the subsequent study. To initially explore the themes of the ergonomics side of autonomous shipping the decision was made to gain a greater understanding of the current mindset that seafarers have towards autonomous shipping. To assess this a survey was designed and disseminated to various maritime educational facilities with the intention to gain a wide variety of opinions among various ranking groups, age groups and other demographics of participants. This was the first study conducted for this thesis and from this point onward will be denominated the *Survey Study*.

Following the conclusion of the *Survey Study*, and subsequent analysis, the next stage of this research was to gain a further detailed insight in terms of knowledge and understanding of autonomous shipping from a sample pool of navigational seafarers. Therefore, the findings of the *Survey Study* were used to design and develop a question guide that would then be delivered to each participant in a semi-structured interview study, which will be denominated as the *Interview Study* from this point onwards.

The data acquisition phase of both the *Survey Study* and the *Interview Study* required participants to detail their opinions on autonomous shipping with limited detail of the applications behind operating the vessel. Therefore, the third study of this thesis aimed to address this limitation by capturing real time data to assess the participants' physical and behavioural skills in the event of encountering an automated bridge. This was achieved by designing multiple simulator exercises to assess the fault recognition skills, both physical and behavioural skills, of participants. Due to the response rate of the *Survey Study* capturing various OOW views of autonomous shipping, an additional exercise was included in the individual study, to capture the opinions of the participants completing the simulator exercises. Therefore, a mixed methods approach was adopted, providing a richer data pool sample of the perception of autonomous shipping in conjunction with the simulator exercises (Johnson, et al., 2007). This was the third and penultimate study and from this point onward will be denominated the *Pilot Study*.

The aim of the fourth and final study was to develop an exercise that utilised the findings of the first three as a foundation, and their limitations, as a guideline for improvement, with the aim to assess the impact of different training styles. Similar to the *Pilot Study*, the *Final Study* of this thesis was to assess the fault recognition patterns of seafarers in a navigational simulator. Additionally, following the conclusion of every participant's exercise, a more detailed follow up survey was conducted with the participant to gain a richer data set. Figure 3.1 shows a visual representation of the relationship between each of the studies and the research framework, detailing how each study impacted the following one.

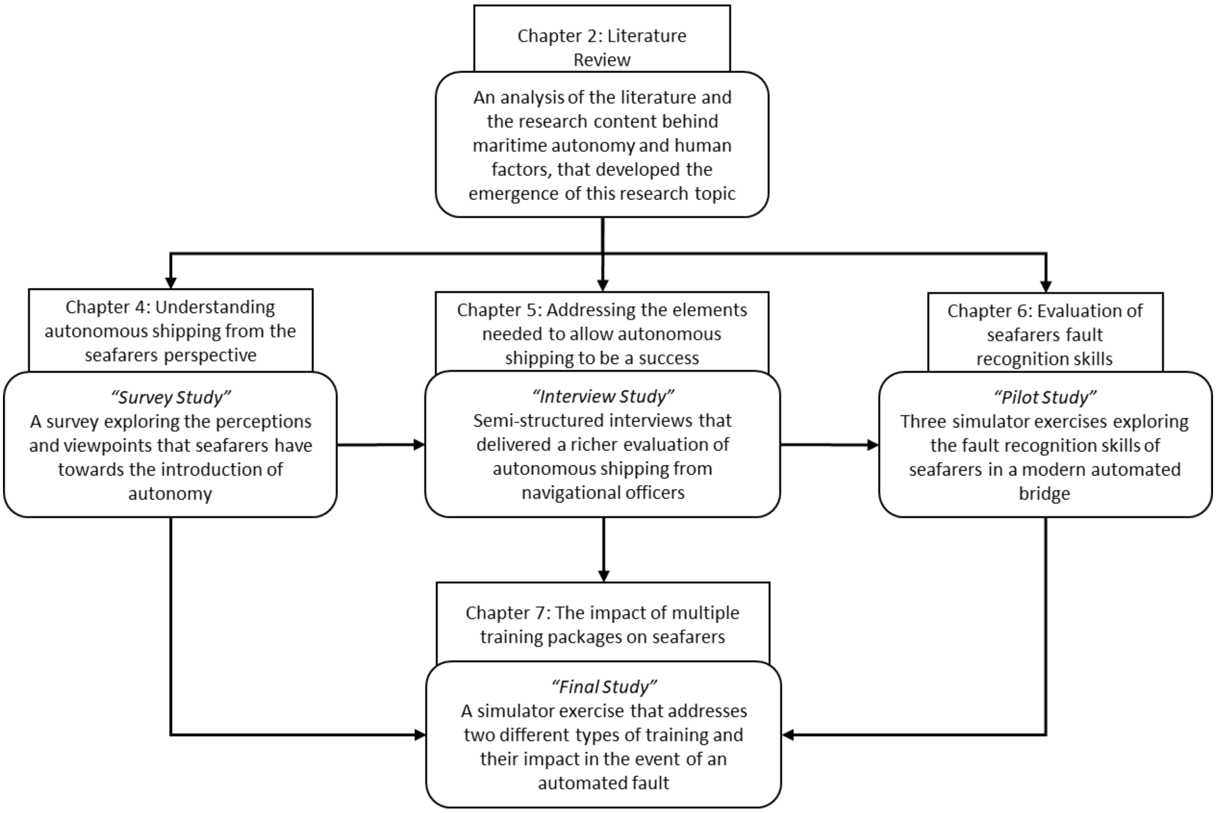


Figure 3.1: Research Chapter Hierarchy

3.4 Survey Study

In preparation for the *Survey Study*, research was conducted into various quantitative methods. The aim of the *Survey Study* was to explore the various mindsets and opinions that navigational seafarers have towards autonomous shipping. With the everchanging scope of autonomous shipping, it is key that operators and seafarers are adopting the opinion that the technology will aid them in their daily operations. However, past research has indicated that when presented with an automated aid, humans will fail to recognise events unless prompted to react and will follow the recommendations of the decision based aid even if it contradicts the individual's training and knowledge (Skitka, et al., 1999). Thus, this study will aim to utilise the opinions of seafarers to understand the how seafarers perceive the concept of autonomous shipping.

3.4.1 Data Acquisition

Before designing or conducting the later tests with human participants it was imperative to gain a strong understanding about how to structure the simulations. Therefore, devising a survey, to be distributed to the navigational seafaring cohort, set the foundations to develop future studies. Moreover, the inclusion of a *Survey Study* would allow the initial objectives of this thesis to be addressed:

- Determine the level of knowledge and understanding that modern seafarers have regarding autonomy and digitised bridges.

- Analyse the seafarers’ perspective towards the current officer training regime and autonomous shipping.

Prior to designing any of the studies, there was an understanding that while SA and other behavioural skills were relevant in the world of maritime navigation, there was not enough attention being drawn to this. A previous study utilising cadets had identified that SA could be improved depending on the training the participants had received and therefore SA could be developed as a crucial navigational skill for the evolution of the navigational seafaring role (Pazouki, et al., 2018). Due to this it was imperative to understand whether this was a common theme among the varying ranks and ages of navigational officers.

Surveys have been proven to be an effective method to acquire data (Pronto, 2015). With autonomy becoming such a prevalent area of research for the maritime industry, gaining a wide scope of opinions will allow the industry to understand the perceptions of the operators which may impact areas such as the installation, design and commercialisation of such systems. Surveys and questionnaires have been proven to be a valuable tool for data acquisition within the maritime industry from studies on various aspects of the world of shipping. Whether that is assessing maritime accidents due to human factors (Shi, et al., 2021) or assessing the volume of training conducted in a marine simulator (Tsoukalas, et al., 2014) a survey allows for a varied participant pool to respond to factors that have an immediate impact on the individual.

3.4.2 Participant pool

The nature of the participant selection process allowed for a wide variety of candidates to take part in the study. Participants taking part in the *Survey Study* had to satisfy the following criteria:

1. All participants must be aged 18 or over
2. All participants must have pursued a career as a navigational seafarer either as:
    a. Navigational officer, any rank
    b. Navigational officer cadet
    c. Deck ratings crew person

By ensuring that the aforementioned criteria were satisfied, it was presumed that participants would have the knowledge and understanding to successfully complete the survey.

3.4.3 Data collation and analysis

Using the aforementioned selection criteria, the survey was disseminated to all British maritime colleges. Additionally, the survey was published on social media platforms to allow maximisation of the response rate. By utilising this method of dissemination, it allowed a wide demographic variety of participants to complete the survey. The survey was constructed using the *Online Surveys* platform, which allowed for all responses to be held in a password secured archive (Online Surveys, 2020). As research has shown, a key method to increase the rate of response is to access a person in a position of power (Hayes, 2000). Therefore, the survey was initially sent to the heads of navigation for all of the maritime colleges, who then promoted the survey within their department. To gain a wide variety of perspectives, the key parameters were collected, and the subsequent variables were assessed:

- Age
- Rank
- Education Level
- Seagoing Experience

Upon receipt of the survey, participants were asked to read the cover letter highlighting the aim and anonymity of the survey allowing participants to answer truthfully, the expectations of the participant and the approximate time that the survey would take to complete. Once the cover letter had been read the next page of the survey offered the participant an electronic acceptance to continue with the survey. The electronic acceptance of the survey guaranteed the confidentiality of the participant's data, however no data collected could identify a participant. The survey response was closed once 100 navigational seafarers had participated and had submitted their responses. Following the acquisition of all participants' results, the raw data was then compiled into a Microsoft Excel spreadsheet and statistical data analysis was conducted using IBM SPSS Statistics 27 software.

Chapter 4 presents further details of the procedure in designing the survey delivered to the participants; the analysis of the survey data; and the conclusions drawn from the study.

3.5 Interview Study

Having gained a variety of data through the quantitative *Survey Study*, the design of the subsequent study was to incorporate the knowledge gained from the analysis of the survey and then use a qualitative study to generate a richer data pool. Therefore, the *Interview Study* was conducted to allow for a deeper understanding of the viewpoints of navigational officers regarding autonomous shipping.

Research has defined a qualitative study as a research method that allows for a greater insight to real-world problems (Moser & Korstjen, 2017). Therefore, unlike a quantitative study, where the aim was is to gain a wide variety of surface level data, the qualitative study was to serve as a platform to gain a greater understanding of the perception of autonomy. Moreover, conducting a qualitative study allowed this thesis to explore the topics addressed in the *Survey Study* and ask questions that could not be addressed with a simple Yes or No response.

For a qualitative study, the most common and proven method is to conduct a semi structured interview. Research has shown that this qualitative method offers a large scope in terms of flexibility in the questions posed and offers an interview in which the questions are more of a guide to discussion points (Bryman, et al., 2021). Furthermore, research has defined the qualitative research interview as an interview where the sole purpose is to accumulate the descriptions of the interviewee’s real world experiences with respect to interpretation of the meaning of the described phenomena (Kvale, 1983). The advantages of conducting a semi structured qualitative interview have been identified as follows (Opdenakker, 2006):

- Allowing for the recognition of social cues

    The recognition of social cues for example tone of voice and body language, offers the interviewer significantly more information beyond the immediate language that is being used in the response to the question
- Allows for no significant delay in time

    Conducting an interview allows both the interviewer and interviewee to communicate and react to each other’s questions or responses. This can allow for the interviewee to deliver a spontaneous response which may not be elicited in other research methods.
- Allows the interview to be recorded
    - Conducting an interview allows for the possibility of recording, resulting in an interview report that offers greater reliability and accuracy than simply taking notes.

Conversely, research has also identified various disadvantages to these points for example length of time to transcribe the interview from the recording and the emergence of a new topic of conversation (Bryman, et al., 2021). However, by taking the correct precautions in the design phase of the interview it was possible to avoid such disadvantages.

3.5.1 Data Acquisition

As autonomous technology has yet to be installed onboard vessels, semi structured interviews allow a connection between the maritime industry and the potential operators of the systems prior to their installation. Various studies conducted in the field of maritime ergonomics and maritime autonomy (Österman, et al., 2010; Li & Fung, 2019; Lee, et al., 2020; Bao, et al., 2021; Yoshida, et al., 2020; Mallam, et al., 2020) have utilised semi structed interviews for data acquisition. Therefore, for the *Interview Study* semi structured interviews were utilised as they delivered a research method that allowed for a qualitative study which captured a more detailed perception and attitude towards autonomous shipping, for each participant. Additionally, the semi structured interview offered more flexibility in the delivery and data capture of the study (Bryman, et al., 2021).

3.5.2 Participant Pool

The aim of the *Interview Study* was to address the introduction of autonomous shipping from a navigational officer's perspective. Therefore, it was imperative to interview a pool of participants with a wide variety of navigational seafaring backgrounds, different cultures and varying positions within the maritime industry. Consequently, the following criteria list was constructed to ensure that the pool of participants represented a varied range of navigational personnel:

1. All interviewees must be aged 18 or over
2. All interviewees must have pursued a career as a navigational seafarer either as:
    a. Navigational officer, any rank
    b. Navigational officer cadet
    c. Deck ratings crew person
3. Interviewees must fall into one of the following categories:
    a. Currently sailing as:
        i. Master
        ii. Chief Officer
        iii. 2nd Officer
        iv. 3rd Officer
        v. Deck Cadet
    b. Have accrued:
        i. 25 years of sea time as a navigational officer
        ii. 5 years of sea time as a navigational officer and have worked as a;
            1. Maritime researcher
            2. Shore based worker within the maritime industry
            3. Maritime educator

In addition to these criteria, it was also imperative to incorporate participants who had an overseas navigation education background to ensure that the interviews were not all UK based. By ensuring that all participants had met the requirements stated in the criteria it was then assumed that the participant would have a satisfactory knowledge of autonomous shipping to undertake the interview.

3.5.3 Data Collation and Analysis

Applying the criteria list to the participant pool influenced the type of interviewee that was required for the study. A recruitment process was conducted, including disseminating the criteria list, to maritime colleges. Additionally, a “call for participants” recruitment post was published on LinkedIn that allowed potential interviewees to directly make contact and express their enthusiasm to take part in the study. Utilising this method of dissemination allowed for a varied pool of participants to complete the interviews. Prior to conducting the interview, each interviewee was presented with an overview of what to expect during the interview, a copy of the question sheet and a timescale estimation for the interview. By issuing the questions in advance of the interview, participants were able to constructively formulate their answers and address multiple aspects of maritime autonomy.

The research method selected to analyse the data delivered from the *Interview Study* was a method of thematic analysis utilising an inductive approach. The results of the study were a qualitative data set in which the interviewees would give their perception regarding each topic. This would then be recorded, transcribed, and analysed highlighting the various themes present in each interview. By adopting an inductive approach, it is then possible to gain a more detailed response regarding autonomous shipping, that would serve as a foundation for subsequent studies.

Following the conclusion of the transcription of the interviews, each interview was then coded using thematic analysis, and various themes were drawn from each interview. Thematic analysis is a research method that allows the researcher to identify and analyse emerging themes within the data pool (Guest, et al., 2011). Moreover, thematic analysis has frequently been utilised as a method to analyse raw data samples extracted from a variety of qualitative studies in both the maritime field and beyond (Kim, et al., 2019). The most widely accepted form of thematic analysis was proposed by Braun and Clarke (2006) within this study, the benefits of utilising thematic analysis are made apparent, and the method utilises a six-step approach:

- Data Familiarisation
- Initial Coding
- Identifying Themes
- Reviewing the Themes
- Defining the Themes
- Evidencing the Themes

Coding and thematic analysis for the *Interview Study* were conducted using Microsoft Office software such as Excel and Word to design the codebook to house the various emerging themes.

Chapter 5 presents further detail on the procedure taken to devise the interview guide, delivered to participants; the coding and theme emergence procedure; and the conclusions drawn from the study.

3.6 Pilot Study

Following the conclusion of the *Interview Study* the subsequent study was then to accumulate data from a real time exercise, through a simulator study. By utilising the knowledge gained from the *Survey Study* and *Interview Study* it was possible to design a research study that incorporated live human testing in a simulated working environment. The first simulator study was designed with the aim to assess the fault recognition patterns of seafarers, addressing topics such as AB, complacency, and SA in the event of a manual fault, an automated fault and a standard alarm scenario.

The transportation industry has incorporated simulation into their individual sector's training and education facilities for years. Research has already provided a wealth of knowledge about simulator use in MET which allows the operator to hone their skills in a time constrained life-like environment without the dangers introduced whilst at sea (Pan, et al., 2020). Subsequently, research has shown that in MET, field simulators have proven their pedagogical value (Jamil & Bhuiyan, 2021). Simulators have been used to address onboard human factors issues as they allow researchers to identify any potential issues and correct them in a safe environment (Hanzu-Pazara, et al., 2008) and research has identified the benefits and impacts that simulators have in today's society with the maritime industry facing challenges, such as COVID-19, to the marine supply chain (Kim, et al., 2021).

3.6.1 Data Acquisition

Human factors have long been documented as a primary cause of maritime incidents (Batalden & Sydnes, 2013) and the SA of seafarers has acted as a factor in various maritime incidents (Marine Accident Investigation Branch - MAIB, 2015; Australian Transport Safety Bureau, 2018; MAIB, 2017; Marine Accident Investigation Branch - MAIB, 2019; MAIB, 2021; Marine Accident Investigation Branch - MAIB, 2017). This has led to research utilising human test subjects participating in a simulated exercise addressing issues such as SA (Pazouki, et al., 2018). Moreover, research has identified that simulator training can improve safety, by designing training procedures that allow operators to maintain high levels of SA throughout their training (Saus, et al., 2010).

With autonomous ships yet to be fully commercialised, the aim of the study was to develop three individual exercises that emulated real life situations. Three exercise scenarios were designed to allow participants to experience an automated system fault, a manual fault and routine maintenance alarms.

3.6.2 Participant Pool

The aim of the *Pilot Study* was to identify if there was a difference between the fault recognition and diagnosis skills of both navigational officers and cadets. As such, all exercises were designed for implementation using the simulator facilities at South Tyneside College – South Shields Marine School. In preparation for conducting the *Pilot Study,* a poster was designed to enhance participant recruitment for the study and placed around the facility. Moreover, if presented with a fault in systems that navigational officers perceive to be reliable, will the participant show an over reliance in trusting the systems or will they use their SA to correct the fault. Due to the nature of the study, the only prerequisite for an individual to participate in the study was that they must be studying or have studied to become a navigational officer.

Incorporating a criterion that allowed for a wide selection process enabled a variety of individual backgrounds to be assessed in the simulator. This allowed for a high variance in participant demographic such as age, nationality, education background and rank all to be considered when conducting statistical analysis on the study. By ensuring that all participants had met the requirements outlined by the selection criterion process it was then presumed that the participant had a sufficient knowledge of the systems that they would encounter within the simulator.

3.6.3 Data collation and analysis

Following the recruitment of the participants, the exercise stations were constructed in a manner where each participant would be required to undertake three individual simulator exercises and partake in an exercise survey. Therefore, participants were arranged into groups with a maximum of four participants per group to allow all four exercise stations to be utilised simultaneously. Once inside the simulator suite each participant would then be analysed, and their timestamp would be recorded for:

- Their location within the simulation suite i.e., was the participant positioned at the helm, radar table, ECDIS or work bench
- What task they were focused on i.e., was the participant concentrating on the paperwork or the navigation of the vessel
- Whether the navigation of the vessel was on autopilot or manual control
- If the participant had attempted to contact:
    - Captain
    - Electrician

    - Duty engineer via engine control room
    - If the participant had recognised a fault

All records of the participants' reactions were cross analysed through live video feed and recordings taken from the closed-circuit television (CCTV). Participants were escorted between exercise stations to avoid them sharing their experiences between exercise stations. Following the acquisition of all participants' results, the data pool was then transferred to a Microsoft Excel spreadsheet for both analysis of the events that had occurred for each participant within every exercise and each participant's response to the survey exercise. Furthermore, the following parameters were collected, and subsequent variables were assessed throughout the study:

- Age
- Rank
- Education Level

Chapter 6 presents further detail on the procedure taken to design each individual exercise delivered to the participants; simple statistics and an event tree analysis (ETA) to analyse the data; and the conclusions drawn from the study.

3.7 Final Simulator Study

With the introduction of autonomous systems potentially beginning to impact global trade, the maritime industry must become aware of any possible stumbling blocks that would hinder the progress of autonomous shipping. Therefore, with the conclusion of the previous studies, various themes began to emerge that would impact and shape the *Final Study*. By addressing various limitations that occurred in each of the previous studies, it was possible to devise a new strategy that assessed the fault recognition skills of navigational officers through different training exercises.

Research utilising participants in simulators has shown that in the event of training there is an increase in awareness displayed whilst in the simulator (Pazouki, et al., 2018). However, this particular study had limitations in terms of participant numbers, range of rank and experience of the participants and fidelity of the simulation.

3.7.1 Data Acquisition

The exercise of the *Final Study* was constructed by using the *Pilot Study* exercise as a foundation. Increasing the length of time of the gyro drift exercise from the *Pilot Study* and introducing additional alarms increased the fidelity of the exercise to capture the realism of a working navigational bridge. In various transportation sectors the fidelity of the simulation has proven to be a key component of ensuring the realism and effectiveness of the training. As shown in the automotive sector, in the event of participants entering a high fidelity simulator, the rate of accidents was almost halved compared to a simulator with low fidelity (Allen, et al., 2007). From the aviation sector, research conducted had initially concluded that increasing the fidelity of the simulation would result in a higher transfer of pilot navigational skills to a real world environment (Klauer, 1997). However, further studies have shown that while in theory the aforementioned is correct, there are benefits and limitations to varying degrees of simulation fidelity, with low fidelity simulators being a financially beneficial option for inexperienced pilots learning new skills and high fidelity being more suited for more experienced pilots learning intricate details of aviation (Noble, 2002). Moreover, research has shown that while increasing the fidelity of the simulation can benefit experts and experienced students, novice students will begin to misunderstand the exercises and become overwhelmed with the result being an inefficient simulation (Alessi, 1988). Therefore, to maximise the cost and training effectiveness of the simulator, the optimum level remains of medium fidelity.

One of the key limitations of the *Pilot Study* was the lack of detail surrounding the post exercise survey (PES). Due to the complexity and duration of the exercise, participants often forgot exactly what they did in the exercise. Additionally, participants may have been aware that there was a fault however, due to a lack of experience or confidence, they may have opted not to react to the fault. Therefore, great care was taken when designing the PES for the *Final Study* as conducting the survey could provide a greater insight into the participants' actions. Research has shown that a post exercise follow-up survey allows the researcher to gain a greater understanding of the mindset that participants have towards simulator testing (Fernandez, et al., 2007). One method of assessing the participants' self-awareness of cognitive workload is through the use of the NASA-Task Load Index (NASA TLX) (Cao, et al., 2009). The NASA TLX has been proven to be a simple method to assess an operator following the completion of a task. It consists of six subscales that allow the participant to self-analyse (Hart & Staveland, 1988):

- Mental Demands
- Physical Demands
- Temporal Demands
- Frustration Levels
- Effort Levels
- Performance of the Participant

Research has shown that over the course of over 20 years the NASA TLX has been utilised successfully in capturing a self-report of operators' cognitive workload, however, if issued during an exercise then it may itself contribute to the cognitive workload experienced by the participant (Sharek, 2011).

One of the main objectives of the *Final Study* was to identify if there was an increase in fault recognition times depending on the training content delivered to participants prior to them entering the simulation suite. Therefore, in the pre-design phase of the *Final Study* one of the main areas of importance was the pre-exercise training content. Studies in the automotive industry have shown that in the event of training participants versus not training participants, trained participants efficiently utilise eye movements to aid them in understanding the information surrounding them (Seya, et al., 2008). Additionally, automotive research has highlighted that training less experienced participants results in less risky manoeuvres and safer driving than what is shown in experienced drivers with less training (Fisher, et al., 2002). The key difference for the automotive industry is that drivers are not mandated to continuously refresh their skills and knowledge base, whereas for the maritime industry, short courses are constantly conducted to ensure that seafarers are trained and refreshed to a certain standard. Studies have shown that the effectiveness of training is dependent on the individual, due to the everchanging scope of technology, with the argument that it is critical to develop a training framework to increase awareness in cyber security in the maritime sector (Canepa, et al., 2021). Therefore, in the development of the *Final Study* emphasis was placed on the training that participants would receive prior to conducting the exercise. Participants would receive one of the following training briefings prior to entry, the contents of which are further discussed in Chapter 7:

- Behavioural skills package
- Technical skills package

3.7.2 Participant Pool

Having gained insight from previous studies it was apparent that, while beneficial to a quantitative study, limiting the selection criteria for participant would increase the effectiveness and quality of the *Final Study*. Therefore, for this study the following criteria were introduced to ensure that participants were:

- Aged 18 or over
- Had accumulated a minimum of 12 months as a navigational cadet

Introducing stricter selection criteria for participants enriched the data from the study and also ensured that all participants had accrued sufficient time on the bridge. Additionally, having a minimum requirement of sea time ensured that all candidates were confident in their abilities to operate as a sole watchkeeper. Setting a minimum sea time at 12 months allowed the study to capture the response rates from participants with the minimum candidature of the requirements to be a qualified navigational officer. Moreover, the rank of the participant was the only key parameter that was collected for the study.

To enhance the recruitment process, contact was made with the South Tyneside College – South Shields Marine School, via the curriculum leaders, to attract potential participants. The aim of the *Final Study* was to address the impact of different training packages and their effect on an individual's SA in the event of an automated fault.

3.7.3 Data collation and analysis

To record the actions taken by participants in the simulator, a drop down selection sheet was designed using Microsoft Excel. The basis of this selection sheet was designed using various actions taken by the participants in the *Pilot Study*. The selection sheet recorded the location of the participant, alarm status, work pack location, vessel control and activity list with data recorded every 30 seconds through the exercise, This allowed a faster and more accurate recording of the events occurring in the simulator. A selection sheet was completed for each participant. Following the completion of the exercise, the CCTV footage was rewatched to ensure that every detail of the actions of the participant was recorded. Following the completion of each participant's simulator exercise, participants were then guided to a room to conduct a PES in isolation to ensure independence of the participants' responses.

3.8 Chapter Conclusion

This chapter has discussed the various research methods and rationales used within this thesis. Throughout this chapter the various methodologies and rationales behind each of the individual studies have been discussed along with how they have addressed the objectives identified in Chapter 1. The work conducted within this chapter has been used to describe various methods, both in the transportation industry and beyond, that have been previously used in quantitative and qualitative research. With maritime autonomy being in its infancy, there is a lack of prior research that has been conducted. Therefore, it was decided to introduce a gradual approach towards each study and their respective methodologies. By adopting a gradual approach towards each study, it was possible to then develop the subsequent study using the findings of the prior study.

Chapter 4. Survey Study

4.1 Introduction

This chapter will detail the preparation of the *Survey Study*, how it was carried out, a full analysis of the methodology and results. Additionally, this chapter will address the research objectives that were achieved through the means of this study and how this study addressed the research questions defined in Chapter 1. Subsequently, the methodological limitations of the study will be identified, and the chapter will conclude with the impact that this study has on the overall thesis.

With autonomous shipping being at the forefront of the maritime industry in terms of revolutionising technology (Department for Transport, 2019), the role of seafarers is expected to evolve and move far beyond the duties of seafarers today, with the aim to introduce a hybridised navigational method that may utilise the seafarer as an autonomous system supervisor (Manuel & Baumler, 2020). However, as previously identified in Chapter 2 there is a lack of knowledge among current seafarers with regard to autonomous shipping. Research has shown that while current seafarers are capable of navigating a vessel, there are issues with a seafarer’s SA that may ultimately impact the transition towards and integration of autonomous shipping (Pazouki, et al., 2018). Therefore, to address the research questions posed by this thesis, it is imperative to identify the opinions and perspectives of the cohort of seafarers that will be involved with the transition towards autonomous operations.

Autonomous shipping will ultimately revolutionise the development of future navigational training. However, current research has identified areas of concern regarding the SA and attitudes towards automation and autonomy (Mallam, et al., 2020). Therefore, this study aims to investigate the perceptions and opinions that current seafarers have of autonomous shipping. Additionally, the fault recognition skills of seafarers will be assessed through a text-based exercise.

4.2 Study Design

The aim of the *Survey Study* is to gain an understanding to the current viewpoints and opinions that seafarers have towards autonomy, their reliance on automated systems and fault recognition skills. In the design process of this study a number of hypotheses were defined that allowed for the creation of the survey in conjunction with RQ1 and RQ3 of this thesis. Additionally, the design of these hypotheses determined the participants demographic variables to be analysed throughout the study. The hypotheses of this study are:

- Hypothesis 1 – Older participants will be more accepting of autonomous shipping.

- Hypothesis 2 – Participants with a higher rank will be unaccepting of autonomous shipping.
- Hypothesis 3 – Participants with a higher level of education will be less trusting of autonomous systems.
- Hypothesis 4 – Participants that have accrued a longer amount of sea time will be unaccepting of autonomous shipping.

Through the introduction of the initial four hypotheses, derived from the review of literature in Chapter 2, it was then possible to explore further sub themes within the survey design and question construction within the survey topics by utilising the various demographic data collected and comparing it to the initial hypotheses, as shown in Table 4.1.

Table 4.1: Survey Study Sub-Themes

Subtheme	Demographic Variable	Hypothesis
Do navigational officers view autonomy and current automation as an aid that can assist their workload and the vessel?	Age	Older participants will be more likely to rely on automation and decision-based aids for the day-to-day operations of the vessel.
	Education Level	Participants with a higher education will view autonomous systems as an aid and not a replacement, more so than lesser educated participants.
	Rank	Participants that have sailed at a higher rank will be less receptive to autonomous shipping due to past experiences that have encountered with automated systems.
	Seagoing Experience	Participants with a longer amount of sea going experience will have experienced more encounters both good and bad with technology and therefore will view the systems as an aid more than participants with less experience.
Have navigational officers recognised the technological advancements in the maritime industry?	Age	Younger participants will have experienced less technological advancements throughout their careers.
	Education Level	Participants with a higher level of education will have a stronger understanding of the technological advancements that are happening within the maritime industry.
	Rank	Participants of a higher rank will have experienced more technological advancements throughout their careers than lesser ranked participants.
	Seagoing Experience	Participants with less seagoing experience will have a greater understanding of the technological advancements due to their recent interactions with maritime educational and training facilities.
Do navigational officers have concerns, with regard to their career at sea, towards autonomous shipping?	Age	Older participants will feel concern for the seafaring occupation in the age of digital shipping.
	Education Level	Participants with a higher level of education will have less concern for a career at sea due to them understanding the evolution of the seafaring job market.
	Rank	Participants of a lower rank will be more excited for the future of shipping.
	Seagoing Experience	Participants with more seagoing experience will be concerned for the longevity of their career at sea
Do navigational officers have an awareness of their cognitive reliance and trust in autonomous and automated systems?	Age	Younger participants will be more inclined to acknowledge the amount of trust they have in the system.
	Education Level	Participants with a lower education level will show more trust in autonomous systems.
	Rank	Participants with a higher rank will trust themselves more than the system.
	Seagoing Experience	Participants that have a longer amount of time spent at sea will trust themselves more than the system as they will have encountered far more systemic issues than that of a less experienced participant.
Are navigational officers self-aware of negative impacts of bias, fatigue, and distractions on the bridge	Age	Older participants will be reluctant to admit that they are at risk of such behavioural issues.
	Education Level	Participants with a higher level of education will be reluctant to admit the risk posed by autonomous systems and their impact on themselves.
	Rank	Participants of a higher rank will be less trusting of systems, therefore will show less bias.
	Seagoing Experience	Participants with more seagoing experience will be more concerned with the risks that autonomous shipping will bring.

4.3 Method

4.3.1 Materials

The data sets were recorded and collected using the Online Surveys platform. By utilising this software, it was possible to comply with GDPR legislation (Data Protection Act, 2023), as access to the response files is both encrypted and password protected. The aim of the survey was to collect demographic data and compare this across the following three research areas:

- Navigational seafarers' views of autonomy
- Navigational seafarers' trust in autonomy
- Navigational seafarers' situational judgement

The *Survey Study* consisted of a questionnaire with 22 sections allowing participants to disclose information regarding their career at sea, educational history, experiences and views on autonomy and their self-perceived trust in autonomous systems. Additionally, all participants were required to undertake three situational judgement questions (SJQ) that had been designed from either past real world shipping incidents or common navigational faults.

The survey question structure for most sections used Likert scale, subjective dichotomous and multiple-choice questioning styles. For the situational judgement section, a ranking method was selected to allow participants to rate what they perceived as the most appropriate to least appropriate answers.

For the Likert scale questions a 7-point Likert scale was introduced to answer the questions. The responses for items in both sections ranged from 1 = 'Strongly Disagree' to 7 = 'Strongly Agree'. All responses to the survey were anonymous, and no participant had any interaction with any of the questions prior to completing the survey.

4.3.2 Procedure

The survey was delivered to the participants by contacting maritime colleges within the UK. Furthermore, to increase the reach of the survey, social media such as LinkedIn and Facebook were utilised. By utilising such platforms, it was possible to ensure that the survey responses were varied in the demographic data of participants.

Figure 4.1 shows the overall structure of the survey, moreover from this structure it can be seen how multiple sections were grouped together to deliver various aspects of the subsequent analysis i.e., the combination of participant background, seafaring background, seafaring experience and navigational short courses are grouped to deliver the demographic data of the individual. As such, the data for each participant can be categorised into the following research areas:

- Demographic data – Background information on the participant.
- Perception of autonomy – The participants views and experiences with automated and autonomous systems.
- Situational Judgement – Scenario based exercises for the participant to show their understanding of how to conduct their watch in the event of a fault.
- Trust in Autonomy – The participants self-awareness of their trust towards autonomous systems

Following the collection of all surveys, the data was organised using Microsoft Excel to produce the initial layout of the data. Subsequently, all statistical analysis such as Pearson's correlations coefficient and analysis of variance (ANOVA) testing were performed using the IBM SPSS Statistics 27 software.

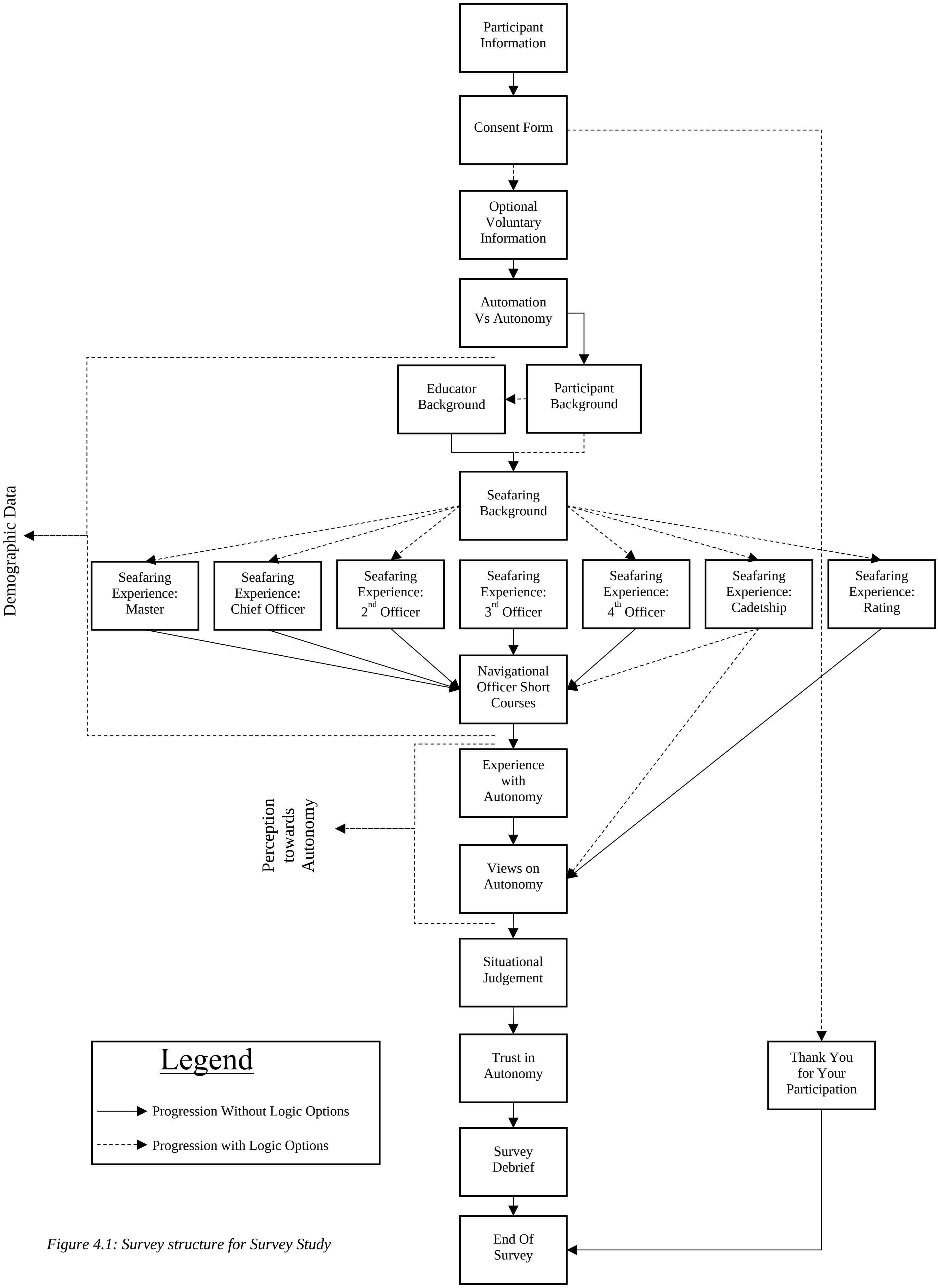


Figure 4.1: Survey structure for Survey Study

4.3.3 Demographic Data

This section captured the following demographic data:

- Age
- Nationality
- Education History
- Sea Time Accrued
- Seafaring Experience

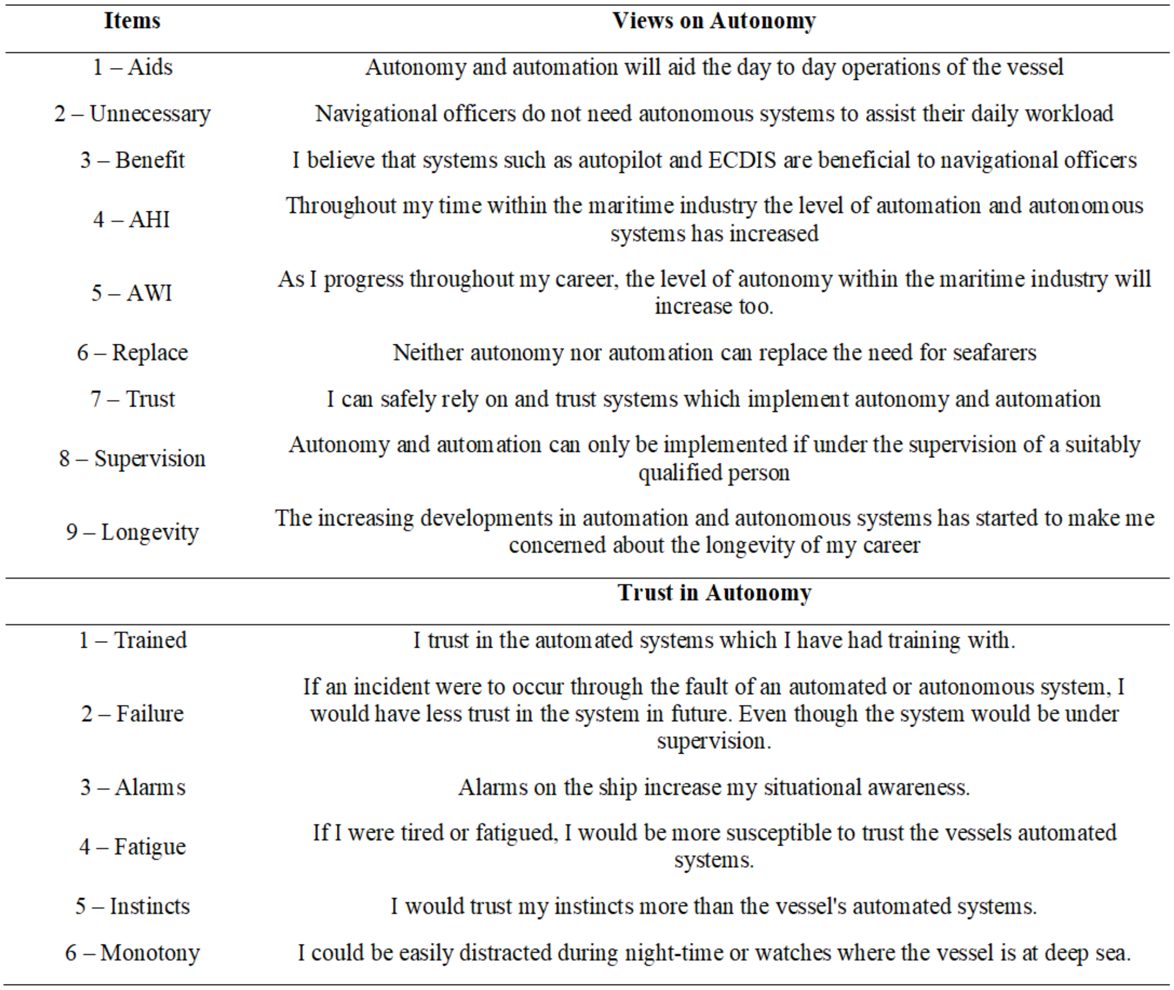
4.3.4 Perception and trust on autonomous shipping

The “Views on Autonomy” section consisted of a 9-item questionnaire assessing the participants views on autonomy benefitting both crew and vessel and the self-perceived impact that autonomy will have on their respective careers. This section allowed the participants to state their opinions on autonomous and automated technology and the views they have regarding the introduction of autonomous shipping.

The “Trust in Autonomy” section consisted of a 6-item questionnaire assessing the participants self-perceived conscious trust in current on-board automated systems, the implications of external factors such as fatigue or deep sea travel and the effectiveness of alarms on SA. In contrast to the “Views on Autonomy” section, the “Trust in Autonomy” section allowed the participants to reflect on their personal experiences with automated technology and how such instances can impact their trust in future technology.

Table 4.2 shows the questions and answering structure for both “Views on Autonomy” and “Trust in Autonomy” sections.

Table 4.2: “Views on Autonomy” and “Trust in Autonomy” Question and Answer Response



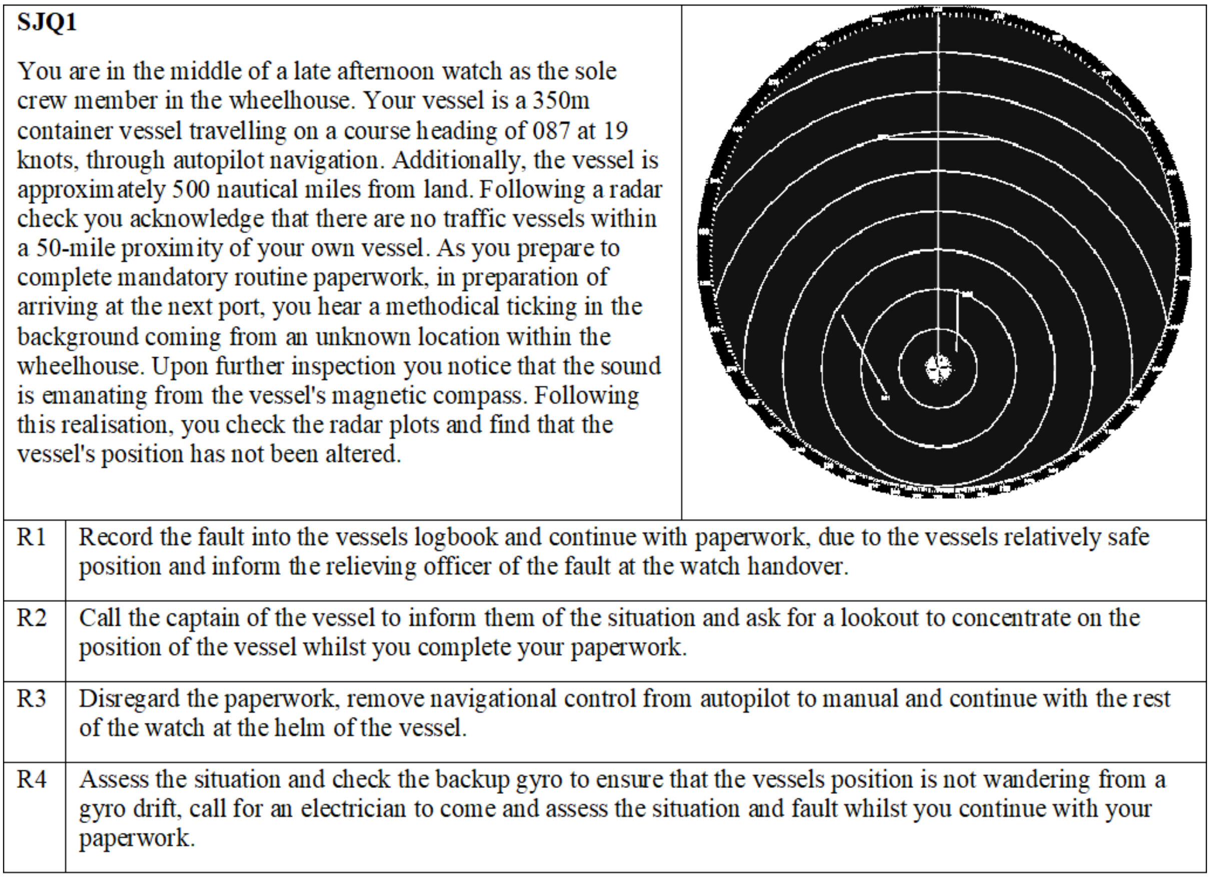
Items	Views on Autonomy
1 – Aids	Autonomy and automation will aid the day to day operations of the vessel
2 – Unnecessary	Navigational officers do not need autonomous systems to assist their daily workload
3 – Benefit	I believe that systems such as autopilot and ECDIS are beneficial to navigational officers
4 – AHI	Throughout my time within the maritime industry the level of automation and autonomous systems has increased
5 – AWI	As I progress throughout my career, the level of autonomy within the maritime industry will increase too.
6 – Replace	Neither autonomy nor automation can replace the need for seafarers
7 – Trust	I can safely rely on and trust systems which implement autonomy and automation
8 – Supervision	Autonomy and automation can only be implemented if under the supervision of a suitably qualified person
9 – Longevity	The increasing developments in automation and autonomous systems has started to make me concerned about the longevity of my career
	Trust in Autonomy
1 – Trained	I trust in the automated systems which I have had training with.
2 – Failure	If an incident were to occur through the fault of an automated or autonomous system, I would have less trust in the system in future. Even though the system would be under supervision.
3 – Alarms	Alarms on the ship increase my situational awareness.
4 – Fatigue	If I were tired or fatigued, I would be more susceptible to trust the vessels automated systems.
5 – Instincts	I would trust my instincts more than the vessel's automated systems.
6 – Monotony	I could be easily distracted during night-time or watches where the vessel is at deep sea.

4.3.5 Situational judgement

This section of the survey consisted of the participant answering three questions which gave them a scenario and 4 possible reactions. The participant was then asked to rank the responses from 1 = ‘least appropriate’, 2 = ‘slightly appropriate’, 3 = ‘appropriate’ to 4 = ‘most appropriate’. The scenarios chosen for the assessment were derived from either prior research into real world maritime incidents or common faults in the utilisation of systems perceived to be reliable by seafarers.

Each SJQ describes a scenario that would have the participant act as the OOW. From the description of each scenario candidates would be able to gain an understanding of the vessel’s position, speed and surroundings. Additionally, within each SJQ participants would encounter a fault that would then prompt them to analyse and rank the responses from 1 to 4. While COLREGs & Ship Management Systems (SMS) offer an insight to rectify and analyse navigational errors, the intent of the SJQs was to understand how the individual processed the scenario and identified the outcome, from a first response perspective, they recognised to be an appropriate action to the unfolding situation. As such, the development of the SJQs were designed to be answered with a ranking based answering procedure.

For the SJQs, all responses were unique to the scenario detailed within the question. The aim of SJQ1, was to give the participant a scenario representative of a fault which would result in a course deviation. The aim of SJQ1, shown in Figure 4.2 (a), was to gain an understanding of whether, if presented with such a scenario, candidates would react appropriately by selecting a suitable response to an automated fault. Subsequently SJQ2, shown in Figure 4.2 (b), was designed with the aim of giving the participant a mechanical fault. The design of SJQ3, shown in Figure 4.2 (c), closely resembled the events of the grounding of the *Lauren Hansen* (Australian Transport Safety Bureau, 2018).



SJQ1

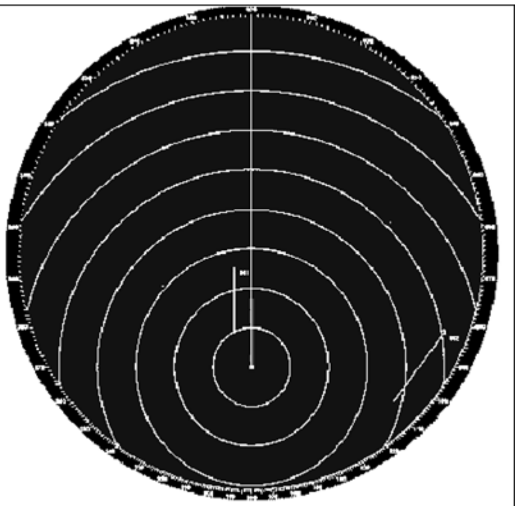
You are in the middle of a late afternoon watch as the sole crew member in the wheelhouse. Your vessel is a 350m container vessel travelling on a course heading of 087 at 19 knots, through autopilot navigation. Additionally, the vessel is approximately 500 nautical miles from land. Following a radar check you acknowledge that there are no traffic vessels within a 50-mile proximity of your own vessel. As you prepare to complete mandatory routine paperwork, in preparation of arriving at the next port, you hear a methodical ticking in the background coming from an unknown location within the wheelhouse. Upon further inspection you notice that the sound is emanating from the vessel's magnetic compass. Following this realisation, you check the radar plots and find that the vessel's position has not been altered.

R1	Record the fault into the vessels logbook and continue with paperwork, due to the vessels relatively safe position and inform the relieving officer of the fault at the watch handover.
R2	Call the captain of the vessel to inform them of the situation and ask for a lookout to concentrate on the position of the vessel whilst you complete your paperwork.
R3	Disregard the paperwork, remove navigational control from autopilot to manual and continue with the rest of the watch at the helm of the vessel.
R4	Assess the situation and check the backup gyro to ensure that the vessels position is not wandering from a gyro drift, call for an electrician to come and assess the situation and fault whilst you continue with your paperwork.

(a)

SJQ2

Your vessel is a 215m bulk carrier, travelling on a course heading of 000 at a speed of 14 knots, through autopilot navigation. Additionally, the vessel is approximately 280 nautical miles from land. At approximately 2 hours into the watch, following a radar check, you acknowledge that there are 2 vessels within a 24-mile proximity of your vessel. From the radar plots, the first vessel appears to be 14 nautical miles on a bearing of 245, travelling at 12 knots with a heading of 345. The second vessel appears to be 6 nautical miles on a bearing of 180, travelling at 19 knots with a heading of 070. After checking the radar, you notice that the positions of the traffic vessels, through the window, do not seem to correlate with the relative positions on the radar display. Upon realising this you notice that the position of the vessel from the vessel's ECDIS corresponds to the radar display too.

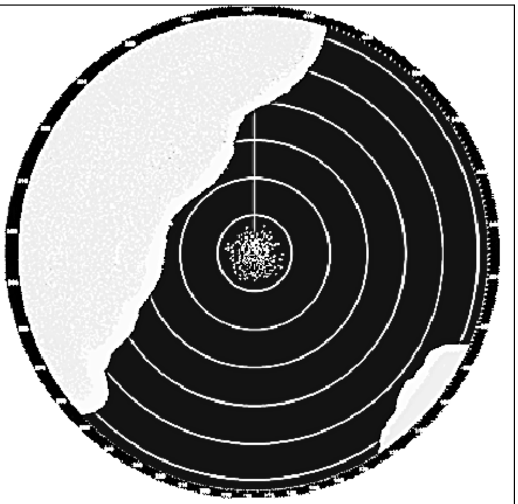


R1	Contact the captain of the vessel to alert them of the situation and take manual control of the vessel until relieved.
R2	Carefully monitor the fault, through means of the watchkeeping log, magnetic compass, navigational systems, and display. And alert relieving Officer of the Watch at the watch handover.
R3	Contact ECR to inform them about the situation unfolding and begin vessels emergency slowdown procedure.
R4	Ensure that the autopilot control is fully operational and assume that the error is from your own judgement due to fatigue.

(b)

SJQ3

Your vessel is a 95m cargo vessel travelling on a course heading of 042 at a speed of 9.2 knots. Additionally, the vessel is 2 nautical miles from land to the north of the vessels position. Your vessel has a planned course alteration position which will put the vessel 0.9 nautical miles from the same body of land. Following a radar check you acknowledge that there are no traffic vessels within a 24-mile proximity from your own vessel. During your watch, you realise that the vessel has made a sudden and unexpected turn to port, without an alarm or indication, as shown on the radar. As the vessel is now swiftly approaching the shallow waters near land you attempt to contact the captain, who does not respond.



R1	Conduct an emergency engine slowdown and adjust the autopilot to starboard, with the aim of bringing the vessel away from the shoreline.
R2	Slowdown the main engine, leave the bridge in an attempt to alert the captain to the situation.
R3	Turn steering control to manual and turn the vessel to hard starboard to avoid the shallow waters.
R4	Slow the main engine down and bring the engine to full astern to reduce the forward momentum of the vessel. Additionally, use the vessel's thrusters to aid course correction.

(c)

Figure 4.2: Situational Judgement Question and Answer Response

4.4 Results

4.4.1 Overview

Prior to analysing any variables, it was key to address each area of the survey and treat the participants as a homogenous group. Therefore Figure 4.3 shows the variation of scores in the "Views on Autonomy" section. The participants, while in favour of vessels employing more autonomous operations, expressed their concerns regarding the impact that autonomy will have on their careers and that autonomy should not replace seafarers. Additionally, participants were hesitant to show complete trust and reliance in autonomy, as over 65% of participants answered item 7 with a score of 3, 4 or 5. All participant responses to items 2, 6 and 9 were inversely scored, i.e., 1 = "Strongly Agree" – 7 = "Strongly Disagree". This was due to items 2, 6 and 9 being negative representations of autonomy on ships.

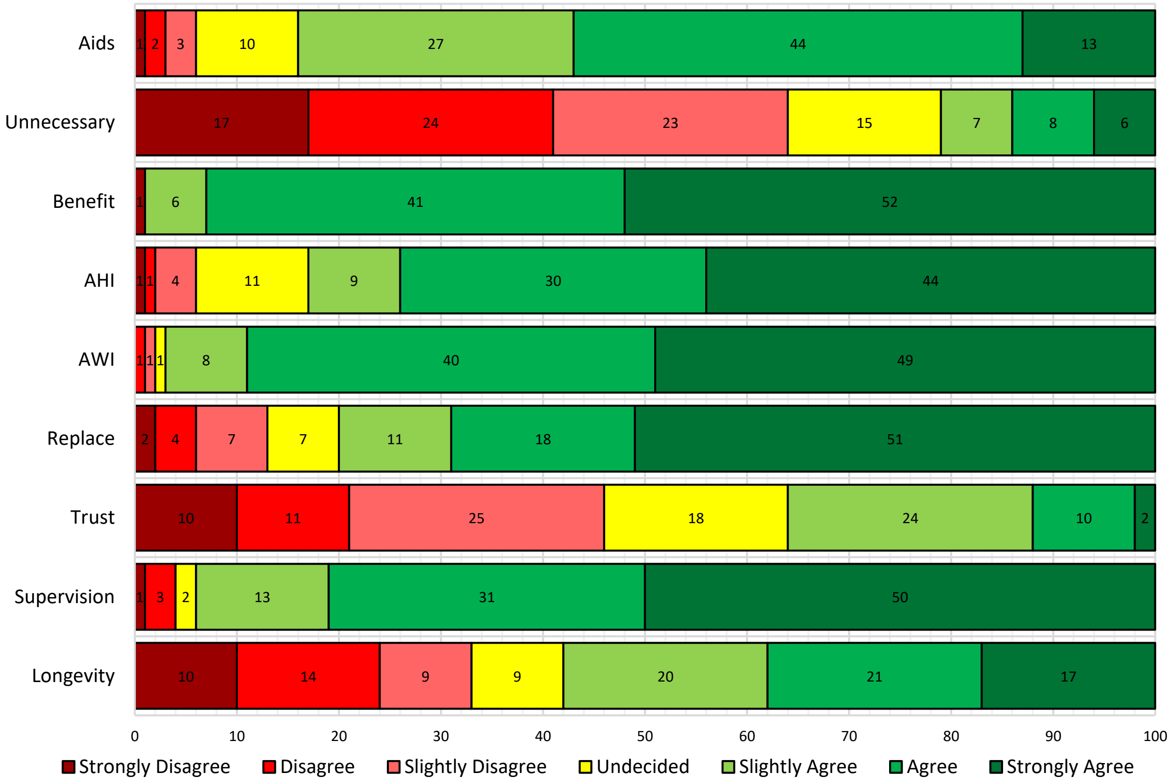


Figure 4.3: Response Rate to "Views on Autonomy"

As a general consensus the participants' trust in autonomy differed depending on how the question was delivered. As shown in Figure 4.4 participants agreed that alarms increase their levels of SA, and that if they receive training with the system then they were in favour of trusting it. However, when questioned on their levels of trust following a failure, despite the system being under supervision, participants were less in favour of autonomy. Furthermore, participants disagreed with the sentiment that they may be susceptible to bias and complacency when fatigued or undertaking night-time and deep-sea watches.

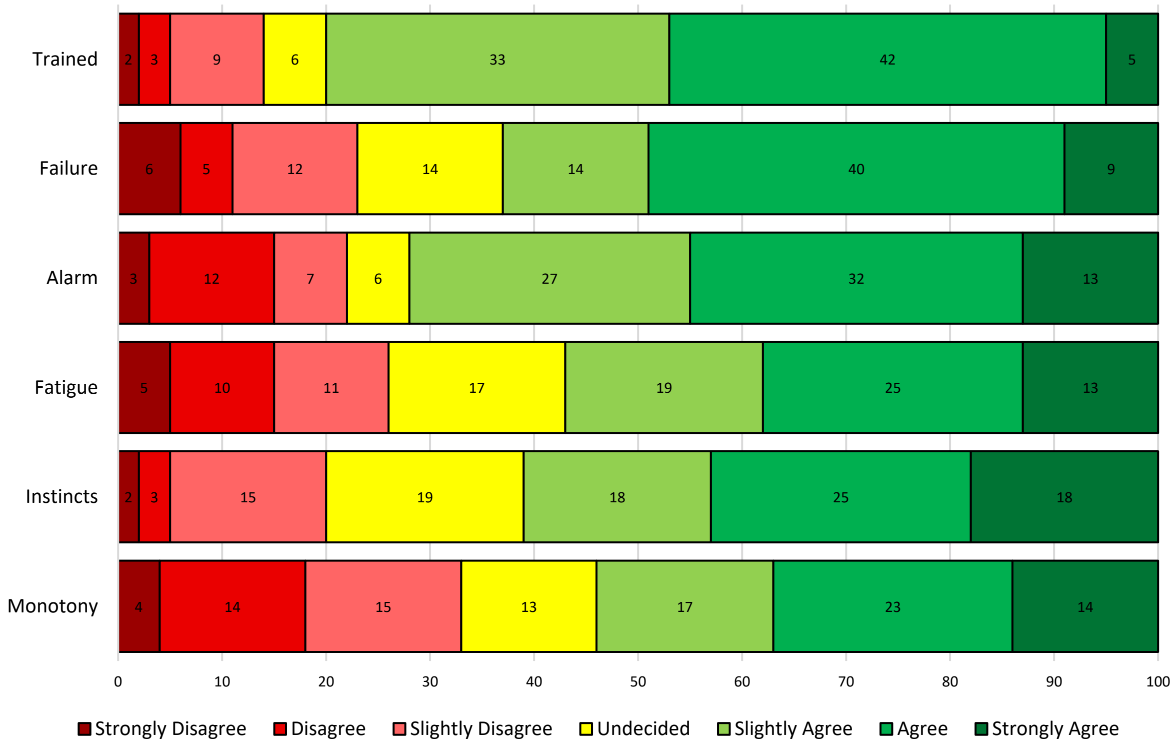


Figure 4.4: Response Rate to "Trust in Autonomy"

For the data analysis on the SJQs, the SJQ and R number correlate directly with Figure 4.2 as shown in Section 4.3.5. Figure 4.5 shows the variation of participant choices for SJQ1. From this it can be seen that 59% of participants selected "R1 – Record the fault…" as the least appropriate response, whereas for "R2 – *Call the captain…*", "R3 – *Disregard the paperwork…*" and "R4 – *Assess the situation…*" had less consistent responses among the participants, with rates of 34%, 27% and 32% for most appropriate, respectively.

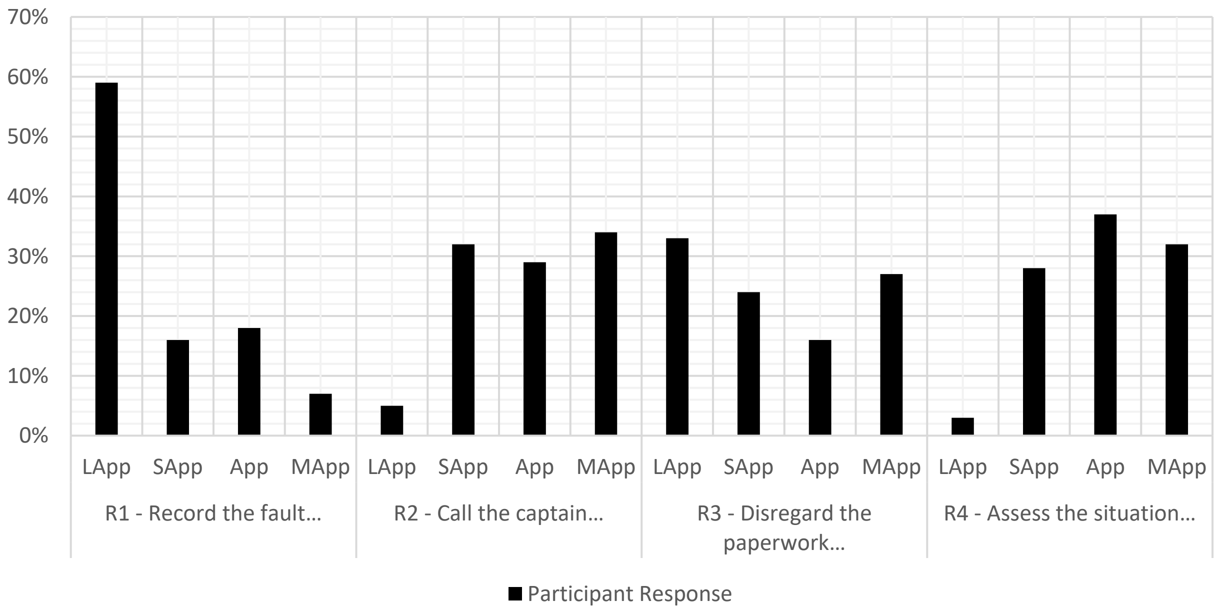


Figure 4.5: Response Rate to SJQ1

Figure 4.6 shows the overall response rate for SJQ2, and from this it can be seen that each response had a definitive selection for the most to least appropriate responses. This is shown with 69% of participants selecting "R1 – *Call the captain…*" and a further 69% choosing "R4 – *Ensure autopilot is operational…*" as the most and least appropriate responses respectively.

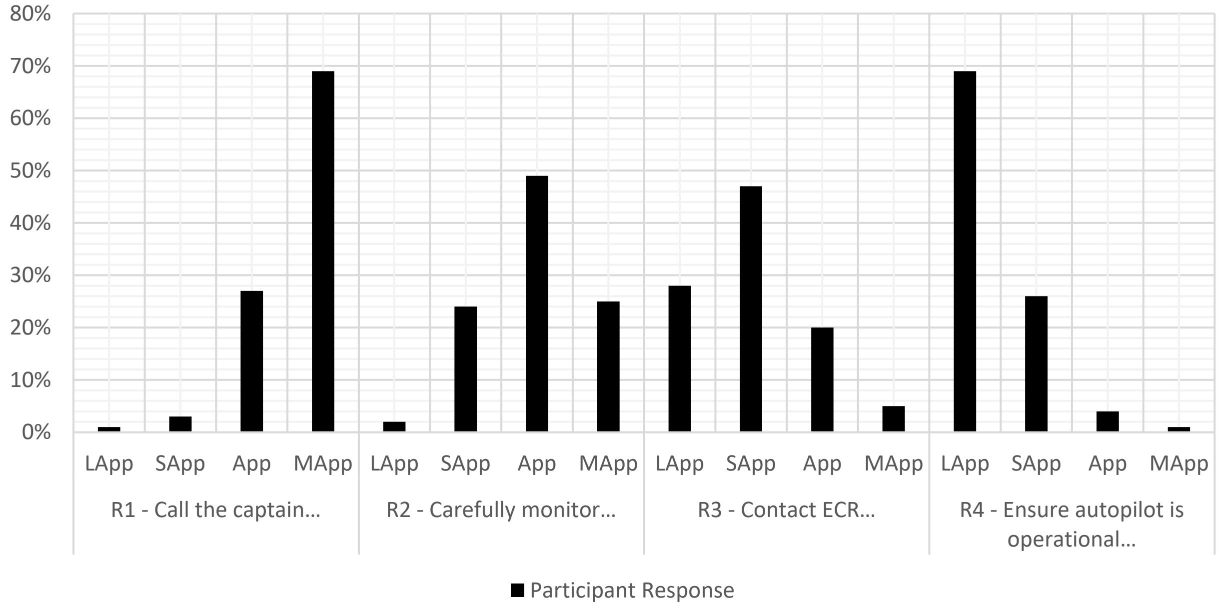


Figure 4.6: Response Rate to SJQ2

Figure 4.7 shows the overall response rate for SJQ3, and from this it can be seen that each response had a definitive selection for the most to least appropriate responses. This is shown with 84% of participants selecting "R2 – *Leave bridge…*" and a further 67% choosing "R3 – *Turn to manual…*" as the least and most appropriate responses respectively.

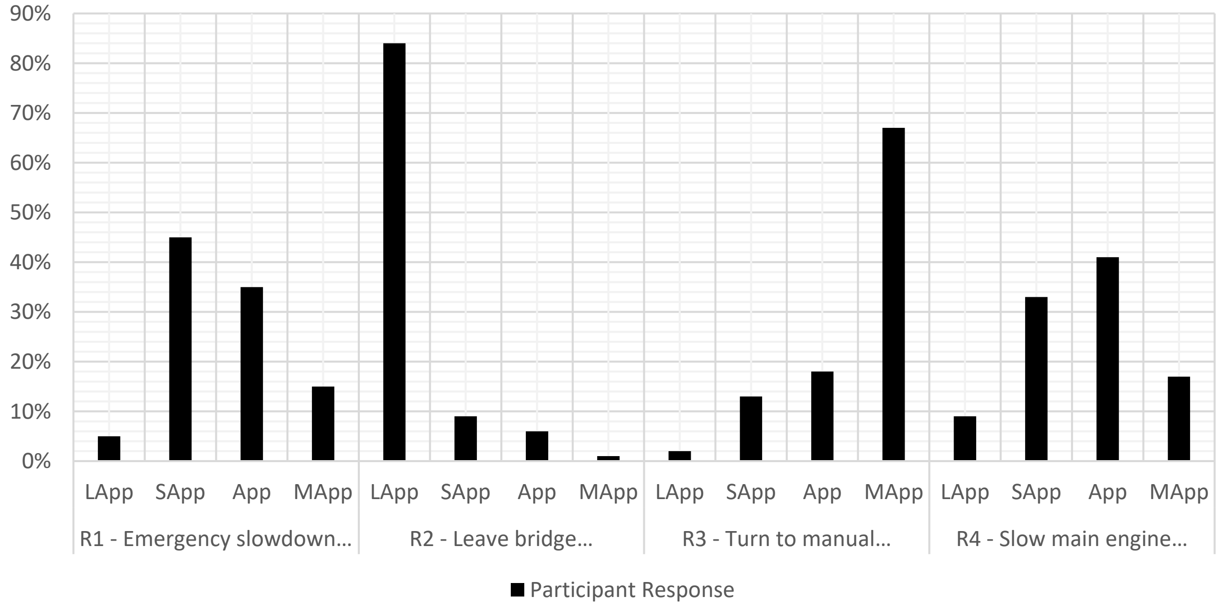
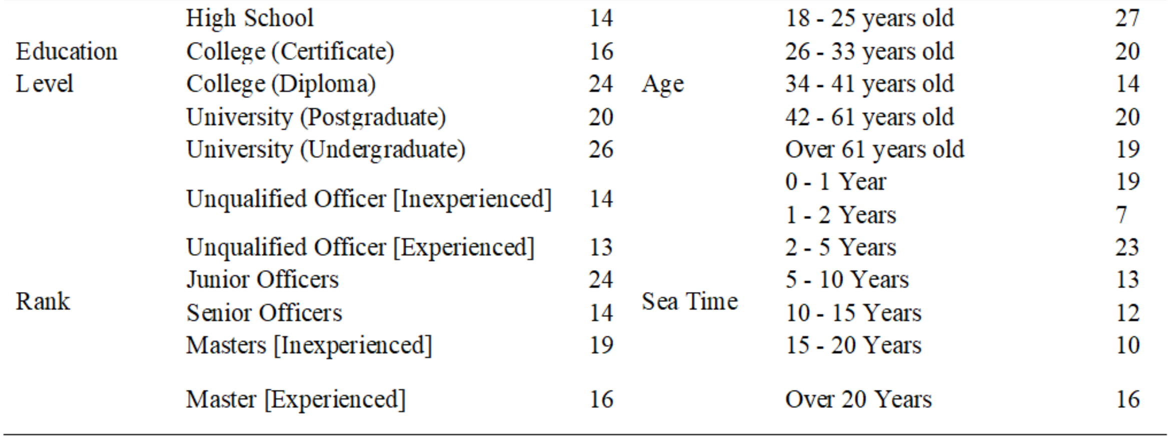


Figure 4.7: Response Rate to SJQ3

4.4.2 *Demographics*

As stated in Chapter 3, Section 3.4.3, 100 participants (n = 100) were surveyed as part of the *Survey Study*. Over half of the participants were aged 34 or older and 70% were fully qualified officers of the watch. Less than half of the participants had undertaken university education. The male to female split was a 91:8 ratio with one participant opting not to answer. Additionally, the demonym of participants was 63% British, 15% European and 22% Rest of World. Due to initial hypotheses devised at the beginning of the chapter, demographic data on the participants' nationality and gender split were not further analysed. Moreover Table 4.3 shows the number of participants under each demographic variable analysed.

Table 4.3: Participant Demographic Data



Variable	**Categories**	**n**	**Variable**	**Categories**	**n**
Education Level	High School	14	Age	18 - 25 years old	27
	College (Certificate)	16		26 - 33 years old	20
	College (Diploma)	24		34 - 41 years old	14
	University (Postgraduate)	20		42 - 61 years old	20
	University (Undergraduate)	26		Over 61 years old	19
Rank	Unqualified Officer [Inexperienced]	14	Sea Time	0 - 1 Year	19
				1 - 2 Years	7
	Unqualified Officer [Experienced]	13		2 - 5 Years	23
	Junior Officers	24		5 - 10 Years	13
	Senior Officers	14		10 - 15 Years	12
	Masters [Inexperienced]	19		15 - 20 Years	10
	Master [Experienced]	16		Over 20 Years	16

When assessing the four variables, it was assumed that all variables were closely correlated. Therefore, a Pearson's correlation matrix was constructed, as shown in Table 4.4, to test this. From this matrix it can be seen that the age, sea time, education level and rank variables are closely positively correlated with each other. Due the close relationship between age, rank and experience it was expected that these variables would increase accordingly with each other. With all variables showing a high level of correlation among, the specific scores of the correlation were considered. The rank variable recorded the highest correlation scores with the other variables, which may be expected as the general assumption may be that the older the participant is, the more experience they may have at sea which would also coincide with a higher participant rank and higher qualification level. To ensure that all avenues had been explored ANOVA tests were conducted on each demographic variable. Subsequently Post hoc analysis was conducted, to distinguish between the groups of participants within each demographic variable, using the Tukey Honestly Significant Difference (HSD) test.

Table 4.4: Pearson's Correlation Values

Variable	**Age**	**Qualification Level**	**Sea Time**	**Rank**
Age	1	0.367**	0.831**	0.696**
Qualification Level		1	0.391**	0.487**
Sea Time			1	0.758**
Rank				1

*Significance Value: $p<0.05$ ** Significance Value: $p<0.01$

4.4.3 Age

Due to the high variation in the ages of the participant pool, groups were organised into subcategories that would increase the number of participants within each age group, this would then allow for a consolidated ANOVA test to be conducted between the age groups of participants with a larger sample pool in each group. To categorise the participants for ANOVA testing, the following participant age groups were utilised:

- 18 – 25 Years – n = 27
- 26 – 33 Years – n = 20
- 34 – 41 Years – n = 14
- 42 – 61 Years – n = 20
- Over 61 Years – n = 19

4.4.3.1 Views on autonomy

Following the categorisation of the age groups of participants, nine 1x5 ANOVA tests were performed on the groups to identify whether the age of a participant impacted their opinion of autonomous shipping. As seen in Table 4.5 Item 4 "AHI" had levels of variation in their response. Due to the results of the ANOVA test indicating that there were statistically significant results (Sig value >0.05), Post Hoc testing was administered to the ANOVA tests to give a greater insight. From this further testing it was found that younger participants believed that they had experienced fewer autonomous technological advancements throughout their careers than older participants. This is shown through the Tukey HSD testing with the 18 – 25 age group having an ambivalent opinion on Item 4 "AHI" when compared with all other age groups. Moreover, participants of the 26 – 33 age group also showed a difference in opinion when compared with the Over 61 age group. From this testing it can be seen that younger participants believe that they have not experienced a change in autonomy over their careers in comparison to older participants.

Table 4.5: "Views on Autonomy" by Age

Item	Total	Mean (SD)					F	Post Hocs
		18 – 25 Years	26 – 33 Years	34 – 41 Years	42 – 61 Years	Over 61 Years		
1. Aids	5.44 (1.157)	5.63 (.967)	5.15 (1.309)	5.47 (1.506)	5.32 (1.003)	5.58 (1.121)	.610	-
2. Unnecessary	4.81 (1.739)	4.59 (1.738)	4.70 (1.720)	5.53 (1.302)	4.42 (1.742)	5.05 (2.013)	1.109	-
3. Benefit	6.41 (1.167)	6.26 (1.163)	6.25 (.786)	6.53 (.640)	6.53 (.513)	6.58 (.607)	.799	-
4. AHI	5.92 (1.323)	4.81 (1.570)	5.80 (1.240)	6.33 (1.047)	6.42 (.607)	6.79 (.419)	11.025*	18 – 25 > 26 – 33 18 – 25 > 34 – 41 18 – 25 > 42 – 61 18 – 25 > Over 61 26 – 33 > Over 61
5. AWI	6.32 (.875)	6.04 (1.224)	6.40 (.681)	6.60 (.632)	6.37 (.761)	6.37 (.684)	1.169	-
6. Replace	2.21 (1.629)	2.22 (1.577)	2.50 (1.670)	2.20 (1.897)	2.11 (1.410)	2.00 (1.764)	.250	-
7. Trust	3.73 (1.536)	4.15 (1.586)	3.50 (1.573)	3.87 (1.552)	3.58 (1.502)	3.42 (1.465)	.875	-
8. Supervision	6.16 (1.195)	6.04 (1.344)	6.10 (1.252)	6.20 (1.373)	6.26 (.653)	6.26 (1.284)	.154	-
9. Longevity	3.54 (1.987)	3.67 (2.184)	3.45 (1.986)	2.73 (1.335)	4.11 (1.997)	3.53 (2.091)	1.042	-

*Significance Value: p<0.05

4.4.3.2 Trust in autonomy

For testing the age groups against each other a further six 1x5 ANOVA tests were conducted. As shown in Table 4.6 there were no statistically significant responses (Sig value >0.05), from the results of the ANOVA testing.

Table 4.6: "Trust in Autonomy" by Age

Item	Total	Mean (SD)					F	Post Hocs
		18 – 25 Years	26 – 33 Years	34 – 41 Years	42 – 61 Years	Over 61 Years		
1. Trained	5.11 (1.278)	5.37 (1.275)	5.25 (1.251)	4.87 (1.598)	4.79 (1.228)	5.11 (1.100)	.767	-
2. Failure	3.19 (1.668)	3.11 (1.625)	2.85 (1.348)	3.4 (2.197	3.26 (1.727)	3.42 (1.610)	.373	-
3. Alarm	4.90 (1.661)	5.59 (1.217)	5.05 (1.731)	4.40 (1.724)	4.68 (1.635)	4.37 (1.892)	2.227	-
4. Fatigue	3.38 (1.722)	3.11 (1.601)	2.85 (1.631)	3.98 (2.264)	3.68 (1.057)	3.63 (1.978)	1.197	-
5. Instincts	3.05 (1.540)	2.78(1.311)	3.20 (1.322)	3.33 (1.915)	2.89 (1.449)	3.21 (1.873)	.475	-
6. Monotony	4.50 (1.789)	4.93 (1.567)	3.85 (1.814)	5.00 (2.035)	4.63 (1.640)	4.05 (1.870)	1.705	-

*Significance Value: p<0.05

4.4.3.3 Situational judgement

Figure 4.8 show the responses for all age groups when answering SJQ1, from this it can be seen that the majority the age groups, with the exception of the 18 – 25 age group, had identified “R1 – *Record the fault…*” as the least appropriate response in the event of an automated course deviation. However, “R2 – *Call the captain…*”, “R3 – *Disregard the paperwork…*” and “R4 –

Assess the situation…" had a greater level of disparity among the participant groups. Upon analysing the "R2 – *Call the captain…*" response, it was found that participants from age groups 26 – 33 and Over 61 had opted to select this as the most appropriate response, with responses rates of 44% and 42% respectively. When analysing "R3 – *Disregard the paperwork…*", it was found that no age group had selected this response to be the most appropriate. However, the 18 – 25 age group had identified this as the least appropriate response, with a response rate of 45%. Then when analysing the "R4 – *Assess the situation…*" response, it was found that the largest proportion of participants from the 18 – 25, 34 – 41 and 42 – 61 age groups had identified this as the most appropriate response, with response rates of 41%, 33% and 42% respectively.

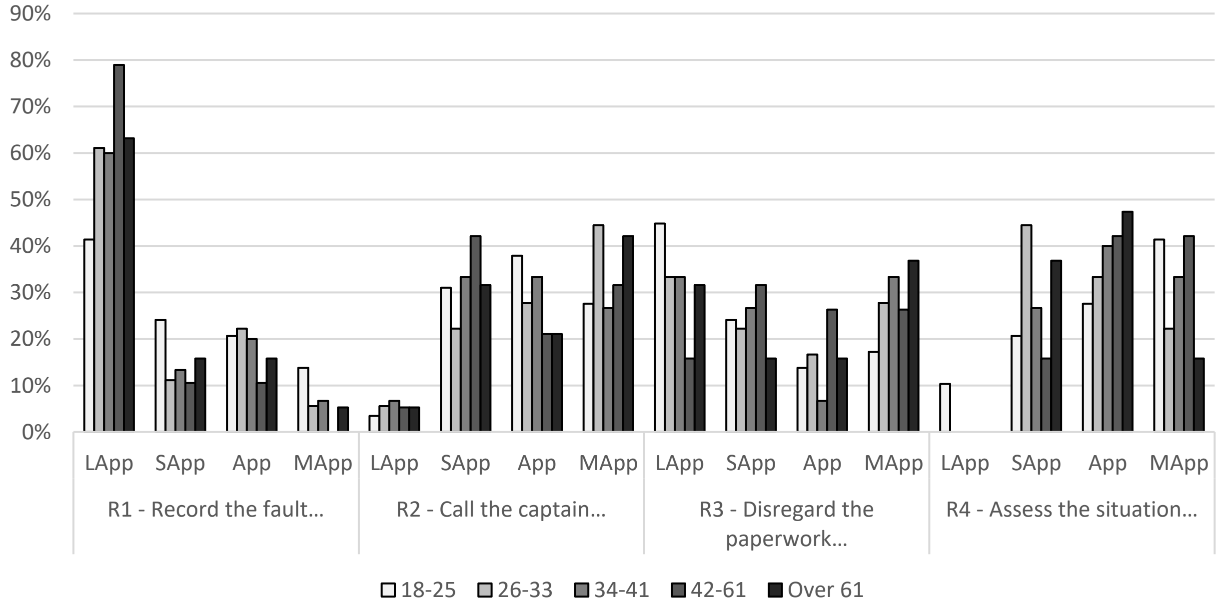


Figure 4.8: SJQ1 Responses by Age

Figure 4.9 shows the response of participants by age group when answering SJQ2I. Every age group had answered in a similar manner with the majority of participants within each group selecting "R1 – *Call the captain…*" to be the most appropriate response and "R4 – *Ensure autopilot is operational…*" to be the least appropriate response.

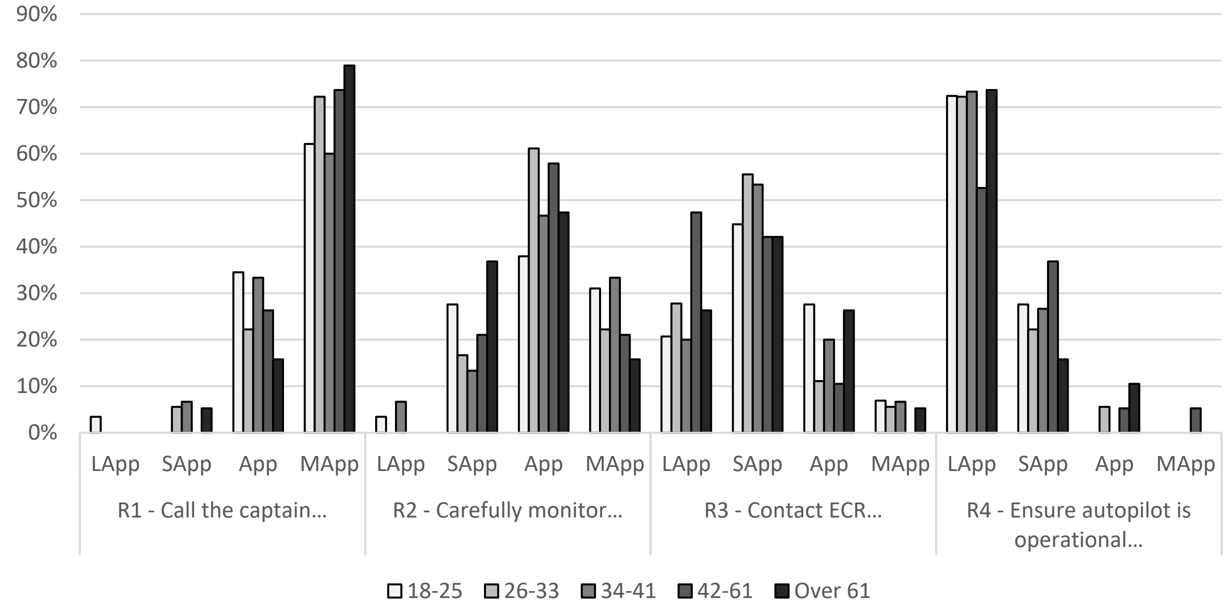


Figure 4.9: SJQ2 Responses by Age

Figure 4.10 shows the response of all participant age groups when answering SJQ3. The results displayed a uniformity of participant responses, as definitive responses were identified to be the most and least appropriate. The majority of participants for all age groups had identified "R2 – *Leave bridge…*" and "R3 – *Turn to manual…*" as the least appropriate and most appropriate responses, respectively.

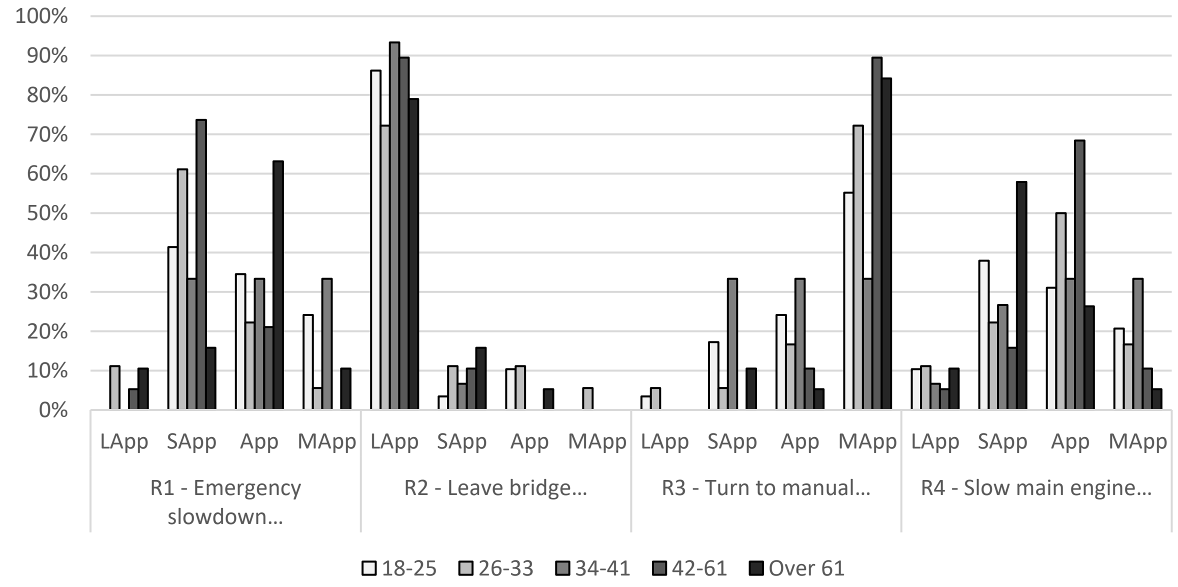


Figure 4.10: SJQ3 Responses by Age

4.4.4 Qualification Level

To categorise the participants for ANOVA testing, participant qualification level groups were constructed as shown in Table 4.7:

Table 4.7: Demographic Data by Qualification Level

Category	Definition	n
High School (HS)	Participants with the highest education level of high school level	14
College (Cert)	Participants with the highest education level of attending college and receiving a qualification level of Higher National Certificate or equivalent	16
College (Dip)	Participants with the highest education level of attending college and receiving a qualification level of Higher National Diploma or equivalent	24
University (UG)	Participants with the highest education level of attending university and receiving a qualification level of bachelor's degree or equivalent, as an undergraduate student	20
University (PG)	Participants with the highest education level of attending university and exceeding a qualification level of bachelor's degree i.e., masters or doctoral degree, as a postgraduate student	26

4.4.4.1 Views on autonomy

Following the categorisation of various educational level groups of participants, nine 1x5 ANOVA tests were performed on the groups to identify whether the education level of a participant impacted their opinion of autonomous shipping. As seen in Table 4.8, both Item 3 "Benefit" and Item 4 "AHI" had levels of variation in their response. Due to the results of the ANOVA test indicating that there were statistically significant results (Sig value >0.05), Tukey HSD testing was administered to the ANOVA tests to give a greater insight. From further testing it was found that participants with a maximum education level of "High School" had less belief that autonomous shipping would benefit seafarers than both the "College (Cert)" and "University (PG)" educational level participants. However, as shown in Table 4.10 while the opinion on Item 3 "Benefit" was different, all participants were, to varying levels, in agreement with the statement.

For Item 4 "AHI" there were disparities in the responses between both the "College (Dip)" and "University (PG)" and the "High School" participant groups. The results of the Post Hoc testing identified that participants of the "High School" educational level had not witnessed as much of an increase in autonomous systems onboard when compared with both the "College Diploma" and "University (PG)" participant groups.

Table 4.8: "Views on Autonomy" by Qualification Level

Item	Mean (SD)						F	Post Hocs
	Total	High School	College (Cert)	College (Dip)	Uni (UG)	Uni (PG)		
1. Aids	5.44 (1.157)	5.14 (1.167)	5.25 (1.342)	5.54 (1.021)	5.54 (1.174)	5.55 (1.191)	.467	-
2. Unnecessary	4.81 (1.739)	4.68 (1.292)	4.81 (1.870)	5.04 (1.574)	4.46 (2.102)	4.95 (1.669)	.393	-
3. Benefit	6.41 (1.167)	5.86 (1.512)	6.63 (.619)	6.42 (.584)	6.38 (.637	6.65 (.587)	2.450*	Cert > HS Pg > HS
4. AHI	5.92 (1.323)	4.86 (1.099)	5.81 (1.109)	6.25 (1.260)	6.00 (1.523)	6.25 (1.118)	3.266*	Dip > HS Pg > HS
5. AWI	6.32 (.875)	6.00 (1.240)	6.56 (.629)	6.25 (.989)	6.19 (.801)	6.60 (.598)	1.494	-
6. Replace	2.21 (1.629)	2.71 (2.016)	1.75 (1.125)	2.42 (1.742)	2.15 (1.736)	2.05 (1.395)	.801	-
7. Trust	3.73 (1.536)	3.93 (1.328)	3.69 (1.57)	3.83 (1.606)	3.62 (1.651)	3.65 (1.565)	.134	-
8. Supervision	6.16 (1.195)	5.86 (1.460	6.63 (.619)	6.00 (1.351)	6.12 (1.366)	6.25 (.851)	.974	-
9. Longevity	3.54 (1.987)	2.64 (1.737)	4.19 (2.040)	3.21 (2.021)	4.08 (1.998)	3.35 (1.872)	1.892	-

*Significance Value: p<0.05

4.4.4.2 Trust in autonomy

Table 4.9 shows the variation in responses for the "Trust in Autonomy" section. For this section six 1x5 ANOVA tests were performed on the participant groups. When analysing the data delivered by the ANOVA tests, it was found that there were no statistically significant results (Sig value >0.05) among the educational levels of participants.

Table 4.9: "Trust in Autonomy" by Qualification Level

Item	Mean (SD)						F	Post Hocs
	Total	High School	College (Cert)	College (Dip)	Uni (UG)	Uni (PG)		
1. Trained	5.11 (1.276)	5.36 (.745)	5.50 (1.414)	5.17 (1.090)	4.92 (1.495)	4.80 (1.361)	.946	-
2. Failure	3.19 (1.668)	3.57 (1.785)	2.44 (1.315)	3.13 (1.541)	3.27 (1.564)	3.50 (2.039)	.314	-
3. Alarm	4.90 (1.661)	5.00 (1.840)	5.31 (1.448)	5.04 (1.681)	4.69 (1.668)	4.60 (1.729)	.694	-
4. Fatigue	3.38 (1.722)	3.57 (1.742)	3.19 (1.559)	3.13 (1.597)	3.42 (1.943)	3.65 (1.785)	.849	-
5. Instincts	3.05 (1.540)	3.29 (1.773)	2.81 (1.471)	3.08 (1.412)	3.12 (1.366)	2.95 (1.877)	.935	-
6. Monotony	4.50 (1.789)	4.36 (1.550)	4.00 (1.826)	5.33 (1.373)	4.35 (2.038)	4.20 (1.852)	.118	-

*Significance Value: p<0.05

4.4.4.3 Situational judgement

Figure 4.11 show the responses for all educational groups when answering SJQ1. From this it can be seen that the majority of educational groups identified "R1 – *Record the fault…*" as the least appropriate response in the event of an automated course deviation. However, "R2 – *Call the captain…*", "R3 – *Disregard the paperwork…*" and "R4 – *Assess the situation…*" had a greater level of inconsistency among the participant groups. Upon analysing the "R2 – *Call the* *captain…*” response, it was found that participants with “College (Cert)”, “University (UG)” and “University (PG)” levels had opted to select this as the most appropriate response, with responses rates of 50%, 35% and 40% respectively. When analysing “R3 – *Disregard the paperwork…*”, it was found that the “College (Dip)” level participant group had split their opinions and opted to identify this as one of the most appropriate responses, with a response rate of 33%. However, the High School education group had split their opinion between this response and “R1 – *Record the fault…*” as the least appropriate response, with a response rate of 43% for both options. Then when analysing the “R4 – *Assess the situation…*” response, it was found that the largest proportion of participants of both the “High School” and “College (Dip)” level participants had identified this as the most appropriate response, with a response rate of 43% and 33% respectively.

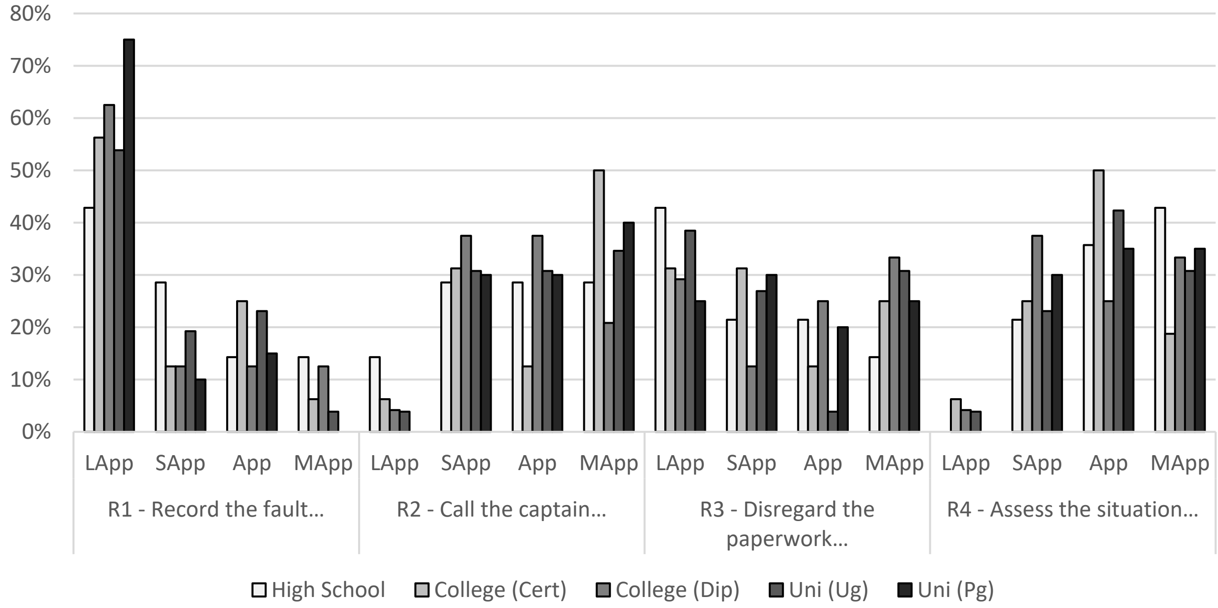


Figure 4.11: SJQ1 Responses by Qualification Level

Figure 4.12 shows the response of participant educational levels when answering SJQ2. All participant groups answered in a similar manner with the majority of participant selecting “R1 – *Call the captain…*” to be the most appropriate response and “R4 – *Ensure autopilot is operational…*” to be the least appropriate response.

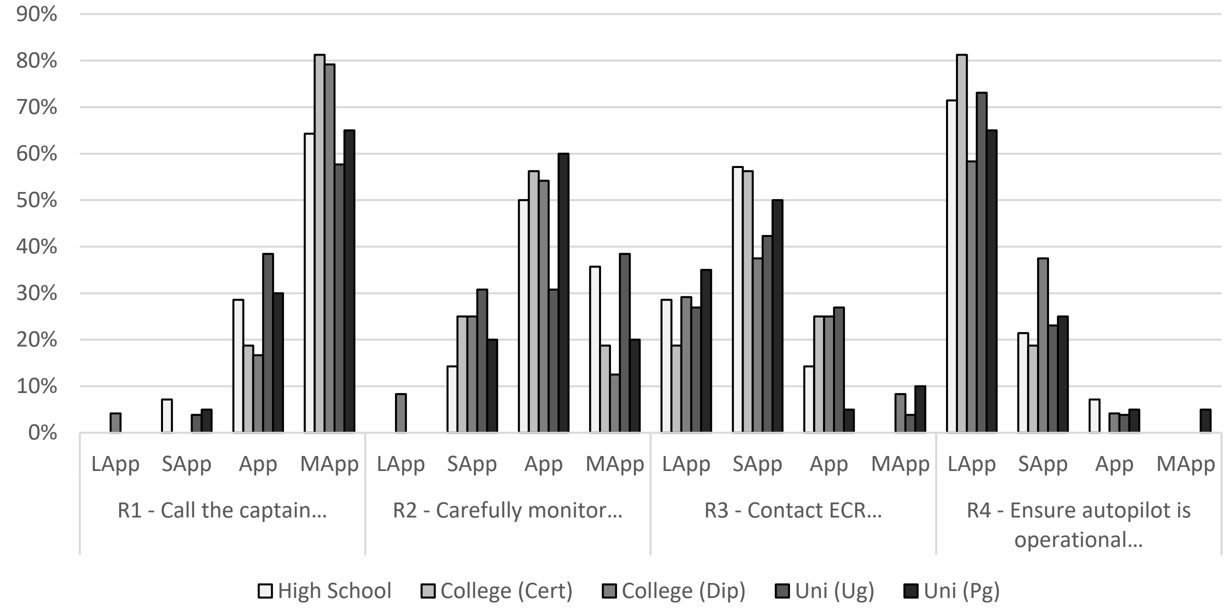


Figure 4.12: SJQ2 Responses by Qualification Level

Figure 4.13 shows the response of participant educational levels when answering SJQ3. The results showed a similar uniformity of participant responses to SJQ2, as definitive responses were identified to be the most and least appropriate. The majority of participants for all educational groups had identified "R2 – *Leave bridge…*" and "R3 – *Turn to manual…*" as the least appropriate and most appropriate responses, respectively.

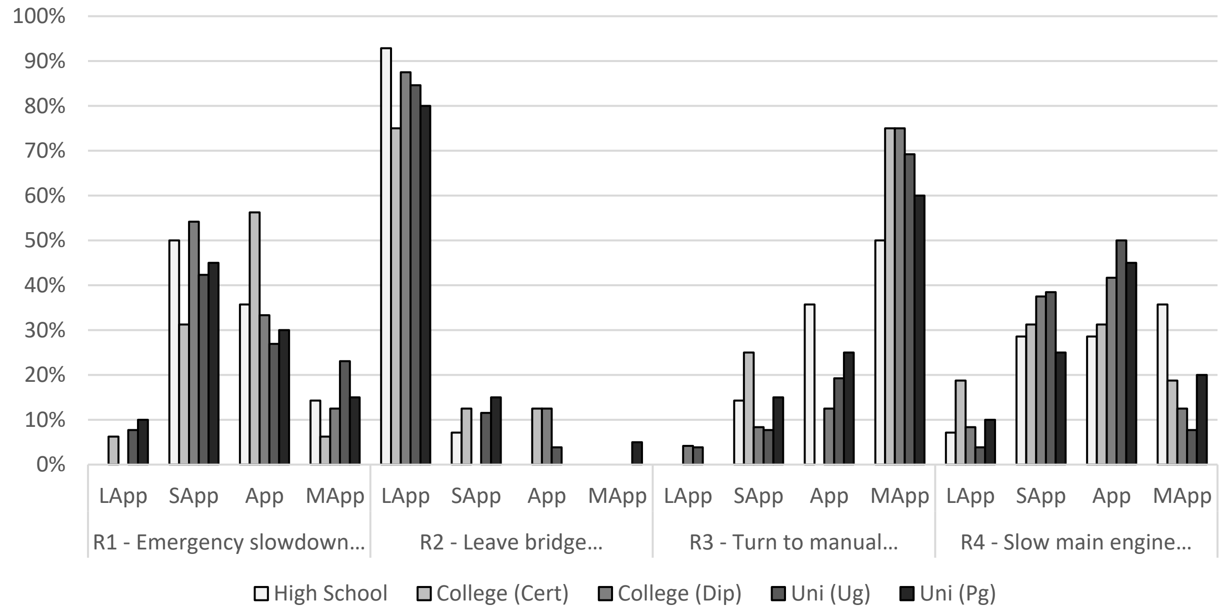


Figure 4.13: SJQ3 Responses by Qualification Level

4.4.5 Sea Experience

To categorise the participants for ANOVA testing, participant Sea Experience groups were constructed as shown in Table 4.10:

Table 4.10: Demographic Data by Sea Experience

Category	Definition	n
0 – 2 Years	Participants with a maximum time spent at sea of up to 2 years of sea going experience	26
2 – 5 Years	Participants who have accumulated between 2 to 5 years of sea going experience	23
5 – 15 Years	Participants who have accumulated between 5 to 15 years of sea going experience	25
Over 15 Years	Participants who have accumulated over 15 years of sea going experience	26

4.4.5.1 Views on autonomy

Nine 1x4 ANOVA tests were conducted to understand whether the length of time spent at sea had an effect on the participants' opinions on autonomous shipping. Table 4.11 shows the variation among the participant groups within each question. As shown in Table 4.11 Item 4 "AHI" was the only question which showed a statistically significant result (Sig value >0.05). Using Tukey HSD testing it was found that participants in the 0 – 2 years sea experience group had experienced less technological advances in autonomous shipping than participants with more sea time. This is shown in Table 4.11 as participant groups with more than 2 years' experience have answered this question more favourably than participants in the 0 – 2 years sea experience group, where this group were more undecided on this matter.

Table 4.11: "Views on Autonomy" by Sea Experience

Item	Mean (SD)					F	Post Hocs
	Total	0 – 2 Years	2 – 5 Years	5 – 15 Years	Over 15 Years		
1. Aids	5.44 (1.157)	5.42 (.945)	5.61 (1.158)	5.44 (1.417)	5.31 (1.123)	.272	-
2. Unnecessary	4.81 (1.739)	4.81 (1.575)	4.74 (1.839)	4.72 (1.768)	4.96 (1.865)	.098	-
3. Benefit	6.41 (1.167)	6.04 (1.148)	6.57 (.662)	6.48 (.653)	6.58 (.578)	2.609	-
4. AHI	5.92 (1.323)	4.42 (1.362)	6.00 (1.168)	6.60 (.500)	6.69 (.471)	31.123*	0 – 2 Years > 2 – 5 Years 0 – 2 Years > 5 – 15 Years 0 – 2 Years > Over 15 Years
5. AWI	6.32 (.875)	5.92 (1.197)	6.48 (.665)	6.52 (.770)	6.38 (.637)	2.643	-
6. Replace	2.21 (1.629)	2.00 (1.497	2.26 (1.685)	2.72 (1.792)	1.88 (1.505)	1.328	-
7. Trust	3.73 (1.536)	3.88 (1.558)	3.83 (1.586)	3.76 (1.615)	3.46 (1.449)	.378	-
8. Supervision	6.16 (1.195)	5.92 (1.197)	6.26 (1.356)	6.24 (1.128)	6.23 (1.142)	.455	-
9. Longevity	3.54 (1.987)	3.69 (2.131)	3.26 (2.027)	3.12 (1.563)	4.04 (2.144)	1.124	-

*Significance Value: p<0.05

4.4.5.2 Trust in autonomy

To assess if seagoing experience impacted on the participants' trust in autonomous shipping, a further six 1x4 ANOVA tests were conducted, on the items questioned within the "*Trust in*

Autonomy” section. From the results of the ANOVA test, as shown in Table 4.12, it was found that there was a statistically significant result (Sig value >0.05) for Item 3 “Alarm”. Post Hoc tests were then conducted on this result which then identified that participants with less sea going experience found alarms benefitted their SA more than participants with over 15 years’ experience.

Table 4.12: "Trust in Autonomy" by Sea Experience

Item	**Total**	**Mean (SD)** **0 – 2 Years**	**2 – 5 Years**	**5 – 15 Years**	**Over 15 Years**	**F**	**Post Hocs**
1. Trained	5.11 (1.276)	5.42 (1.172)	4.83 (1.497)	5.16 (1.106)	5.00 (1.327)	.974	-
2. Failure	3.19 (1.668)	3.42 (1.701)	3.94 (1.581)	2.80 (1.683)	3.54 (1.679)	1.159	-
3. Alarm	4.90 (1.661)	5.73 (1.116)	4.70 (1.820)	4.84 (1.675)	4.31 (1.715)	3.674*	0 – 2 Years > Over 15 Years
4. Fatigue	3.38 (1.722)	3.23 (1.751)	3.13 (1.576)	3.48 (1.782)	3.65 (1.810)	.466	-
5. Instincts	3.05 (1.540)	2.69 (1.320)	3.26 (1.602)	3.28 (1.568)	3.00 (1.673)	.802	-
6. Monotony	4.50 (1.789)	4.73 (1.663)	4.43 (1.879)	4.48 (1.960)	4.35 (1.742)	.214	-

*Significance Value: $p<0.05$

4.4.5.3 Situational judgement

Figure 4.14 shows the responses to SJQ1 for the variation of seagoing experience. From Figure 4.14 it can be seen that the majority of participants from groups with more than 2 years of seagoing experience had identified “R1 – *Record the fault…*” as the least appropriate response. Whereas the group with the least seagoing experience, 0 – 2 years, had identified both “R1 – *Record the fault…*” and “R3 – *Disregard the paperwork…*" as the least appropriate responses. Conversely, that the group with the most seagoing experience, over 15 years and the 2 – 5 years of experience groups had selected “R2 – *Call the captain…*” as the most appropriate response with a rate of 46% and 35% respectively. When analysing “R3 – *Disregard the paperwork…*”, it was found that no participant groups had identified this as the most appropriate response. Moreover, this option was the 2nd most common choice as the least appropriate response. Then when analysing the “R4 – *Assess the situation…*” response, it was found that the largest proportion of the participants of the 0 – 2 years and 5 – 15 years of experience groups had identified this as the most appropriate response, with a response rate of 38% and 40% respectively.

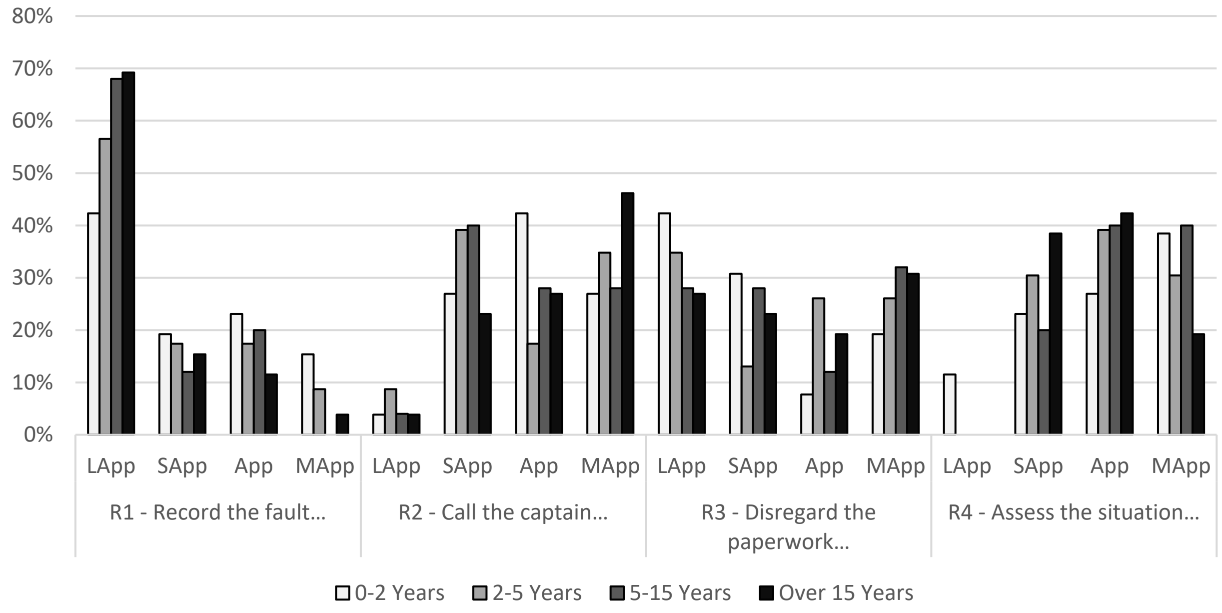


Figure 4.14: SJQ1 by Sea Experience

Figure 4.15 shows the response of all participant groups when answering SJQ2. All participant groups had answered in a similar manner with the majority of participants selecting "R1 – *Call the captain…*" to be the most appropriate response and "R4 – *Ensure autopilot is operational…*" to be the least appropriate response.

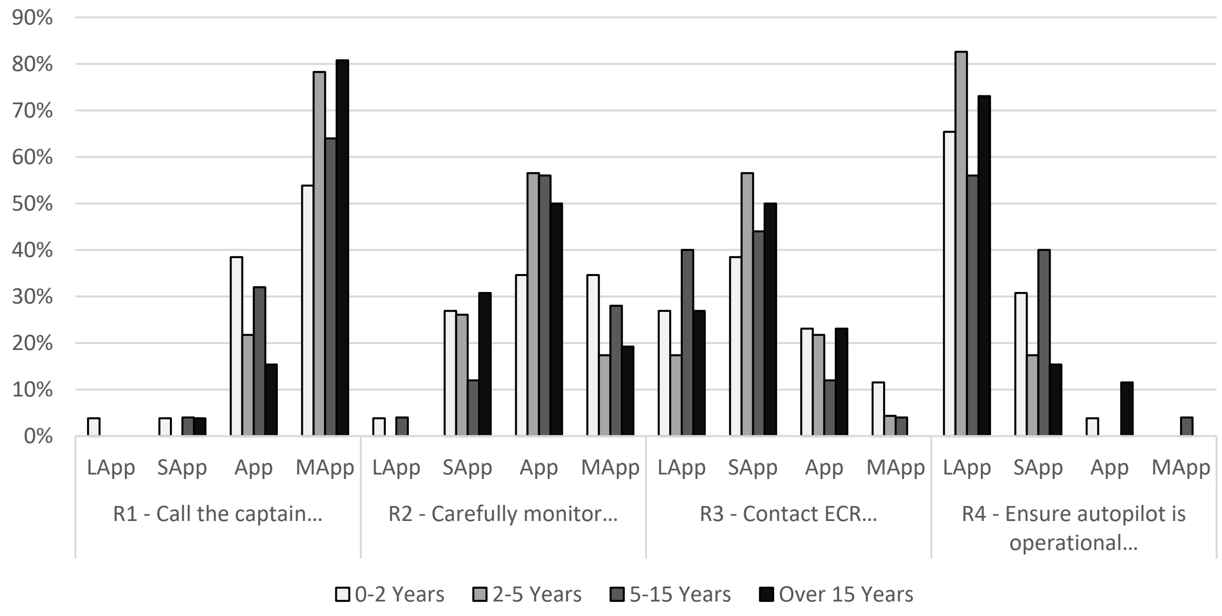


Figure 4.15 SJQ2 by Sea Experience

Figure 4.16 shows the response of groups of participants with varying seagoing experience when answering SJQ3. The results showed a similar uniformity to participant responses to

SJQ2, as definitive responses were identified to be the most and least appropriate. The majority of participants for all educational groups had identified "R2 – *Leave bridge…*" and "R3 – *Turn to manual…*" as the least appropriate and most appropriate responses, respectively.

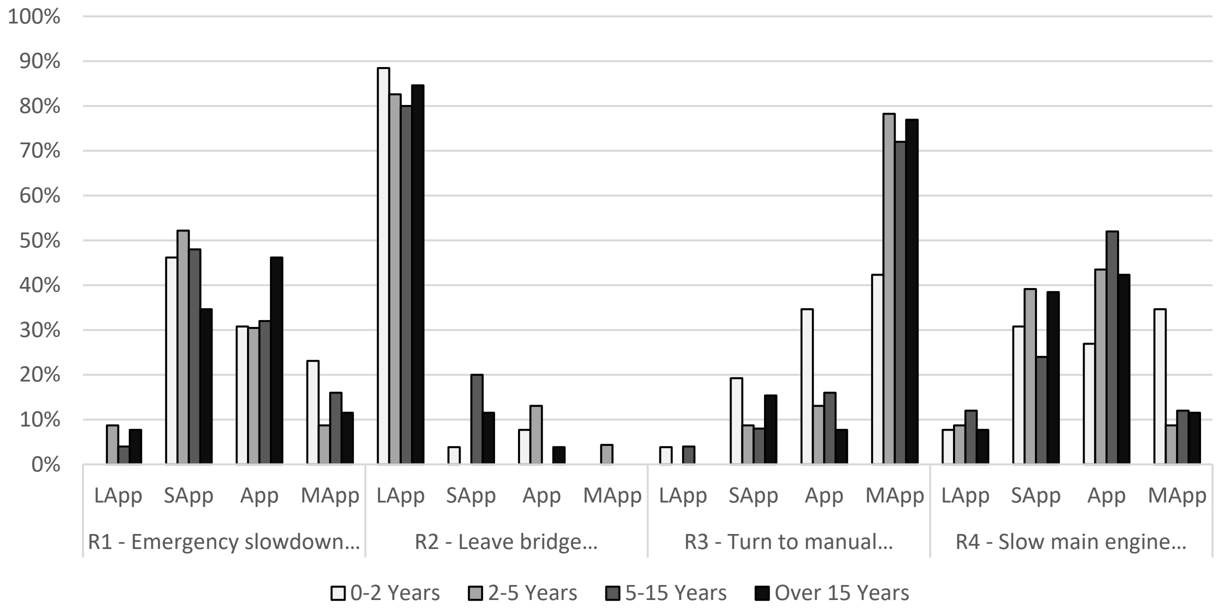


Figure 4.16 SJQ3 by Sea Experience

4.4.6 Rank

To categorise the participants for ANOVA testing, ranking groups were constructed, as shown in Table 4.13:

Table 4.13: Demographic Data by Rank

Category	**Definition**	**n**
Unqualified Officers (UNQ)	Participants from Unqualified Officer [Inexperienced] and Unqualified Officer [Experienced] groups	27
Officers of the Watch (OOW)	Participants from Junior Officers and Senior Officers groups	38
Master	Participants from Masters [Inexperienced] and Masters [Experienced] groups	35

4.4.6.1 Views on autonomy

Nine 1x3 ANOVA tests were conducted to gain a greater understanding of whether the rank of participants made a statistically significant difference within the questions posed. As shown in Table 4.14, for the majority of results there were no statistically significant responses (Sig value >0.05). However, for the statement "Throughout my time within the maritime industry the level of automation and autonomous systems has increased", it was found that there were variances between the responses of the groups. Using a Tukey HSD Post Hoc test it was found that officers within the higher-ranking groups differed from lower ranking groups. This is shown in

Table 4.14 where the OOW and Master groups agreed with the statement, whereas the UNQ group was undecided on this matter.

Table 4.14: "Views on Autonomy" by Rank

Item	Mean (SD)				F	Post Hocs
	Total	UNQ	OOW	Master		
1. Aids	5.44 (1.157)	5.59 (1.047)	5.39 (1.079)	5.37 (1.330)	.321	-
2. Unnecessary	4.81 (1.739)	4.63 (1.621)	5.11 (1.673)	4.63 (1.896)	.881	-
3. Benefit	6.41 (1.167)	6.15 (.683)	6.42 (.553)	6.6 (.818)	2.399	-
4. AHI	5.92 (1.323)	4.81 (1.52)	6.13 (1.212)	6.54 (.561)	18.709*	OOW > UO Mst > UO
5. AWI	6.32 (.875)	6.15 (1.064)	6.39 (.823)	6.37 (.770)	.716	-
6. Replace	2.21 (1.629)	2.04 (1.506)	2.39 (1.733)	2.14 (1.63)	.421	-
7. Trust	3.73 (1.536)	3.81 (1.57)	3.82 (1.608)	3.57 (1.461)	.283	-
8. Supervision	6.16 (1.195)	5.81 (1.545)	6.42 (.758)	6.14 (1.24)	2.080	-
9. Longevity	3.54 (1.987)	3.67 (2.148)	3.37 (1.866)	3.63 (2.030)	.228	-

*Significance Value: p<0.05

4.4.6.2 Trust in autonomy

A further six 1x3 ANOVA tests were conducted, on the items questioned within the "*Trust in Autonomy*" section and when analysing the participants by rank it was found that there were differences between the ranking groups for item 3. Using a Tukey HSD Post Hoc test, it was found that higher ranking groups disagreed with the statement "alarms benefit situational awareness" in comparison to the lower ranking groups. This can be seen in Table 4.15 as the mean value of each group show that participants of the UNQ group agreed with the statement whereas the OOW and Master groups were closer to being undecided.

Table 4.15: "Trust in Autonomy" by Rank

Item	Mean (SD)				F	Post Hocs
	Total	UNQ	OOW	Master		
1. Trained	5.11 (1.276)	5.41 (.888)	4.92 (1.583)	5.09 (1.147)	1.156	-
2. Failure	3.19 (1.668)	3.26 (1.678)	2.95 (1.659)	3.40 (1.684)	.699	-
3. Alarm	4.90 (1.661)	6.07 (.781)	4.37 (1.634)	4.57 (1.770)	11.340*	OOW > UO Mst > UO
4. Fatigue	3.38 (1.722)	3.26 (1.789)	3.16 (1.685)	3.71 (1.708)	1.043	-
5. Instincts	3.05 (1.540)	2.85 (1.379)	3.00 (1.542)	3.26 (1.669)	.555	-
6. Monotony	4.50 (1.789)	4.37 (1.690)	4.63 (1.777)	4.46 (1.915)	.181	-

*Significance Value: p<0.05

4.4.6.3 Situational judgement

With regard to SJQ1, as shown in Figure 4.17, "R2 – *Call the captain…*" proved to be the least appropriate response from the Master, 74%, and OOW, 63%, groups, whereas the UNQ group decided that "R3 – *Disregard the paperwork…*" was the least appropriate response, with a response rate of 55%. Conversely the most appropriate responses differed among the participant groups, with both the Master, 55%, and the UNQ, 33%, groups selecting "R4 – *Assess the situation…*", and the OOW group split between "R1 – *Record the fault…*", 37%, and "R3 – *Disregard the paperwork…*", 37%.

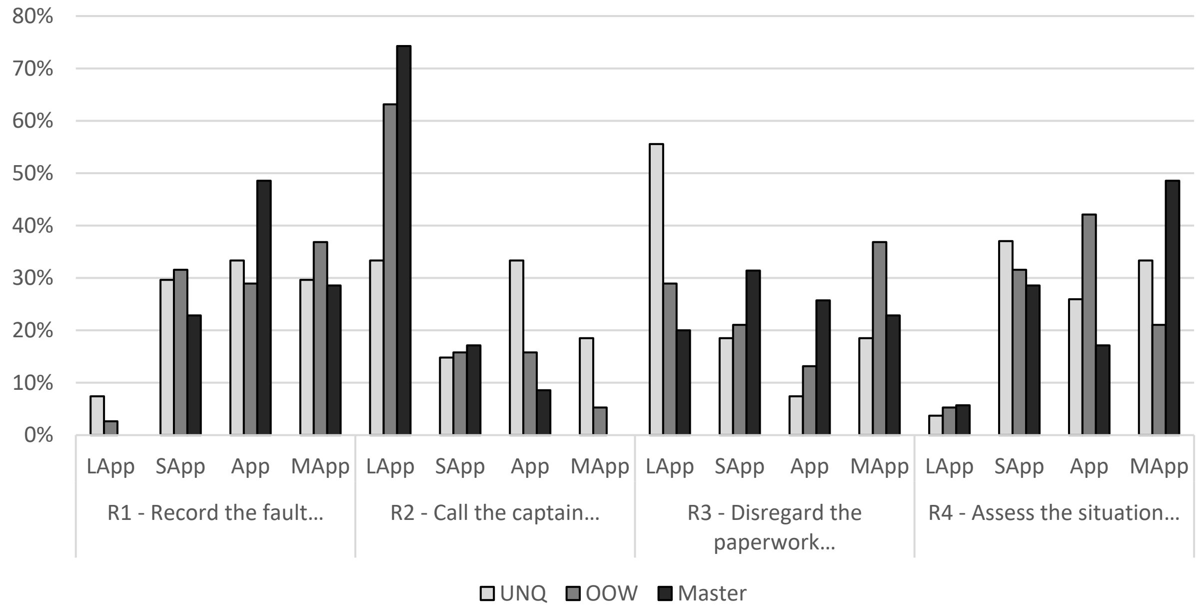


Figure 4.17: SJQ1 by Rank

Figure 4.18 shows the overall response percentages of participants by rank for SJQ2. From this it can be seen that the participants tended to respond in a similar manner with "R1 – *Contact the captain…*" as the most appropriate response and "R4 – *Ensure that the autopilot operational…*" was the most selected response for least appropriate for all ranking groups.

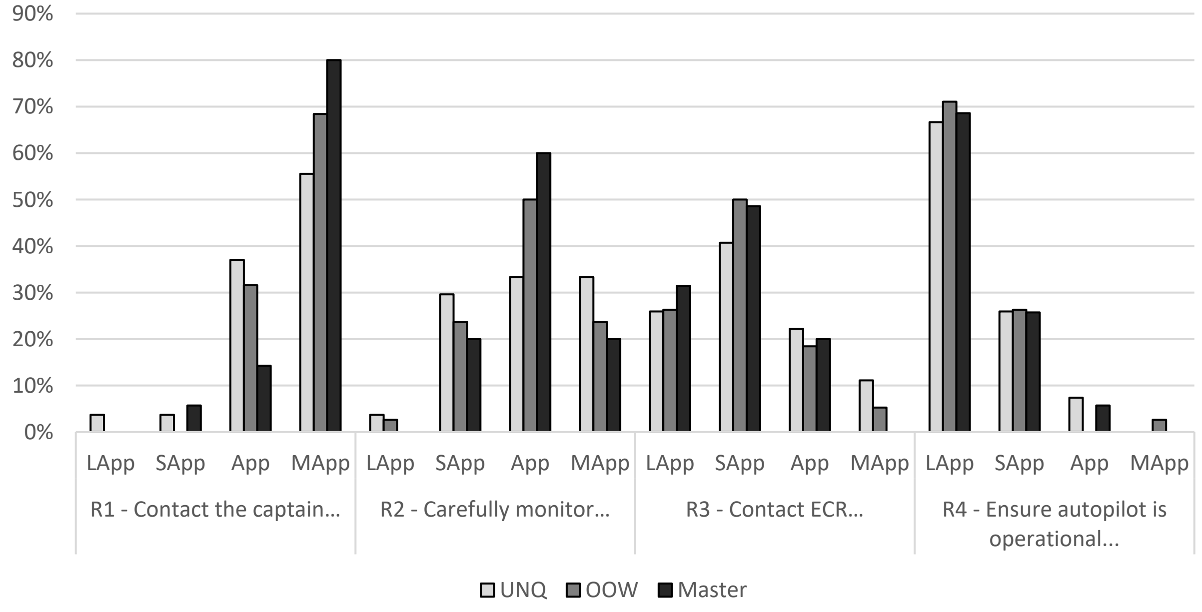


Figure 4.18: SJQ2 by Rank

As shown in Figure 4.19 the response rate for SJQ3 participants show that the majority selected "R2 – *Leave bridge…*" as the least appropriate response, regardless of ranking group, whereas the most commonly selected response for most appropriate was "R3 – *Turn to manual…*" among all ranking groups

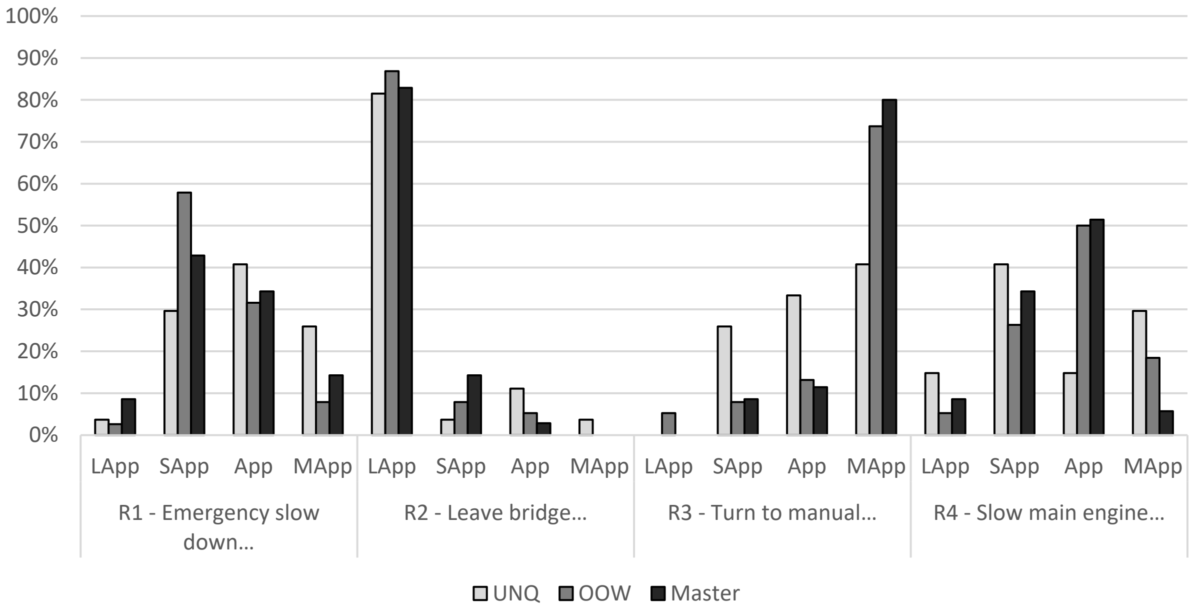


Figure 4.19: SJQ3 by Rank

4.5 Findings

4.5.1 Perception among participants

The consensus towards autonomy was generally favourable among the participants of the survey. When analysing the group for the "Views on autonomy" section it was identified that participants tended to agree that autonomy and automation can aid vessel operations and benefit human operators. Furthermore, participants tended to view automated systems as a necessity to navigation in assisting the OOW with their daily duties. However, participants tended to believe that a vessel should not solely rely on autonomy as the primary source of navigation, thus negating the need for the OOW, and that systems implementing autonomy should only be used under supervision. When questioned about the levels of conscious trust that participants would place in an autonomous system the results were far more varied, with 46% and 36% of participants disagreeing and agreeing with the sentiment respectively. This offers an interesting viewpoint that while officers are excited and welcoming of autonomy, they do view it as a tool that should be used to benefit the OOW and not surpass or remove them. Fundamentally the participants believed that the overall responsibility and final decisions for the control of the vessel should made by the human operator.

Regarding the “Trust in autonomy” section, participants were more varied in their responses to the questions. Participants were mostly in agreement that if trained in how to use a system then they would show trust in the system and most participants believed that alarms enhanced their SA. Additionally, participants were mostly in agreement that if a fault were to occur with the system their trust would not be swayed providing that the system is under supervision in the future. However, participants were less inclined to agree that if fatigued they would trust the system more and were scattered in their responses for the situation, when in an eventless or night watch they would easily be distracted.

By analysing the SJQ section it was possible to gain a greater understanding of the participants’ thought process when encountering a system fault. For SJQ1 participants believed that the requirement of a lookout was unnecessary, by identifying R2 – “*Call the captain of the vessel to inform them of the situation and ask for a lookout to concentrate on the position of the vessel whilst you complete your paperwork”* as the “Least Appropriate” response. Whereas participants choices varied among the other 3 response selections for “Most Appropriate”, “Appropriate” and “Slightly Appropriate”. SJQ1 delivered the highest variance among responses as SJQ2 and SJQ3 had definitive response selections for “Most Appropriate” to “Least Appropriate”. The participants were able to identify appropriate responses in the event of an automated gyro drift fault. Issuing the participants with a text-based scenario and response has shown that participants can recognise an appropriate answer if they are given choices rather than independently solving the fault.

Regarding SJQ2 participants identified R1 – “*Contact the captain of the vessel to alert them of the situation and take manual control of the vessel until relieved”* as the “Most Appropriate” and R4 – “*Ensure that the autopilot control is fully operational and assume that the error is from your own judgement due to fatigue”* as the “Least Appropriate” responses. This indicates that the participants are less likely to be satisfied with making assumptions on the equipment and are likely to investigate the fault further. Moreover, participants have opted to alleviate the responsibility from themselves by alerting the captain to the fault.

For SJQ3 the participants selected R3 – *“Turn steering control to manual and turn the vessel to hard starboard to avoid the shallow waters”* as the “Most Appropriate” and R2 – *“Slowdown the main engine, leave the bridge in an attempt to alert the captain to the situation”* as the “Least Appropriate” responses. Both selections highlight that in the event of imminent threat the participants are likely to undertake manual control of the vessel to attempt to remove the vessel from impending danger. SJQ3 was constructed to resemble the design of the events that occurred during the grounding of the landing craft *Lauren Hansen* (Australian Transport Safety

Bureau, 2018). The results of SJQ3 contradict the events that occurred during the incident. The grounding of the vessel occurred due to the OOW opting to leave the bridge to find the captain whereas the participants here identified that response as the “Least Appropriate” action to take.

4.5.2 Age

When analysing the age groups of the participants, the ANOVA testing identified that the only item that showed any statistical significance was the question of *“Throughout my time within the maritime industry the level of automation and autonomous systems has increased”*. From this question it was found that younger participants could not address the question effectively due to their age. This was to be expected as the Pearson’s correlation shows that as the age of participants increase so will their experience at sea, indicating that older participants will have experienced a greater increase in automation throughout their careers.

Further analysis into the SJQs, regarding the participants age, shows that for SJQ1 the largest proportion of participants from the 18-25 age group had displayed signs of uncertainty in their overall response and identified R3 – *“Disregard the paperwork, remove navigational control from autopilot to manual and continue with the rest of the watch at the helm of the vessel.”.* Whereas most participants from the other age groups agreed that R1 – *“Record the fault into the vessels logbook and continue with paperwork, due to the vessels relatively safe position and inform the relieving officer of the fault at the watch handover.”* as the least appropriate response. This has shown that older participants have the understanding to record and provide evidence of the fault. Moreover, younger participants have shown an uncertainty in their own navigational abilities as they believe taking manual control to be an equally inappropriate action.

For SJQ1 the largest proportion of three age groups, 18 – 25, 34 – 41 and 42 – 61, had identified R4 – *“Assess the situation and check the backup gyro to ensure that the vessels position is not wandering from a gyro drift, call for an electrician to come and assess the situation and fault whilst you continue with your paperwork.”* as the most appropriate response. Whereas participants from the oldest and the 26 – 33 age groups had opted to alleviate the responsibility of their watch to the vessel’s master by selecting R2 – *“Call the captain of the vessel to inform them of the situation and ask for a lookout to concentrate on the position of the vessel whilst you complete your paperwork.”* as the most appropriate response. The variation in responses has shown that many seafarers are inquisitive to assess the fault but have the knowledge to adhere to correct protocol.

4.5.3 Qualification Level

From ANOVA analysis of the participants' qualification level, it was found that two items delivered responses that showed statistical significance. The first question that was identified to have any significance in response deviation was Item 3. *"I believe that systems such as autopilot and ECDIS are beneficial to navigational officers"*. From the ANOVA testing it was found that participants with a high school education level had opted to answer this question differently from the "College (Cert)" and "University (PG)" education levels with high school participants only slightly agreeing with the statement. The reasoning behind this may be due to a lack of understanding of the technology resulting in the participants with a high school educational level opting to choose the "Slightly Agree" response. Furthermore, the following question that was highlighted through ANOVA testing was Item 4. *"Throughout my time within the maritime industry the level of automation and autonomous systems has increased"*. From this question it was found that again participants with a high school education level had opted to answer this question differently from the "College (Dip)" and "University (PG)" education levels with high school participants being closer to an "Undecided" response. As shown through the Pearson's correlation testing, the education level of a participant correlates closely with the rank of a participant, indicating that participants with a lower education level will also have a lower rank which would highlight that participants of this category have yet to experience technological advancements that a more educated participant would have experienced.

The situational judgement questions identified a different insight to the responses of the participants. SJQ1 showed that the majority of participant from all educational groups had chosen R1 – *"Record the fault into the vessels logbook and continue with paperwork, due to the vessels relatively safe position and inform the relieving officer of the fault at the watch handover."* as the least appropriate response. However, the selection for most appropriate response showed a greater of level of disparity among the Qualification Level groupings of participants. Participants with higher educational groups had selected R2 – *"Call the captain of the vessel to inform them of the situation and ask for a lookout to concentrate on the position of the vessel whilst you complete your paperwork"* as the most appropriate response, whereas participants from the High School group selected the most appropriate response to be R1 – *"Record the fault into the vessels logbook and continue with paperwork, due to the vessels relatively safe position and inform the relieving officer of the fault at the watch handover."*. Therefore, it could be concluded that participants with a lower educational level felt compelled to do further investigation into the course deviation fault, whereas participants with a higher education level opted to alert the captain to alleviate the responsibility to the senior operator as per the guidelines of the STCW-10. This may indicate that, despite the varying levels of educational background, the participants would not allow this to influence their response selection. Beyond this, no obvious conclusions could be drawn from the results. When analysing SJQ2 and SJQ3 the results showed unity among the educational groupings of participants.

4.5.4 Sea Experience

Following the ANVOA testing for the “Views on Autonomy” section, it was found that only item 4– “AHI” had any statistical significance among the ranking groups of participants. This was to be expected due to the large variation of sea experience of the participants and the fact that autonomy at sea is a relatively modern technological advancement. Moreover, this expectation was further confirmed through the Post Hoc tests, with the statistically significant differences coming from the 0 – 2 Years group in comparison to the other participant groups.

When assessing the *Trust in autonomy* section, only 1 item provided a statistically significant response. Item 3 – “Alarm”, showed a difference between the 0 – 2 Years and the Over 15 Years groups. The variation in response may have been due to the length of time spent at sea for the Over 15 Years participant group. Having accumulated such a long time at sea this participant group would have experienced a wide variety of scenarios where systems may have malfunctioned and alarms may have incorrectly sounded, resulting in the participant having less faith in the system.

The SJQs delivered a wide variety of responses from each participant group. The results from SJQ1 found that participants with less seagoing experience were split between R3 – “*Disregard the paperwork, remove navigational control from autopilot to manual and continue with the rest of the watch at the helm of the vessel”* and R1 – *“Record the fault into the vessels logbook and continue with paperwork, due to the vessels relatively safe position and inform the relieving officer of the fault at the watch handover.”* as the most inappropriate responses, whereas participants with more seagoing experience opted to select R1 – *“Record the fault into the vessels logbook and continue with paperwork, due to the vessels relatively safe position and inform the relieving officer of the fault at the watch handover.”* As the least appropriate response. When analysing for the most appropriate responses, all participant groups were split between R2 – *“Call the captain of the vessel to inform them of the situation and ask for a lookout to concentrate on the position of the vessel whilst you complete your paperwork”*. And R4 – *“Assess the situation and check the backup gyro to ensure that the vessels position is not wandering from a gyro drift, call for an electrician to come and assess the situation and fault whilst you continue with your paperwork.”* As the most appropriate response. However, for SJQ2 and SJQ3 the results were delivered with uniformity between the participant groups.

4.5.5 Rank

As identified by the ANVOA testing for the "Views on Autonomy" section, only item 4 – "AHI" had any statistical significance among the ranking groups of participants. However, due to the question asked in item 4 – "AHI", the reason for this difference may be due to the variance in rank as participants of a higher rank will have experienced an increase in levels of autonomy throughout their careers when compared to participants that have only begun their maritime career.

For the "Trust in Autonomy" section, only Item 3 – "Alarm" had any variance among the participants' rank. This may be due to the variation in watchkeeping experience levels within the ranks, with lower ranks having a stronger belief that alarms increase SA compared to participants of a higher rank. Again, this can be expected as more experienced officers will understand the different alarms that sound on the bridge, some of which may be false alarms or routine alarm testing.

For all three SJQs, the groups tended to answer in a similar manner. For SJQ1, the UNQ group varied their choices among all the responses, with only R3 – "*Disregard the paperwork, remove navigational control from autopilot to manual and continue with the rest of the watch at the helm of the vessel"* being firmly highlighted as the "Least Appropriate" response. This indicates that the UNQ group may value their paperwork and view it as a priority of navigational officers. Conversely, for the OOW and Master groups, choices showed variation among the responses with R2 – *"Call the captain of the vessel to inform them of the situation and ask for a lookout to concentrate on the position of the vessel whilst you complete your paperwork"* suggesting that participants of a higher rank will prioritise the safety of the vessel over paperwork.

For both SJQ2 and SJQ3 all ranking groups answered similarly. With all ranking groups answering in a similar manner, it shows that the response of a participant is not dependent on the participant's rank. Despite the UNQ group being of a lesser rank than the OOW and Master groups there is not a great deal of variation in the response. Moreover, both questions contain subtle differences in the response rates for various answers, however, the general consensus for both SJQ2 and SJQ3 for each demographic group follows a similar pattern when treating the participants as a homogenous group of seafarers.

4.6 Methodological Implications

Through the analysis of the data collect for the *Survey Study*, various opinions and viewpoints were gathered from seafarers. As such, the use of a survey was to provide a foundational knowledge-base to be utilised for the subsequent studies of this thesis. Moreover, this data provided a general understanding of the human automation relationship topic, with the aim that subsequent studies would delve further into the research area. Due to the nature of the survey, complex thought processes could not be reported. Therefore, the *Interview Study* of Chapter 5 aimed to deliver a deeper perspective from seafarers. Using the SJQ as a method to question participants proved to be successful. However, structuring them as a ranking question proved to be difficult to analyse the data, due to the sample size of participants. Adopting a method that combines an SJQ with a single best answer (SBA) approach for future research would provide a more efficient method of data analysis.

4.7 Chapter Conclusion

The *Survey Study* has identified various dependent variables that may impact the fault recognition skills of navigational officers. As has been shown, in the maritime industry there is no immediate demographic factor that can influence the navigational safety skills of seafarers. Despite the methodological implication identified, this chapter has allowed for the development of a survey that has acknowledged various dependent variables such as the participants’ rank, seafaring and educational backgrounds, and age. Fundamentally the findings have initially shown that despite these potentially influencing factors being present, they ultimately had no direct effect on the response pattern of the participants. Certain aspects of the dependent variables may have contributed to the variation in responses in the SJQs and precise items in the survey. However, there is no conclusive evidence of this.

The conclusions of this study identify the outlook and knowledge level that seafarers have regarding autonomous shipping. The results of the study found that officers are receptive towards the introduction of autonomous shipping. Furthermore, the participants showed an understanding of what autonomous shipping would mean for the maritime industry. However, there are concerns about the responsibility for, and safety of, the vessel, in the event of the introduction of an unmanned vessel. Moreover, when comparing opinions and trust levels among the cohort of participants, it was found that participants of a higher rank had a similar outlook towards autonomy as that of the less experienced groups. As such the perspectives documented through the *Survey Study*, will be further explored in greater detail by means of the *Interview Study*. Moreover, the knowledge gained will act as the foundation for both the *Pilot Study* and *Final Study*.

The next chapter will utilise the responses collated from this study and develop a qualitative *Interview Study* that will analyse the trust in autonomy and experiences with autonomy sections in greater detail.

Chapter 5. Interview Study

5.1 Introduction

The following chapter introduces and details the second study conducted for this thesis. The chapter documents the development preparation, execution, findings, and the thematic analysis of the results of the *Interview Study*. Furthermore, this chapter will identify the research objectives that were achieved and will address how the research questions posed in Chapter 1 are answered through the study. This chapter will then highlight the methodological limitations of the study and conclude with the impact that the *Interview Study* has on the complete thesis.

Due to the novelty of maritime autonomy, the topic has quickly become a hotly debated subject (Porathe, 2019). Research has shown that MASS has a multitude of benefits that will allow the maritime industry to take a technological step to align itself with other transportation sectors and experience environmental and economic benefits (Batalden, et al., 2017). However, Issa, et al. (2022) identified that autonomous shipping has multiple unknown factors that could prohibit the safe daily operations of the vessel. Additionally, this research has highlighted legal difficulties, job security and training among many others as concerns against MASS. Conversely research has been conducted, identifying that MASS should only be implemented on small cargo vessels, for the industry to experience the benefits while reducing the negative impact (Vos, et al., 2021). However, despite this research being conducted, the pros and cons of autonomous shipping from the perspective of the OOW have yet to be identified.

Chapter 4 captured a generic overview of the perception of the navigational officer regarding the aspects of seafaring and the industry that will be impacted with the introduction of MASS. The second study was to interview participants on a one to one basis regarding the various aspects that could be impacted on by the introduction of maritime autonomous navigation. All participants of the following study were required to have a minimum of 12 months of navigational watchkeeping experience, and it was desirable for participants to have some knowledge of autonomy. Following the completion of the interviews, the recording of each interview was saved and transcribed. Each transcription was then assessed with a multitude of codes identified from every interview. These codes were then grouped together using a method of thematic analysis to identify the various overarching themes that were discussed within the interviews conducted.

The work conducted in the *Interview Study* utilised the varying perspectives and opinions of seafarers, gained through the *Survey Study*, as a platform to introduce a more detailed question set to be delivered through an interview-based approach. The collation and subsequent analysis of the data of the *Survey Study* introduced a number of findings that the *Interview Study* looked to address in greater detail. Furthermore, this study aims to identify the aspects of the maritime industry that require revision both currently and for the introduction of MASS from the perspective of the individuals that have first-hand experience in maritime navigation.

5.2 Study Design

The main objective of the *Interview Study* was to document the multitude of aspects of MASS which seafarers perceive to require greater attention prior to installation. The structure of the *Survey Study*, was to deliver a preliminary question set to a wide number of participants, thus gaining a fundamental understanding of what the general opinions of autonomous shipping are among seafarers. Therefore, by using the *Survey Study* as a platform, it was then possible to create a highly detailed question set to be delivered to a smaller group of participants to explore the findings of Chapter 4 in greater detail. By recording opinions of autonomous shipping from the perspective of the OOW, the subsequent simulator studies of Chapters 6 and 7 could then be designed with greater detail due to the knowledge gained from the *Interview Study*. Additionally, the findings of the *Interview Study* would be used to shape the narrative of the subsequent simulator studies in terms of both identifying the seafarers' knowledge of human factors and strengthening the rationale of the simulator work.

With the aim of the study being to address the introduction of autonomous shipping from a navigational officer's perspective, the aspect with the highest level of criticality was to develop a question set that provided a wealth of information from each participant. The question set would be designed to explore the themes of automation trust, MET and autonomous legislation in a high degree. Subsequently, by developing the question sets in an interview structure allowed the interviews to flow smoothly and give the participant the platform to answer the questions freely. Both the question design process and reviewed literature from Chapter 2 had identified the following hypotheses aligning with RQ1, RQ2 and RQ4 of this thesis:

- Hypothesis 1 – Participants would show concerns for job security with autonomous shipping.
- Hypothesis 2 – Participants will acknowledge the benefits of autonomous shipping but will emphasise the value of maintaining crewed vessels.
- Hypothesis 3 – Participants will believe that the navigational officer curriculum has too much emphasis on outdated subjects and that there is a lack of technology and simulator training within the navigational officer curriculum.

- Hypothesis 4 – Participants will believe that SA will be a highly impactful factor in the future development of navigational officers.

By developing the aforementioned hypotheses, it would then be possible to combine this with the wider perspective of automation trust introduced within Chapter 4 and construct various question sets to pose to the participants.

5.3 Method

5.3.1 Procedure

The *Interview Study* was designed with the intention to gain a greater understanding on the opinions and viewpoints that were shared among the navigational officer community. In doing so it was then possible to better arrange the subsequent studies in this thesis. The data sets of each interview were recorded through the Zoom Meetings software, developed by Zoom Video Communications. The aim of each interview was to conduct an in-depth discussion around the following five subject areas:

- Navigational Background
- Autonomous Shipping
- Revision of Legislation
- Impact of Autonomous Vessel Operations in Maritime Education
- Human Factors

Each of the subject areas contained a variety of questions that would then allow for the exploration of emerging themes that would then be cross analysed with each interviewee. By utilising such platforms, it was possible to ensure that the applicants were suitable for the study. A copy of the interview question sheet can be found in Appendix A – Interview Guide.

5.3.2 Interview Structure

5.3.2.1 Navigational background

Section 1 of the interview was structured to allow the interviewee to become comfortable with the interviewing structure. During this section the interviewee would answer 3 questions pertaining to their individual background with their navigational career at sea, vessels they have previously sailed on and their own experiences of what it means to be a navigational seafarer. The questions posed within the navigational background section are as follows:

- What age were you when you began your career as a deck officer and what year was it?
- What was the driving force for you in becoming a navigational officer?

- From your perspective, can you describe a standard navigational watch and what to expect throughout the duration of the watch.

5.3.2.2 Autonomous shipping

This section of the interview was designed to explore the opinions that the interviewees have of autonomous shipping. Within this section, interviewees were questioned on subjects such as their personal views on autonomous shipping, potential concerns regarding the introduction of autonomous shipping, when they may expect to see autonomous shipping becoming standardised for the maritime industry.

By posing the 6 questions within this section to the interviewees, it was possible understand the perspective that the interviewees have towards autonomous shipping. Additionally, this question set could then indicate how much knowledge of and thought about autonomous shipping the interviewees had prior to being interviewed. The questions for this section were structured as follows:

- What are your opinions and views on autonomous technology?
- The introduction of autonomous vessel operations is looking to initially start with a manned wheelhouse and conduct “supervised” navigation. Going forward past the transition stage what are your views on removing helmsman and navigational officers? Do you feel that the ships master should be onboard despite the vessel being under autonomous operations?
- What are your greatest concerns on the introduction of autonomous technology within the maritime industry and more specifically merchant ships?
- When do you think that autonomous shipping will become the norm for the maritime industry?
- To you what does the term “Autonomous Shipping” mean?
- What do you think the introduction of autonomous shipping will mean for seafarers and the maritime industry?

5.3.2.3 Maritime Legislation

The aim of the “Maritime Legislation” section was to explore the understanding that the interviewee has towards autonomous shipping operations. By including this section in the *Interview Study*, it was possible to gain a greater understanding on how seafarers view the maritime industry and their perceptions of how autonomy will be introduced. The questions delivered in this section were as follows:

- What organisations, do you feel, will be important in the development and implementation of maritime autonomous vessel operations?
- What regulations and legislation do you think will be heavily impacted upon the introduction of autonomous systems to merchant vessels i.e., STCW, International Organisation for Standardisation (ISO), COLREGs, International Convention for the Prevention of Pollution from Ships (MARPOL), Health and Safety at Work Act 1974 (HASAWA)?
- To allow autonomous vessel operations to be introduced, what medical requirements do you feel need to be revised and do you think that mental health should be considered among these?

5.3.2.4 Maritime Education and Training

Due to the changes that autonomous shipping will bring to the navigational syllabus, it was key to assess the interviewees' understanding of what will be impacted. Therefore, this section allowed interviewees to express their concerns regarding the current curriculum of navigational officers, how the maritime industry may have to change their recruitment styles to entice young people to undertake a career at sea and what they feel should be included in the curriculum for autonomous shipping to be a success. The questions that addressed the aforementioned topics are as follows:

- What are your views regarding the change in the education standards of navigational officers?
- What areas of the educational syllabus do you feel should be revised, and why?
- How do you think autonomous vessel operations will impact on certification for qualified officers and future prospective operators?
- How do you think autonomous vessel operations will impact young person recruitment drives for the maritime industry considering the possible reduction in crewing numbers?
- At some stage there will be a situation where the educators will be teaching students a form of navigation where they have no prior experience. How do you feel this would affect future generations of seafarers?
- With technology growing so rapidly how do you think constant updates would impact the navigational officer syllabus?

5.3.2.5 Maritime Human Factors

As documented in Chapter 2, one of the leading causes of maritime incidents is human error. Moreover, with human factors being a concern for the maritime industry it is key that the human automation relationship is addressed with the utmost care as autonomous shipping is introduced. Therefore, the aim of this section was to allow interviewees to express their opinions on the human automation relationship. It allowed the interviewee to demonstrate their awareness of the topic as well as highlighting potential factors such as fatigue and SA and their importance in the introduction of autonomous shipping and human factors. By asking the following questions it was possible to address the areas mentioned:

- Do you feel that modern seafarers can be competent in resolving potential machine errors? And how do you view the relationship between the autonomous system and the human operators i.e., navigational officers and helmsman?
- Statistics from Lloyds Register and Det Norske Veritas Germanischer Lloyd (DNV GL) have shown that the leading cause of maritime incidents can be attributed to human error. So how do you think operators can resolve a potential machine error and reduce the magnitude of the incident?
- Do you think that the length of time at sea could negatively affect an operator’s response to a fault i.e., is the operator more alert during the first few weeks of their contract vs the final few weeks?
- What is your opinion in regular situational awareness training to ensure that an operator is suitably alert during their watch? And how frequently do you think that situational awareness should be trained for navigational officers?

5.3.3 Participant Selection and Analysis

To locate and identify suitable participants for the study, national maritime institutes were contacted with the aim of utilising faculty and students from the institutions. Furthermore, to diversify the participant pool of the study, non-governmental organisations (NGO) were contacted to increase the awareness of the study.

Following the conclusion of the participant selection, all participants were issued a copy of the question sheet. In doing so this would allow the interviewees sufficient time to develop a detailed answer to each question when interviewed. The participant selection criteria identified within Chapter 3, produced 16 individuals who were eligible to take part in the study. Participants of the study were all male and had conducted all or part of their navigational officer training within the UK.

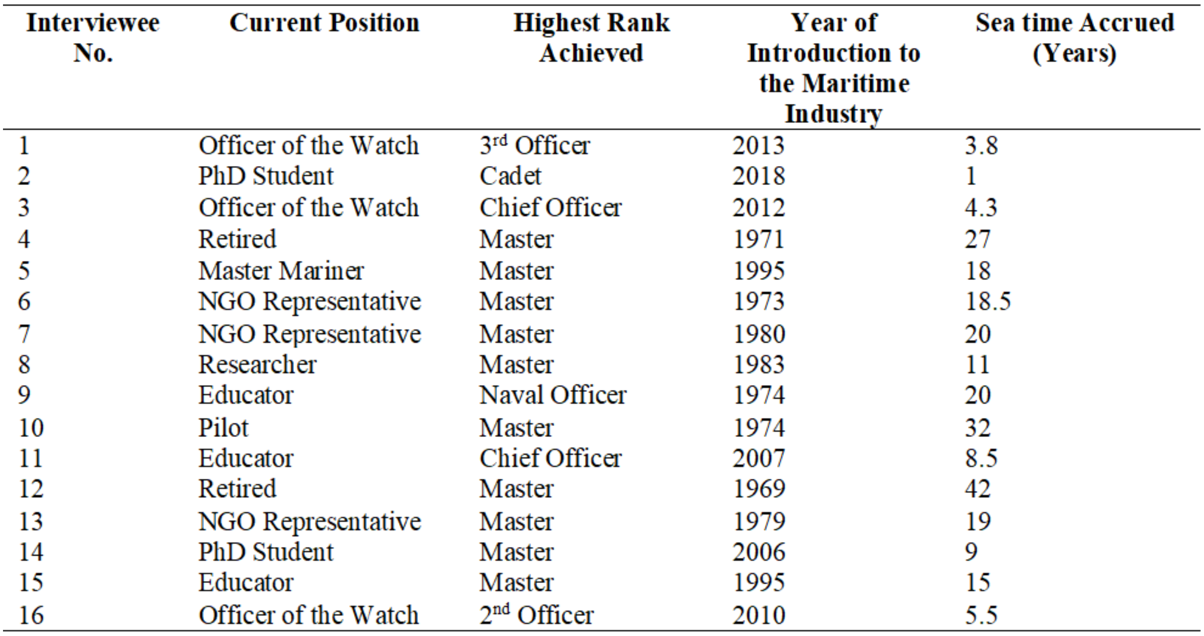
As detailed in Chapter 3, following the conclusion of all interviews, each interview recording was transcribed to document the responses. Subsequently, a thematic analysis approach was adopted for the interviews, using Microsoft Excel, a codebook was created detailing the various codes and themes that were drawn from the transcriptions.

5.4 Results

5.4.1 Initial Analysis

The *Interview Study* produced 16 individual interviews that ranged from 17 minutes and 9 seconds to 2 hours 5 minutes and 31 seconds, with a mean running time of 49 minutes and 14 seconds. Table 5.1 shows the current industrial roles, highest rank achieved, the year they had begun their career in the maritime industry, amount of sea time that the individual has accrued over their career and the length of each interview per individual.

Table 5.1: Interviewee Data



Interviewee No.	Current Position	Highest Rank Achieved	Year of Introduction to the Maritime Industry	Sea time Accrued (Years)
1	Officer of the Watch	3rd Officer	2013	3.8
2	PhD Student	Cadet	2018	1
3	Officer of the Watch	Chief Officer	2012	4.3
4	Retired	Master	1971	27
5	Master Mariner	Master	1995	18
6	NGO Representative	Master	1973	18.5
7	NGO Representative	Master	1980	20
8	Researcher	Master	1983	11
9	Educator	Naval Officer	1974	20
10	Pilot	Master	1974	32
11	Educator	Chief Officer	2007	8.5
12	Retired	Master	1969	42
13	NGO Representative	Master	1979	19
14	PhD Student	Master	2006	9
15	Educator	Master	1995	15
16	Officer of the Watch	2nd Officer	2010	5.5

5.4.2 Autonomous Shipping

When discussing the topic of autonomous shipping various themes were introduced throughout each participant’s interview. The most commonly discussed theme was “Introducing Maritime Autonomy” with 53 occurrences of the theme, whereas the theme that was discussed the least was the topic of the “Environment”, with 6 occurrences. Table 5.2 shows the various themes discussed throughout the interview process, the number of occurrences that each theme was explored and a summarised detailing of each theme.

Table 5.2: Emerging Themes from Autonomous Shipping Question Set

Autonomous Shipping		
Theme Name	**Occurrence**	**Description**
Introducing Maritime Autonomy	53	Describes the viewpoints and mindsets that the individual has towards the introduction of autonomy
Human Automation Relationship	46	Describes the viewpoints and mindsets that the individual has towards the human automation relationship
The Role of the OOW	29	Describes the individuals opinions towards the evolution of the OOW role
Ethics of Maritime Autonomy	27	Describes the risks and safety measures the individual has identified with autonomous ships
Knowledge on Autonomy	21	Details the knowledge level of the individual towards autonomy in the maritime industry
Environment	6	Identifies the environmental impact of autonomous shipping

5.4.2.1 Introducing Maritime Autonomy

The overall consensus among the interviewees was positive towards the introduction of autonomy, with interviewees believing that autonomy has the potential to benefit the industry provided certain safety parameters are implemented. Interviewees believed that autonomy requires a form of supervision, and the vessels will still require a crew to conduct preventative maintenance onboard as a minimum. Concerns regarding the high expense that comes with autonomy were voiced, however this transitioned towards concerns for the removal of crew when shipping companies and owners are faced with the economical long-term benefits of autonomy, with the debate of financial reward versus safety becoming a key topic. The introduction of autonomy will include various subsystems that will communicate with each other. With this in mind, the view from certain interviewees was that new systems should look to implement other technology such as decision-making technology and that the user interface must be streamlined in the information that an operator receives.

"Systems must implement decision support. Decision support being the advice or rapid processing of all situational factors that can be presented to a navigator in a meaningful way, so better decisions can be made…I'd be reluctant to allow a ship to make an alteration to the course without human intelligence deciding whether or not it's safe" (Interviewee 8).

As the question set progressed the interviewees began to diverge in opinion. One group of interviewees believed that the fully autonomous vessel is a concept that they believed would not be fully optimised during their career. Conversely, others believed that once the legislation and infrastructure for autonomy had been created then the maritime industry could foreseeably transition rapidly. Disregarding the implementation of autonomy, the consensus among interviewees was that autonomy should be gradually introduced with multiple phases of autonomy being introduced over an allotted period of time to allow the industry and operators sufficient time to acclimatise to the technology.

"In the developed world I think it could be the norm say within 15 years, particularly in predetermined routes between Tokyo or Yokoyama and the west coast of America where you see nothing between these places…it will take a lot longer for the developing world, quite simply because they may not have the infrastructure to support it and we have to assume these systems will involve satellite communication…so if it happens it will be a gradual change rather than an instantaneous event" (Interviewee 4).

The discussion of fully unmanned vessels introduced concern for deep sea travel. Due to the various implications such as distance from land and system failure, the interviewees raised arguments against unmanned deep sea transit. Moreover, certain interviewees alluded to unmanned autonomous vessels being used for inland transit on predetermined routes in low density traffic areas, which would alleviate the risk of collision and communication errors.

"Harbour movements, coastal trade and inland waterways may see an increase in autonomous vessels where there are obvious benefits to this technology where supervision will be provided and an increase of productivity. I don't think it is feasible at all on a global/international scale. The infrastructure for autonomous technology is not really implicated anywhere yet but on a local scale" (Interviewee 16).

5.4.2.2 Human Automation Relationship

Interviewees identified that autonomous systems would benefit the OOW by alleviating pressures of workload and external stressors by commanding control of the vessel. Additionally, through the autonomous system controlling the vessel, fatigue would be relieved from the OOW due to less concentration being required on watch. While autonomous systems will prove a beneficial tool for the OOW there is the risk of the operator favouring the system over their own judgement creating issues such as AB and an overreliance towards the system which may result in a degradation of navigational skills.

"With the growing level of autonomy on ships with people, what is the relationship between that autonomous system and the people and that's one of our main interests going forwards. Because automated systems can be intimidating to mariners who are not confident in it, and you know if you have an officer of the watch is not particularly confident and the system is doing something, you may say, well that's a very expensive system, you know I'm not going to interfere with it" (Interviewee 7).

Discussions into the human automation relationship highlighted that interviewees believed vessels should not become completely unmanned due to the lack of redundancy that autonomous systems have. Humans will act as the failsafe in the event of a system failure. Moreover, despite humans being a symptom of failure they are rarely the root cause of the failure. Therefore, systems must be designed in a manner that keeps the human in the loop of the decision-making process.

"What we don't want is a situation where something goes wrong with the automation, and it tells the human you take over now. Because the human hasn't been in the loop and isn't situationally aware to just be told, I mean the worst case scenario is "a captain's asleep in his room at night. And gets an alarm saying the system just shut down because there's been a problem, and you know he's going to take over manually and, he doesn't know what's happening because yeah somebody hasn't been in the loop, so you do have to have that relationship looked at" (Interviewee 7).

Fundamentally, as the industry moves towards autonomous navigation, the transition will not result in a complete overhaul in fleet operations. For a prolonged period of time there will be a mixed fleet navigating around the world, which may result in communication errors in the event of remote navigation. This could further fragment the human automation relationship.

"…when the ships are done a lifetime within Europe and usually go to Africa, so they're operating older ships there than we generally operate within the Western hemispheres and I think that'll be the case with autonomous shipping, which means we have to think about things like vessel communications…" (Interviewee 1).

5.4.2.3 The Role of the OOW

Prior to the installation of autonomy, interviewees believe that the role of the OOW must be defined and addressed. Understandably, most interviewees expressed their concerns about the longevity of the seafaring occupation:

"Seafarers are not handicapped by mathematical algorithms and Kalman filters…There is no substitute for seamanship and ship handling by an experienced seafarer in emergency situations" (Interviewee 16).

Interviewees believe that the successful evolution of the OOW role, lies with the development of both technological knowledge and behavioural skills of an individual. The mindset of the interviewees was that, as autonomy is introduced, the OOW role will undergo an evolution to potentially an officer that is trained in all aspects of the vessel and not limited to the navigation of the vessel, allowing individuals to supervise the system while conducting other tasks onboard. Furthermore, autonomy will develop new careers pathways within the industry introducing new officer roles and combining an OOW onboard responsibility, similar to the removal of the radio officer role from the maritime industry a decade ago.

"We've seen over the years how ships have reduced down on labour. If you look at, from a deck officer, before we wouldn't touch the radio equipment. They use the electric radio officers for that which we don't have anymore. So that's that gets short, so you could end up with a smaller amount of crew, bigger workload for the same money, or possibly no job at all, which obviously is a great concern, especially if the industries aren't necessarily there to provide you with an alternative employment within the maritime industry." (Interviewee 3)

5.4.2.4 Ethics of Maritime Autonomy

Multiple interviewees expressed their concerns with autonomy. With seafaring being a very hazardous profession, the interviewees detailed their concerns with the risks and safety requirements to which autonomy must conform. Most interviewees believed that a responsible person must remain onboard, not only for the safety of crew and vessel, but also to carry out the vessels distress obligations:

"Vessels are also legally required to deviate from their passage with all haste in order to assist in search and rescue operations or to persons in distress, autonomous vessels would not be capable of helping humans in danger, as rapid decision making can decide whether someone lives or dies. It is not simply a question of appraising a situation, emotional factors are involved and prior experience of crew in similar situations ensures a rescue can go ahead. It would not be possible to deploy life-saving equipment in certain sea conditions without the input of a crew and casualty handling after an incident." (Interviewee 16).

Additionally, safety concerns such as cyber security and minimum manning requirements were discussed. The idea of an unmanned vessel introduces the risk of hackers and cyber piracy. Furthermore, interviewees expressed their concerns of such risks with autonomous manned vessels in the event of a vessel being cyber hijacked. Removal of the human from the loop may mean that the systems are too complex for the OOW to regain control:

"If you're going out to deal with hazardous substances or dangerous situations, it may be wise to have a totally automated vessel, but it is then the question of where do you put the human intelligence in the loop? Because what I can tell you is that there are no software programmers that I've ever met that have any decent or reasonable understanding of the problems that seafarers face that's why ECDIS is such a dreadful mess." (Interviewee 8).

Other ethical issues were discussed within the interviews. The sentiment shared by many interviewees was that the adoption of unmanned autonomous ships should never be fully implemented worldwide due to socio-political pressures. Additionally, all interviewees agreed that an autonomous vessel must not be treated differently to current vessels as not every country would have the infrastructure to produce autonomous vessel at the beginning of maritime autonomy:

"Can you imagine a ship going from Vladivostok to San Francisco autonomously, the Americans are never going to allow a ship that's come from Russia to go across the north Pacific Ocean into the west coast of the States just won't happen. And they'll be the sort of reasons why it will never, in my view, it will never become the norm" (Interviewee 6).

5.4.2.5 Knowledge on Autonomy

The cohort of interviewees expressed their concerns regarding the industry's knowledge of autonomy. Multiple interviewees detailed their concerns that the developers of autonomous systems are doing so without the input and knowledge-base of navigational officers. Due to the exclusion of the input of the OOW, the introduction of autonomy will experience multiple setbacks and potential failures before it is fully adopted into the developed world. Furthermore, the interviewees believed that the development of autonomy will improve, and legislation will further develop in the event of a catastrophic failure event similar to the creation of Safety of Life at Sea (SOLAS) following the grounding of the Titanic.

"It is dependent on the emergency protocol and legislation needs a catastrophic event to increase the speed of development, like SOLAS and Titanic. If something happens some situation occurs where the ship cannot go, what do you want to do? Do you want to the continue the mission by manned mode? Or do you want to stop the ship at that point and waiting for rescue? So, if you want to bring the ship back then I believe there needs to be crew on the vessel as only ship master is not enough to solve the problem." (Interviewee 2).

Various interviewees expressed their views that the maritime industry should continuously revise their legislation on autonomy throughout each degree of autonomy that the industry implements. Moreover, various interviewees had detailed their knowledge of the current level of legislation that is being produced for MASS i.e., the varying levels of autonomous ships:

"I'm aware there's the four levels of autonomous shipping from manned with a degree of automation to completely remote controlled. I think it's possibly being driven by cost…I think a lot of the drivers are financial, with a ship where everything's just working 24/7 without any humans on board the ship. Obviously, you'll have all the human factors and all the human elements ashore, instead of on the ship." (Interviewee 13).

With the volume of modern technology installed on the majority of current vessels, interviewees expressed their confusion as to the lack of automation knowledge that current OOW have on modern systems. Additionally, interviewees claimed that there is a lack of knowledge within the industry about technology. The consensus among the interviewees regarding autonomous systems is to implement a standardised bridge system that is uniform between manufacturers to reduce the learning curve for the OOW.

"Looking at systems such as Autopilot and ECDIS, why is there no focus or drive towards optimising these systems before introducing new systems?" (Interviewee 2)

5.4.2.6 Environment

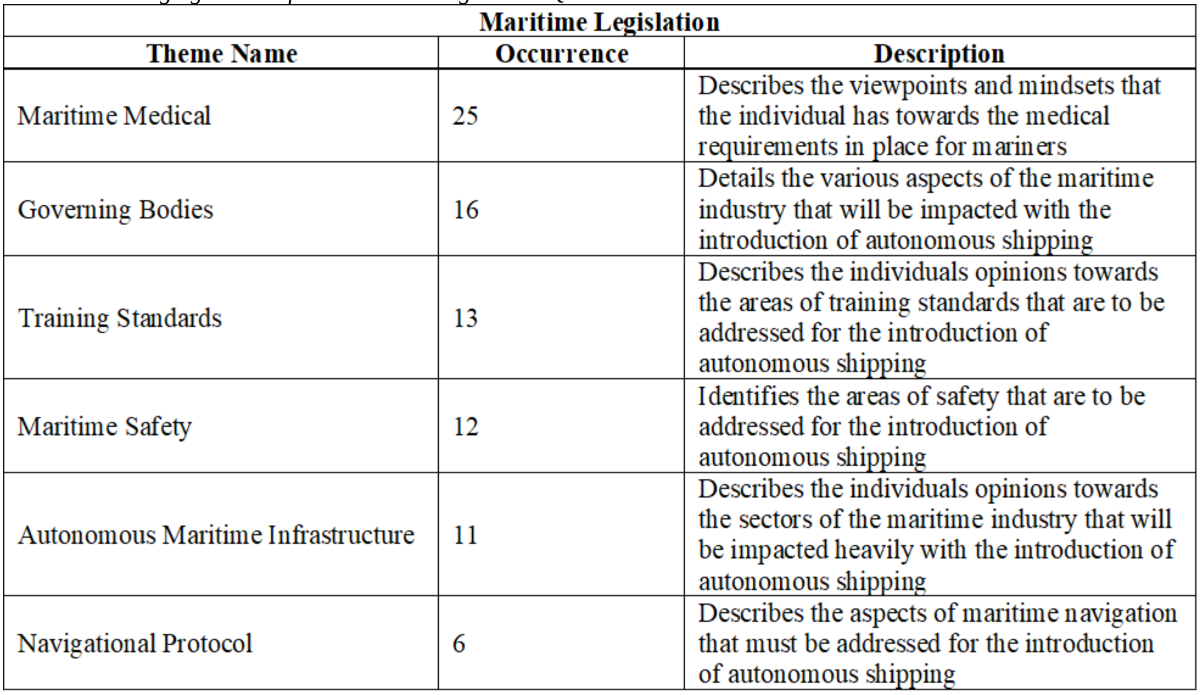
The interviewees identified the various environmental elements that a vessel must endure, such as tidal forces, wind effects and MARPOL designated special areas. Furthermore, with aspects such as inclement weather and traffic to safely navigate, the maritime industry has a significant number of variables that they must address that do not affect other areas of autonomous transportation. Maritime accidents tend to occur in subpar conditions which can be exacerbated without the inclusion of the OOW in the loop or crew onboard. Additionally, with the various sizes of bodies of water and specific rules that vessels must adhere to when travelling through special areas, unmanned transit could prove very difficult:

"You get autonomous busses now and monorails in airports that drive themselves autonomously. But that's where they're almost operating on fixed routes and systems, whereas shipping has so many variables like weather, traffic, tide, wind, debris in the sea, I think there's a lot of hurdles to overcome and it's over a vast area as well you have a range of water sizes from the Pacific and Atlantic Ocean and. Then you get some more congested areas where there's more traffic, like the Panama and Suez Canals… We also have to think about the environmental impact and pollution of the industry too. What happens if there are oil spills from running aground?" (Interviewee 1)

5.4.3 Maritime Legislation

The discussions within the topic of "Maritime Legislation", established a multitude of themes that were explored. Throughout the interviews the theme that was analysed the most frequently was the theme of "Maritime Medical" with 25 occurrences. Conversely the theme that was discussed the least was "Navigational Protocol" with 6 occurrences. Table 5.3 shows the various themes discussed throughout the interview process, the number of times that each theme was explored and a summary of each theme.

Table 5.3: Emerging Themes from Maritime Legislation Question Set



Maritime Legislation		
Theme Name	**Occurrence**	**Description**
Maritime Medical	25	Describes the viewpoints and mindsets that the individual has towards the medical requirements in place for mariners
Governing Bodies	16	Details the various aspects of the maritime industry that will be impacted with the introduction of autonomous shipping
Training Standards	13	Describes the individuals opinions towards the areas of training standards that are to be addressed for the introduction of autonomous shipping
Maritime Safety	12	Identifies the areas of safety that are to be addressed for the introduction of autonomous shipping
Autonomous Maritime Infrastructure	11	Describes the individuals opinions towards the sectors of the maritime industry that will be impacted heavily with the introduction of autonomous shipping
Navigational Protocol	6	Describes the aspects of maritime navigation that must be addressed for the introduction of autonomous shipping

5.4.3.1 Maritime Medical

The consensus among all interviewees was that the industry must overhaul the entire medical testing procedure for the OOW prior to the introduction of MASS. Interviewees believe the main aspect which should be assessed is the mental health of an individual:

“I think mental health should always be considered, even as it stands today. It is absolutely essential that mental status should be part of the health assessment” (Interviewee 4).

Additionally, several interviewees then proceeded to express their concerns with connectivity to home and that with the reduction of crewing numbers, onboard communities could impact the mental health of an individual:

“Minimum manning might be reduced, resulting in fewer people onboard and fewer people to interact with. People’s mental health might be affected in that regard unless they upgrade the facilities and services for crew” (Interviewee 11).

However, with mental health being addressed within the medical requirements for mariners, it was also noted that participants believe that it should not halt the progress of the OOW, and that the maritime industry should have measures in place to aid individuals:

“I think the ENG 1 should include mental health, but what I wouldn’t want to see with ENG 1, is it stopping someone's career. I think it should involve people being given help and assistance, rather than them failing the ENG 1 and not being able to go to sea at all, because they've had mental health issues. I think it should lead to help and support, rather than being a career ending part of the process” (Interviewee 13).

Ultimately, the opinions among the interviewees remained consistent, with the idea that the inclusion of a form of psychometric testing to enable the maritime industry to assess the mental states of individuals prior to boarding a vessel would be beneficial with immediate effect.

Another aspect that was congruous among the interviewees was the idea of the current medical standards being out of date for the OOW. The general opinion among the interviewees highlighted that for current systems and crewing numbers the modern medical for the OOW is inadequate for individuals and requires a complete overhaul:

"The whole ENG 1 needs to be reviewed. For such a highly sophisticated, high level, high stress, high intensity operation in an 21st century industry, why are we subjecting our operators to 20th century requirements? It is woefully inadequate" (Interviewee 6).

5.4.3.2 Governing Bodies

Interviewees identified various governing bodies such as IMO and regulatory bodies, e.g., classification societies and flag states, as key contributors to the success of autonomous shipping.

"I think national regulatory bodies in the UK like the Maritime Coastguard Agency (MCA) have huge departments looking into autonomy and other future technologies for shipping and ports in the UK, and I think industrial bodies will create codes of practice and codes of conduct at an international level". (Interviewee 6).

Furthermore, as the interviews progressed, many interviewees discussed topics that should continuously be addressed as autonomous shipping advances beyond the introductory stage. The consensus among the interviewees was that the governing bodies of the maritime industry operate at a slower pace than the rate at which technology is developed and produced.

"…I think the IMO is in serious danger when it's already been overtaken by the industry it's the nature of the technological advances are so rapid…" (Interviewee 6).

Moreover, multiple interviewees express their concerns for governing and regulatory bodies having their interests being initiated through commercial gain rather than conducting their approach to the benefit of the industry and safety of the maritime workers:

"Governing bodies and flag states are very much led by commercial concern. With the development of ECDIS, driven by the manufacturers, developing, and selling what they think we want and not listening to what we are telling them we need. The IMO must do things for the right reasons" (Interviewee 10)

5.4.3.3 Training Standards

The interviewees agreed that with the introduction of autonomous systems, the training standards for the OOW will require a major overhaul. Among the interviewees, the participants that were involved in an educational role or a less experienced officer made a greater input to this theme. With systems being produced from various manufacturers, the interviewees expressed their concerns for multiple training requirements for a single system:

"STCW will obviously have to go undergo more training. For example, we do our ECDIS courses with the STCW, we have to do type specific, if more than one autonomous system is entered into the shipping, which there will be, different companies vying to be the first, does that mean that you have to learn one system and then have to do a specific training course to learn that system" (Interviewee 1).

Furthermore, the interviewees expressed their concern regarding the industry not detailing the requirements for potential systems, and not relaying this to the maritime education standards to implement changes to the curriculum. This delay is slowing down the progress towards the implementation of autonomous operations in the maritime education syllabus:

"What is the new standard, for operators going forward? It has to include topics beyond COLREGs, buoys, radar theory. What else do they need to know? It all comes back to troubleshooting and IT problem solving. If operators are not on the ship, then there need to be more teaching how to diagnose and fix systems from behind a screen." (Interviewee 15).

5.4.3.4 Safety

Various areas of safety were identified by the interviewees in the discussion of legislation. Interviewees highlighted subjects such as fire safety, safety protocols, crew and cargo safety as all fundamental topics that require revision prior to the introduction of autonomy.

"…Different areas of the industry must be updated to allow autonomous to be fully introduced. Areas such as fire safety protocol, minimum manning requirement, safety vessels, crew safety to name a few all require extensive research to ensure that these new vessels are safe…" (Interviewee 5).

Additionally, certain interviewees detailed how they believed that autonomous shipping could benefit from an accident database that records near miss incidents, past accidents, and ongoing investigations. This will then develop a library of knowledge that can be shared among the autonomous fleet to improve the safety of vessels within this category:

"The sharing of information between autonomous ships will allow vessels to learn and adapt to past experiences which I believe would help" (Interviewee 1).

Due to reduced crew numbers, an onboard injury may result in a casualty being left unattended for a prolonged period of time or there could be a financial burden to extract the casualty from the vessel. Moreover, the reduced crew size could result in an inflated workload for the remaining crew. Reduced crew sizes could result in internal conflicts among crew and multiple hazards and risks could arise from mixed gender crews:

"Any accident onboard would significantly reduce the manning onboard, meaning extra workload for the remaining crew… You could not sail with mixed genders due to the various issues that may arise" (Interviewee 12).

5.4.3.5 Infrastructure

The sentiment among the cohort of interviewees was that multiple facets of maritime infrastructure will undoubtedly be impacted by the introduction of autonomous shipping. For the continuous development of autonomous systems and operations, the maritime industry must adapt and have a firm foundational knowledge of what autonomy means for the industry going forward:

"Many faces of the industry will see change. But what is important is that knowledge is standardised across the board. If the rest of the world accepts and implements these measures what would happen if a country such as the USA does not conform to the standard" (Interviewee 12)

Moreover, with the introduction of autonomous shipping, multiple aspects of maritime infrastructure will need to be renovated and adapted to cooperate with emerging technologies, aspects such as port and harbour authorities, insurance companies and P&I clubs in addition to pilotage were all identified by the interviewees as key figures in the transition to autonomous shipping:

"Ports and harbour authority will require an overhaul due to the way ports and harbours operate. Autonomous shipping may require new infrastructure to allow these vessels to safely berth, which current ports do not have." (Interviewee 4).

"Identifying risks is vital and this can be done by regulators, port authorities, ship owners and insurance companies. Identifying the risks and managing them will allow for a smooth transition for autonomy." (Interviewee 7).

5.4.3.6 Navigation

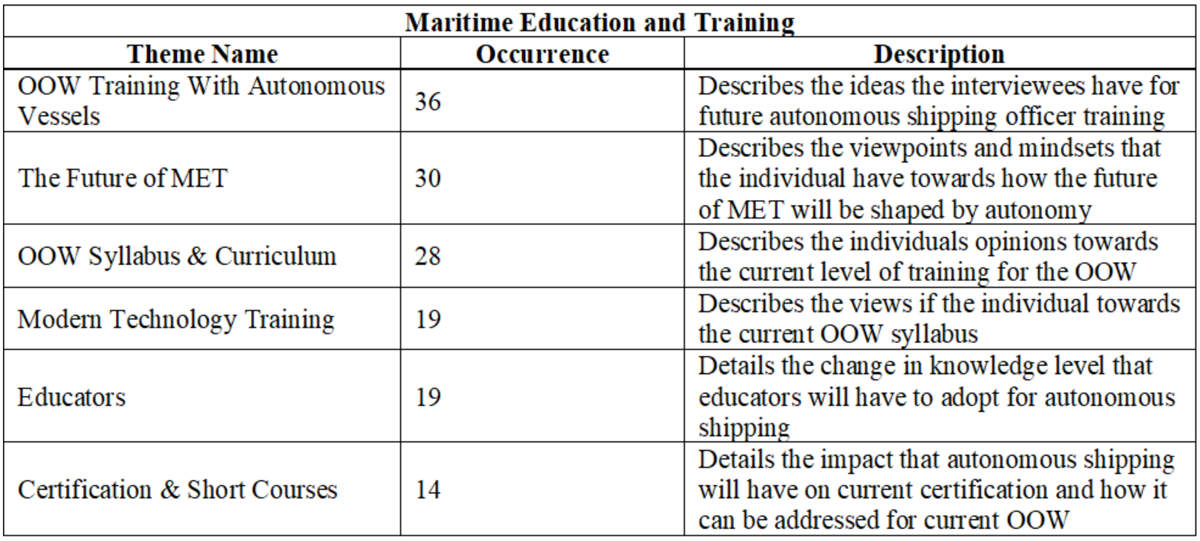
All interviewees believed that with the introduction of autonomy, will come a vast update to the current navigational protocol for vessels. It was highlighted that the COLREGs require modernisation with aspects such as mixed fleet communications being adopted into such regulations.

"You have to be able to identify that another ship is there by looking at radar, ECDIS listening to very high frequency (VHF) etc. If there are no external communications, how will this be identified?" (Interviewee 10).

5.4.4 Maritime Education and Training

The discussions within the topic of "Maritime Education and Training", established various themes that were explored. Throughout the interviews the theme that was identified most frequently was "OOW Training With Autonomous Vessels" with 36 occurrences, whereas the theme that was discussed the least was "Certification & Short Courses" with 14 occurrences. Table 5.4 shows the various themes discussed throughout the interview process, the number of times that each theme was explored and a summary of each theme.

Table 5.4: Emerging Themes from Maritime Education and Training Question Set



Maritime Education and Training		
Theme Name	**Occurrence**	**Description**
OOW Training With Autonomous Vessels	36	Describes the ideas the interviewees have for future autonomous shipping officer training
The Future of MET	30	Describes the viewpoints and mindsets that the individual have towards how the future of MET will be shaped by autonomy
OOW Syllabus & Curriculum	28	Describes the individuals opinions towards the current level of training for the OOW
Modern Technology Training	19	Describes the views if the individual towards the current OOW syllabus
Educators	19	Details the change in knowledge level that educators will have to adopt for autonomous shipping
Certification & Short Courses	14	Details the impact that autonomous shipping will have on current certification and how it can be addressed for current OOW

5.4.4.1 OOW Training With Autonomous Vessels

The interviewees agreed that various aspects of the current navigational officer syllabus must be updated to efficiently introduce autonomous officer training. The interviewees agreed that training must incorporate behavioural skills training with the inclusion of skills such as fault diagnosis and fault recognition. Additionally, the interviewees believed future training should also include a foundational knowledge of technology and electrical system to enable the OOW to become a more rounded problem solving mariner:

"Subjects such as critical thinking, troubleshooting and fault recognition will all be big aspects of training but there needs to be a way of putting them into the IMO syllabus…Critical decision making, and critical analysis will let the officer think a little bit differently if something is going

wrong…people may forget how to tie knots, but they'll have to understand sensor technology" (Interviewee 7).

Further questioning within the Topic of MET identified that future training should allow for the expansion of the OOW curriculum and should widen the knowledge base of the OOW rather than remove the fundamentals of navigation. Moreover, many interviewees were of the opinion that training must become standardised globally as currently there are various subjects being taught and omitted depending on the country that the OOW is being trained in. Additionally, the interviewees believed the key to optimising autonomous shipping training lay with the shipping companies and that shipping companies have to do more to promote further training both ashore and onboard.

"Looking at ECDIS for example, it can be seen that we are going to miss the boat on this. When they brought ECDIS in because they could and not because they should. They rushed in with different manufacturers making them, but we missed the standard…if you go from one ship to the other and use a different manufacturers system you have to do type specific training because they are so different" (Interviewee 11).

Furthermore, certain interviewees highlighted flaws with the OOW training programme too. The belief was that modern cadets, while being sent to sea for a minimum of 12 months, were not receiving sufficient beneficial watchkeeping time:

"It's interesting what has been said about watchkeeping and sea time, you can do a run from Papua New Guinea to Panama at 15 knots at a course of 091 and you get 28 days sea time. But what have you done but look out of the window" (Interviewee 6).

5.4.4.2 The Future of MET

The interviewees had a varied response on what they perceived the future of MET to entail. Multiple aspects were identified when discussing this theme. Overall, the interviewees believed that as MET advances, multiple career pathways will be created for future workers. However, this idea of the creation of prospective jobs met a mixture of opinions, from both positive to negative:

"Control centres that will control these autonomous and remote systems will demand high staffing to meet the safety levels and that will be around the clock…they will still need that seafaring knowledge" (Interviewee 9)

"There would perhaps be an increase of seafarers in port and coastal shipping. But deep sea shipping would see a massive decline resulting in a loss of careers for deep sea mariners" (Interviewee 16)

The interviewees believed that with technology the OOW would have to become accustomed to, frequent system updates should be delivered in an efficient manner to the OOW with the main focus of system update training being on interface usability. Additionally, the idea of training the OOW in cybersecurity was identified by many interviewees:

"Updates have to be done by a memory stick or device which cannot be corrupted… Cybersecurity would have to come into the syllabus to aid this. We may end up with OOW who also understand cybersecurity and how to stop malicious attacks and that may become another role in the industry" (Interviewee 3)

Moreover, various concerns were identified by the interviewees. Aspects such as simulators replacing sea time and career concerns were highlighted through the discussions, with the main consensus being that while autonomous systems are beneficial, knowledge needed to be learned directly through sea going experience and not solely taught through the maritime simulators:

"I am a passionate advocate for a training vessel. My training in the navy consisted of six trainee crew being in control of a training vessel for a week…After you are done with that you then had a level of situational awareness and these skills and attitudes baked into you, that could not be achieved in a simulator" (Interviewee 8)

5.4.4.3 OOW Syllabus & Curriculum

The current OOW syllabus became a focal point for all interviewees. The consensus among the cohort was that subjects such as celestial navigation and chartwork are outdated in modern times. With systems such as ECDIS, automatic identification system (AIS), global positioning system (GPS) and radar being implemented in the wheelhouse there is a lack of focus on the technology side of navigation and too much emphasis on obsolete subjects:

"In all honesty the syllabus has not changed since I was a cadet…currently there are more automated systems on the bridge as well as electronics and new technology, but we are still doing the same length courses on radar. There needs to be longer courses on how to operate automated equipment like autopilot and other navigational equipment." (Interviewee 15).

"We do teach cadets lots of things they may never use, such as celestial navigation…I think we are one of the few nations that still teach it, pretty much everywhere else in the world has gotten rid of it… I know students do struggle as they cannot relate to it…" (Interviewee 11)

Moreover, with the addition of new technologies in the current climate of seafaring, aspects such as simulator experience and communications were identified as areas that require more emphasis prior to the introduction of autonomous ships.

"System updates could result in a manned ship have a communication breakdown with an autonomous ship or two autonomous ships using different systems having a breakdown in communications and this must be taught using simulators." (Interviewee 1)

5.4.4.4 Modern Technology Training

The interviewees detailed their experiences with various systems that are located on the bridge. The belief among the interviewees was that the MET places too much emphasis on obsolete and redundant skills such as cargo operations, celestial navigational, meteorology and chartwork. Conversely, there is a lack of training on modern bridge systems beyond what is learned within the simulator suite. Many interviewees highlighted the lack of focus on system diagnosis for faults with systems such as ECDIS, AIS and Autopilot:

"I think to be honest, to advance maritime education, we need to attach to higher education establishments…old subjects can be removed because they aren't needed. We now need to look at getting more automated systems added into training. There has been a massive drive over the past six years to educate everyone on ECDIS and that's just the beginning" (Interviewee 9).

Furthermore, all interviewees believed that MET does not fully optimise current training methods. The views among the group were that training systems such as navigational simulators do not get efficiently utilised throughout the cadetship. The belief was that simulators can aid and enhance the development of navigational skills among cadets and young officers. Additionally, the utilisation of simulators can aid the development of communication skills, fault recognition skills and psychological skills such as SA If used efficiently, the interviewees highlighted that simulators can be used as a tool to teach young mariners about the dangers of AB, fatigue, and complacency.

"We will need to incorporate more simulation training as this will help develop and sharpen different skills that we use at sea. Also using simulators will let us understand the risks associated with watchkeeping such as complacency and fatigue" (Interviewee 2)

"Competency based simulator training will greatly impact educational facilities" (Interviewee 5).

"More simulator time is needed for practicing navigational skills and develop more in depth emergency response training" (Interviewee 16)

5.4.4.5 Educators

The idea of educators teaching young people and students in a form of navigation that they may not have direct experience with, divided the interviewees. Less experienced members of the cohort believed that for a tutor to be capable of teaching autonomous navigation then they should have personal experience in using such systems whilst at sea. Moreover, educators should undergo frequent training to maintain their navigational knowledge:

"It would simply not be possible to lecture on a navigation topic with zero experience. Even masters with over 30 years of experience should have to revalidate their skills every 5 years" (Interviewee 16).

Conversely, interviewees from an educational background believed that educators who have accrued sea time offer an authentic learning which is beneficial to the student, yet do not believe that sea time is necessary to educate students.

"It's always nice if lecturers have done the job before…The experience of physically doing the job gives the teaching element a better standard of teaching, but it isn't a must have" (Interviewee 15).

Furthermore, many experienced interviewees detailed that theoretical knowledge does not need first-hand experience and that multiple aspects of autonomous shipping will be derived from past maritime incidents. With highly sophisticated simulators, multiple aspects of navigation can be learned by both student and educator from the comfort of the simulator suite:

"I don't think you need to have done it in practice to teach it… if we just talking about anti-collision work and navigational work, sophistication of simulations now is such that you can quite honestly train somebody from that point. I'm not suggesting that you should do that only for seafaring but just from a navigational point of view, you can train people on simulators without any doubt whatsoever" (Interviewee 6).

Nevertheless, all interviewees agreed that maritime educators are not suitably paid, which has resulted in a lack of high quality educators with a wealth of knowledge being available to the MET sector. Multiple interviewees highlighted that the maritime industry should follow the aviation industry and offer an incentive for highly experienced mariners to impart their knowledge within MET facilities on an annual basis:

"In shipping, if you come ashore to be a teacher you get paid considerably less so it's very difficult to attract really good instructors, because people rather started seeing the bigger money. However, in aviation it's the other way around, if you can convince them an airline pilot to teach, they actually get paid more." (Interviewee 7)

5.4.4.6 Certification & Short Courses

Many interviewees believe current certification should not become invalid but should transition to a limited stage, detailing the OOW responsibilities within the autonomous fleet. Moving forwards, the group of interviewees agreed that to increase the knowledge of current officers, various short courses should be introduced and should be tested on a more frequent basis. Moreover, such short courses should include subjects such as SA and detail the technological advancements within the bridge watchkeeping system:

“I think our ticket will, initially, still remain valid for being unlimited on any tonnage. I think, however maybe we'll have to do a course and maybe a validation course just to say that we have undergone further training, maybe we'll have to do an advanced autonomous ship handling course. But any courses need to dive further into the technological advancements in the industry and look at things like situational awareness” (Interviewee 1).

5.4.5 Maritime Human Factors

The discussions within the topic of “Maritime Human Factors”, established various themes that were explored. Throughout the interviews the theme of “OOW Knowledge and Understanding” was identified as the most frequently discussed theme with 54 occurrences. Conversely, the theme of “System Knowledge” was the least discussed theme with 16 occurrences. Table 5.5 shows the various themes discussed throughout the interview process, the number of times that each theme was explored and a summary of each theme.

Table 5.5: Emerging Themes from Maritime Human Factors Question Set

Maritime Human Factors		
Theme Name	**Occurrence**	**Description**
OOW Knowledge and Understanding	54	Describes the knowledge and understanding towards systems that would benefit the OOW
Autonomous Navigational Systems	37	Describes opinions towards the relationship between current and future navigational systems and the OOW
Careers at Sea	21	Describes the individual’s opinions towards the working life at sea
Behavioural Traits	18	Describes the behavioural skills the individual has identified that need improvement with autonomous ships
System Knowledge	16	Details the system knowledge level of the individual towards autonomy in the maritime industry

5.4.5.1 OOW Knowledge and Understanding

Discussions regarding maritime human factors prompted a plethora of subjects to be discussed within the interviews. The consensus among the interviewees was to improve the understanding of the term SA. The interviewees believe that while there is some acknowledgement of SA within the training regime, there is a lack of emphasis on this subject when working at sea. Many interviewees furthered their discussions on SA by introducing aspects such as the idea of developing a human factors based short course using maritime bridge simulators to educate and improve SA and complacency. However, the interviewees identified that further education would come with a high financial expense to the individual undertaking it:

"The training we do right now, doesn't give students enough to be situationally aware…we need more of a push to stretch trainees further in simulators and challenge them. But to increase simulator usage and introduce further courses will be too expensive so I don't know how that can happen" (Interviewee 11).

The interviewees agreed that current short courses are far too diluted with too much emphasis being placed on classroom activities. All interviewees believed that short courses should have a better balance of technology studies in the classroom and practical technical skills training conducted in the simulator. Moreover, the interviewees believed that short courses, beyond those detailed in the STCW training regime, should be promoted by shipping companies and refresher courses should be conducted as "pre-deployment training" to help focus the individual for their upcoming sea trip:

"Companies should train their staff, especially senior officers on incidents, situational awareness refreshers and simulator training" (Interviewee 13)

"If you have been off for a couple of months, I think there should be videos and quizzes for the officer, stuff to get his mind working days before he gets on the vessel…we all become complacent and if you have been off work for a long period of time then you should have to undertake a day course at college to try and mitigate these risks as people are aware of situational awareness when they get onboard." (Interviewee 3).

5.4.5.2 Autonomous Navigational Systems

When discussing the topic of the autonomous human-machine relationship, the interviewees agreed that increasing the knowledge of SA is paramount for the success of autonomous shipping. Furthermore, as systems become increasingly more sophisticated and reliable, the operator may have an overreliance and bias towards what the system is displaying. This then led many interviewees to highlight the risks with highly complex user-machine interfaces:

"Over reliance of the equipment can be a big factor in keeping a safe watch. if you're over reliant on the systems, you get too comfortable then you might not notice when things go wrong…As autonomy comes in systems can't be overly complex to the point if something goes wrong the operator doesn't know how to sort it" (Interviewee 1).

Furthermore, it was believed by the interviewees that life onboard can create complacency. The interviewees understood that a vast majority of maritime incidents caused by human error. However, many interviewees believe that the statistics and journalism do not report the number of incidents that have been averted due to human intervention. Many interviewees identified that the wheelhouse is rarely silent with various alarms sounding, often with little to no action being required to monitor such events. This leads to alarm fatigue and a dismissive attitude for common alarms. Consequently, advancing the control from manned systems to autonomous systems, many interviewees voiced their concerns regarding keeping the OOW in the decision-making loop:

"*You need to have an awareness and understanding and possibly quite an in depth understanding of how to take the control back off systems, if necessary, in order to do something with it…The bridge is not a silent place there are many alarms that you need to know and overcome"* (Interviewee 6)

5.4.5.3 Careers at Sea

With all interviewees having over 12 months of experience at sea, many aspects were raised regarding the daily life of the OOW and how this would be impacted with the introduction of autonomous shipping. The belief among the interviewees was that trip times need to be standardised globally, as the average trip time varies between nations. However, all interviewees did not believe that the length of trip can negatively affect the mood and moral of the OOW although time extensions that the OOW had not planned for can widely impact the concentration levels of the individual. However, the interviewees agreed that the length of the trip can impact the navigational ability of the OOW as external social factors such as family, friends and social media can create a feeling of detachment from their role onboard:

"Time away need to be more regulate. Individuals are more alert when they go onboard compared to when they leave. Seafarers can work onboard for 14 months straight. During my last trip, there was one seafarer who joined months before me and left after I did and that isn't fair to him or his family" (Interviewee 2)

The interviewees also identified fatigue as a contributor to the SA and concentration of the OOW. Many interviewees had expressed their concern for the lack of true rest that an individual receives onboard and that with the potential for reducing crew size this will be further impacted. This concern further extended towards individuals feeling pressure to not declare working hours to ensure that their job is completed. However, multiple interviewees had detailed their understanding of fatigue sometimes being unavoidable from inclement weather and arduous manual labour based tasks onboard:

"I think it is your work rest pattern that has a bigger effect. We changed our watch patterns to six on 12 off to give ourselves a longer period of rest, you still end up working the same amount of time, but you end up getting longer periods of rest and then having the longer periods of rest

I found when I got off the ship, I found that I was more or less as refreshed as when I joined the vessel" (Interviewee 3)

5.4.5.4 Behavioural Traits

As autonomous shipping is introduced, the interviewees identified multiple behavioural skills and traits that should be exhibited by future OOW. Many interviewees believed that highly sophisticated systems require a high level of vigilance and confidence to operate. Moreover, it is believed by the cohort that systems, if operated correctly, can be trusted with caution. However, due to the working life on the bridge, the belief among the interviewees was that the OOW should not be easily distracted and be able to maintain a high level of concentration while keeping watch:

"If your vigilant at doing a job, you're more likely to see that something's going wrong or be reactive when something is going wrong. If you're there for an easy time and an easy ride, then you could end up just missing it and being blasé about it because you're not concentrating, you're not focused and that cannot happen in the future" (Interviewee 1)

5.4.5.5 System Knowledge

The interviewees agreed that for the OOW to evolve in the world of autonomous shipping, knowledge of the systems is paramount. The belief is that system knowledge can be improved through system familiarity, in addition to streamlining and simplifying the data given to the OOW, with the OOW developing their fault diagnosis and recognition skills. Many interviewees agreed that, while autonomous shipping is beneficial to the OOW, it should be used as a navigational tool and not supersede the commands of the OOW. Moreover, the autonomous system should always have a degree of human input. Multiple interviewees further expressed their concerns that for maritime autonomous systems to succeed, the installation of autonomous systems in other transportation sectors should be researched:

"The frequency of training need to be increased, I think an annual course including situational awareness and equipment communications would be great. Looking at the aviation industry, pilots have to sit a simulator assessment where they have to spend a certain amount of time in the simulator annually. So, the maritime industry could learn from that to keep up to date with the latest technology updates" (Interviewee 15).

5.5 Findings

As further research is conducted into autonomous shipping, multiple aspects must be addressed to ensure the success of automating the navigational facilities of the ship. From this study it is apparent that many of the interviewees are positively receptive of the introduction of autonomous ships. However, this is not without concern for a multitude of factors that will affect the operators in the early stages of autonomy. Aspects such as the ethical dilemma of vessel routes, in terms of investigating maritime incidents, communication errors and updating training standards have been identified within literature (Issa, et al., 2022). These factors were reiterated and confirmed by the interviewees. However, this study provided further clarity that navigational officers are aware of the risks that autonomy will bring. The interviewees identified human factor areas such as over-reliance, vigilance and SA as topics that are not receiving sufficient recognition within literature. Furthermore, these human factor aspects, if not suitably addressed, could cause delays and fractures within the human automation relationship and result in many OOW not trusting the system to navigate the vessel, resulting in a significant step back in the introduction of autonomy.

It was acknowledged by all interviewees that the MET sector must undergo a significant transition to adopt not only autonomy but all emerging technology to the navigational OOW curriculum. Research has identified the lack of framework for MET with regard to autonomous shipping (Emad, et al., 2022). Furthermore, it is a common idea for the maritime industry to learn and enhance the safety of systems from the aviation industry, an idea that has been identified from research (Turan, et al., 2016) and consolidated from this study. Conversely, the findings of this study have shown that the consensus among navigational OOW is that the current UK MET navigational OOW curriculum is not able to be developed into an autonomous shipping syllabus. Subjects such as chartwork and celestial navigation do not educate students in the mindset of problem solving and troubleshooting. Furthermore, the interviewees identified various areas of the current MET curriculum that must be overhauled to ensure that autonomy is a success when it is introduced. Nevertheless, the maritime industry must not allow technology to overtake legislation. With the rates of the design of technology increasing over time, governing and regulatory bodies within the industry must develop guidelines, rules, and training regimes to safely implement such systems.

Research has identified that various emerging technologies such as VR, augmented reality (AR) and mixed reality (MR) would be beneficial to educate students within MET (Mallam, et al., 2019). However, to fully achieve that stage of education, foundations need to be created. This study has identified the need for increasing the utilisation of simulator technology to modernise and improve the navigational officer curriculum. As autonomous shipping guidelines are introduced, simulator suites will allow current and prospective navigational officer to hone their navigational skills and learn about emerging technologies within a safe environment. The input from the operators will be valuable as training regimes are developed for autonomous vessel navigation. However, the findings from the interviews have identified that educators within MET should have first-hand experience with the subjects that they would be teaching as this offers an authentic perspective on the students' education. Moreover, the industry must offer greater incentive to attract highly qualified personnel from a life at sea.

Elements of HAT were apparent throughout many interviews and responses. HAT is a topic that has been introduced to the maritime industry. However, much of the focus towards HAT is directed to the maritime aspects such as ship inspection (Ellwart & Schauffel, 2023). From the interviewees' opinions it is understood that OOW, while have concerns regarding the longevity of their careers, believe that the role of the OOW will evolve into a technical support officer. Moreover, due to the safety and ethical risks associated with shipping, in addition to the preventative maintenance conducted by crew, removing crew completely does not currently seem a viable option. Furthermore, as the OOW role is redefined throughout the introduction and early stages of MASS, the expectation among the OOW cohort is for the MET sector to direct their focus towards aspects such as HAT, technology, and critical thinking.

At the beginning of this chapter, four hypotheses were drawn from the initial outlook of the study. The *Interview Study* has addressed the hypotheses of the study as follows:

- Hypothesis 1 – Participants would show concerns for job security with autonomous shipping.
    - The interviewees identified concerns with the future job market for seafarers due to the introduction of autonomy. However, all interviewees expressed their excitement for future job prospects due to the evolution of the OOW role and consequential development of future skills that will be incorporated into autonomous seafaring positions.
- Hypothesis 2 – Participants will acknowledge the benefits of autonomous shipping but will emphasise the value of maintaining crewed vessels.
    - Many interviewees highlighted the importance of maintaining crew onboard, even in the event of a fully autonomously operated vessel. Aspects such as minimum manning capacity, seafarers' mental health and wellbeing, preventative maintenance and ethical responsibilities were among the critical discussion points that the interviewees had shown concern over. Additionally, the discussions of such topics led interviewees to determine that, while sophisticated systems will have the potential to operate a vessel unmanned, there will still be the possibility of system failure that will require seafarers on board.

- Hypothesis 3 – Participants will believe that the navigational officer curriculum has too much emphasis on outdated subjects and that there is a lack of technology and simulator training within the navigational officer curriculum.
    - The general census among all interviewees is that the current maritime OOW curriculum does not support the technological side of seafaring. Many interviewees believe that the entire OOW syllabus requires a complete overhaul with the removal of outdated subjects in favour of both simulation and critical thinking. Thus, giving current seafarers an advantage to cope with the potential steep learning curve of autonomous shipping.
- Hypothesis 4 – Participants will believe that situational awareness will be a highly impactful factor in the future development of navigational officers.
    - As autonomous systems will take control of the navigational aspects of the vessel, the interviewees agreed that the OOW should have a high level of situational awareness to ensure that, in the event of a malfunction, they would be able to interject themselves into the decision-making loop. Moreover, the discussion of both HATs and HITL closely aligned with the research and literature reviewed in Chapter 2.

By conducting semi structured interviews, participants were given the platform to vocalise their opinions and experiences with automation and navigation. Additionally, the interviews delivered a rich data set from the participants, allowing the foundations set within chapter 4 to be developed further. Moreover, analysing each interview using thematic analysis, allowed various themes to be identified that could then aid the development of subsequent studies.

The aim of this study was to capture the navigational officers’ perspective towards the introduction of autonomous shipping. By constructing the questions into 4 definitive sets, various themes could then be derived from the interviews. The research conducted within this chapter has provided valuable insight, from the perspective of the OOW, regarding the areas they believe will be beneficial to introduce in further training for autonomous shipping and will then provide the rationale for the development of the simulator studies for this thesis.

5.6 Methodological implications

Conducting semi-structured interviews provided a great insight into autonomous shipping from the perspective of the OOW. However, various challenges were present during the data acquisition. Both the interview and transcription processes were highly time consuming as was the data analysis. The latter was also subjective to the researcher. Due to the nature of the semi structured interviews and the open-ended questions, interviewees were given the opportunity to discuss a variety of topics in a varying degree of detail. Resulting in the interview times ranging from under 20 minutes to over 2 hours. Moreover, the information delivered by the interviewees differed greatly depending on the participant willingness to explore the questions further. Despite the varying length of the interviews, the study reached a point of thematic saturation, meaning that the same themes were discussed throughout each interview.

5.7 Chapter Conclusion

The findings of this study alone provide the maritime industry a wealth of knowledge towards the implementation of autonomous systems. Moreover, this research has provided a valuable insight for both current and future research towards MASS and MET. The work conducted within this chapter has identified fault recognition and fault diagnosis as two key skills from the OOW that will be highly impacted by the introduction of autonomous shipping. It is also understood that the working life of the OOW is in a highly stressful environment with multiple alarms and distractions occurring during a navigational watch. Having been identified by industrial representatives, these factors are assessed and introduced as focal points for subsequent studies in this thesis. The aim of this chapter was to answer research questions developed in Chapter 1, which aided the construction of the hypotheses for this study. Ultimately, this study has shown that whilst navigational officers are intrigued by the idea of autonomous shipping, there are a multitude of safety factors that have to be addressed before the systems are introduced. Moreover, autonomous shipping will evolve the role of the OOW into a supervisory role, yet the current cohort of OOW are not sufficiently equipped with the skill set to compliment and supervise autonomous navigation systems.

This chapter detailed the work that has defined the rationale behind the choices taken for subsequent simulator studies. Aspects such as fault recognition, fault diagnosis and SA were constant themes that were discussed by each interviewee. Therefore, from this knowledge, the initial *Pilot Study*, using a bridge watchkeeping simulator, could be designed using the knowledge gain from Chapters 4 and 5, with the aim to address the human automation relationship between operator and navigational system in the confines of a navigational bridge environment.

Chapter 6. Pilot Study

6.1 Introduction

This chapter presents the third study conducted for this thesis. The chapter details the development, preparation, execution, findings, and statistical analysis of the results of the preliminary simulator study. Similar to the participants of previous studies, the participants selected for this study had a seafaring background. In this study, participants were tested over three simulator exercises to analyse their performance and instructed to complete a questionnaire to analyse their opinions on autonomy. Basic statistical analysis and ETA were used to analyse the data collected from the study. Subsequently, this chapter will look to address the research questions, RQ4 and RQ5, presented in Chapter 1 and how the design and findings of this study impact on this body of research. This chapter will conclude with the methodological limitations and how the study could be improved for future research and will address the impact that this study will have on the maritime industry.

As the maritime industry looks to implement autonomous shipping, it is imperative, for the success of MASS, that the industry has a firm understanding of how the current cohort of navigational officers can develop and evolve their watchkeeping skills to harmonise the human-automation relationship. As identified in Chapter 5, maritime education is a potential concern for the industry with the main focus of the navigational officer curriculum being centred on outdated topics such as celestial navigation and paper chartwork. Seafarers from various backgrounds expressed their interest in increasing the level of simulator work within the navigational officer syllabus. Moreover, Chapter 5 identified that individuals from a navigational officer background believe that by incorporating aspects such as simulation as a method to train qualified navigational officers in autonomous shipping and SA, the maritime industry may move towards a harmonious human-automation relationship upon the arrival of autonomy. Thus, by using the idea of visual perception as a foundation it was then possible to develop a fully interactive bridge fault simulation study.

The aim of this study is to develop a method that measures aspects such as the fault recognition and fault diagnosis skills of participants in a bridge watchkeeping setting. By designing multiple scenarios with various faults implemented into the system, it would be possible to develop a study that allows participants a greater level of immersion through real-time, interactive exercises.

6.2 Study Design and Impact

This study was designed with the main aim being to identify the fault recognition and diagnosis skills of navigational officers with current bridge technology. Constructing the study with multiple exercises allowed participants to display their navigational skills in various scenarios while encountering mechanical or automated system faults. Prior to the design of the study, various hypotheses were identified which aided in the structuring of each exercise and linked this study with the initial research questions of this thesis.

- Hypothesis 1 – Subjecting a human navigational operator to standard wheelhouse-based distractions, such as routine paperwork, will result in a disregard for alarms and hazardous situations.
- Hypothesis 2 – Human operators are more receptive to a mechanical based fault rather than an automated system fault.
- Hypothesis 3 – Human operators will show bias and a degradation of situational awareness in the event of an automated system fault.

6.3 Method

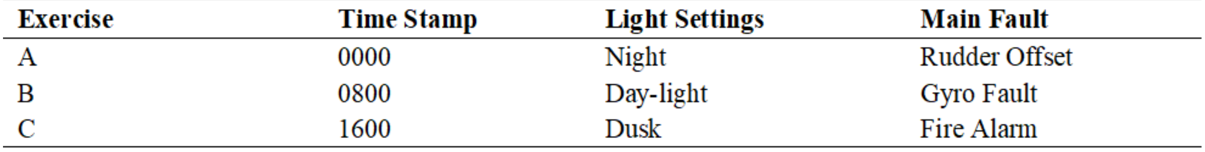
The *Pilot Study* was defined in two different sections as follows:

- Simulator Experiment
- Maritime Officer Questionnaire

6.3.1 Simulator Experiment

The aim of the simulator experiment was to assess whether a navigational OOW can successfully recognise and diagnose a fault with an automated navigational system, deemed highly reliable by seafarers and the maritime industry. At the preliminary stages of the research, various system faults were considered; however, it was decided that the best way to assess a participant’s fault recognition would be to introduce a subtle fault in a system which they would consider reliable. The simulator experiment was split into three independent exercises which then allowed the possibility to examine the test subjects on a multitude of navigational faults over the three different time stamps, allowing for different light settings within each exercise. The thee exercise stations that were designed for the physical simulator experiment, with corresponding variables, are shown in Table 6.1.

Table 6.1 Exercise variables for "Pilot Study"



Exercise	Time Stamp	Light Settings	Main Fault
A	0000	Night	Rudder Offset
B	0800	Day-light	Gyro Fault
C	1600	Dusk	Fire Alarm

Using the participant selection criteria as detailed in Chapter 3, the study analysed a group of 50 individuals, from the navigational section of shipping crews, operating a simulated vessel within the wheelhouse. The study monitored each participant and their own experience within the bridge. Each exercise was carried out using Kongsberg secondary bridge suites. Each suite implemented the Kongsberg Polaris simulator software, which allowed participants to control the simulator, and Seaview R5 visual software, which gave the participants a visual feedback representation of their actions when controlling the simulated vessel. The layout of the simulator included three screens in front, giving the participants a 120° view of the forward of the vessel, and a screen at the backside of the simulator suit, allowing participants to view the aft and wake of the vessel. Additionally, the suites were equipped with a steering control unit, a workstation with fire alarm (FA) control and a control console that included systems that would be expected to be located within the wheelhouse i.e., ECDIS, radar and telegraph. The construction of the bridge in the simulator is representative of a simplified view of the systems that are to be expected on board a live vessel, with the main difference being the lack of port and starboard bridge wings. Figure 6.1 shows the integrated bridge simulator set up.

Figure 6.6.1 Bridge watchkeeping simulator configuration

6.3.1.1 Materials

In preparation for each experiment, a different exercise was created, using the simulator suite. In addition to the simulator, quizzes and a work pack were issued to the participants within each test station to imitate basic paperwork, expected to be completed on the bridge during the navigational officers' watch time.

To maintain continuity throughout each test station, the same vessel and operational parameters were used, which were pre-programmed into the simulation software. For the experiment, the ship chosen was the M/S Magnitogorsk, a Panamax bulk carrier, travelling at 14 knots following a course heading of 000. The vessel's autopilot had been configured to sound an off- course limit alarm once the vessel had exceeded a cross track limit of 1 nautical mile (nm) off-course, which can be altered at sea depending on sea state and weather. The vessel's particulars are shown in Table 6.2:

Table 6.2 Ship particulars for M/S Magnitogorsk

L.O.A [m]	**Beam [m]**	**Draught Aft [m]**	**Draught Fwd [m]**	**Deadweight [Tonnes]**	**L.P.P [m]**	**Max Power [kw]**	**Full Speed [knots]**
215	31.8	11.5	11.5	22691	162.9	9,180	14.4

6.3.1.2 Procedure

Three 20 minute exercises were designed with unique faults that would occur within each exercise, to ensure authenticity and immersion in the simulator. Participants would have to undertake all three exercises to ensure they could be assessed on each testing station. However, the order in which the participant completed the tests was arbitrary and would be based on the participant's choice.

Before the start of the first exercise, all participants were given a familiarisation briefing. The briefing detailed how to operate the system, in terms of controlling the simulated vessel and communications with the instructor, for the exercises the instructor would be researcher. Subsequently, participants completed all three exercises. The exercises were created to ensure that all participants experienced: a mechanical fault, in the form of a rudder offset failure (ROF); a series of alarms, in the form of routine FA testing; and an automation fault, in the form of an autopilot gyro drift failure (GDF). Each exercise was given a different fault, traffic condition and time stamp within the corresponding test station. From the literature review conducted in Chapter 2, it was evident that course deviation and human interaction greatly contributed to many maritime incidents. Moreover, by analysing the findings of both the Survey Study and Interview Study it was understood that failures affecting the vessel's gyro compass and navigational system were quite common for seafarers to encounter onboard. As such, the findings preceding the Pilot Study would act as a foundation and from prior research conducted in this thesis it was found that a fault which can occur on the bridge is a gyro drift error. The routine FA testing is conducted weekly by the engine crew onboard whereas the rudder offset can be caused by a range of issues that may cause a jam with the steering gear. However, the gyro drift may be caused by a faulty set of batteries powering the magnetron of the system causing the gyro to wander, which then would result in the vessel's autopilot following an incorrect plot line. Different time stamps were issued to each exercise to ensure that the participant was aware of the change of station.

Beyond the variables, all three exercises were configured in a manner to provoke the participant to respond to errors and faults which occurred in the simulation. Visual cues in the form of cloud patterns, star positions and the wake were in view. Resultant alarms were activated to allow the participant to inspect the fault further at their own discretion and communications were set up between each test station and the monitoring station to create a feeling of supervision for the participant, allowing them to call the captain or anyone else they deemed relevant for the experiment. As a further measure, every participant was monitored using CCTV and microphones located in each testing station, thus allowing the instructor to record and monitor the participant's action throughout the exercise.

All exercises ran for a total of 20 minutes, thus allowing the participant to operate the simulator for an hour in total. The participants were issued with a work pack upon entry to the exercise. In each work pack the participants received the following items: three answer sheets to complete in their corresponding workstations, a ship particulars work sheet, which they could attempt to complete over the course of their time in the simulator suites and a logbook with three exercise pages for them to highlight any abnormalities in the exercises.

By monitoring, analysing their work packs and debriefing them, every participant was able to convey acknowledgment of any abnormalities, if detected, within each exercise. For each exercise, variables were required to display the corresponding traffic vessels in the simulations. Table 6.3 shows the parameters for the variables.

Table 6.3: Parameters of traffic vessels encountered in "Pilot Study" exercises

Exercise	Vessel	Distance [Nm]	Bearing	Speed [knots]	Heading
ROF	A-001	10.1	050	12	135
GDF	B-001	3	245	18	330
	B-002	4	015	12	180
	B-003	12	345	24	090
FA	C-001	5	180	350	13
	C-002	10	215	080	18

6.3.1.3 Rudder Offset Fault Exercise

Upon entering the test station for the ROF exercise, the participant was presented with a darkened wheelhouse as the time stamp read midnight. Figure 6.2(a) shows what the participant would be able to see on the radar.

As the participant begins the exercise, they know that the vessel would travel at a course of 000 as per the orders of the autopilot. At 11 minutes into the exercise the rudder of the vessel would begin to offset to an angle of 7.5 degrees to starboard. To add to the ROF the turning indicator would begin to freeze at 11 minutes in order to assess whether the participant could recognise the fault using their own judgement. This would in fact hamper any manual operation and encourage the participant to believe that the vessel may not be turning as the indicator is not moving. However, at 18 minutes into the exercise the indicator heading would unfreeze, and the correct turning angle would be displayed. From the start of the ROF (11th minute) the magnetic compass would begin to make a clicking sound indicating that the vessel is turning and furthermore the radars of the vessel would begin to indicate that the vessel is turning as the fault is purely mechanical and not systemic. The final visual cue to indicate the turning of the vessel is the position of the stars. Should the participant look out of the windows onto the simulated sky they would begin to see that the stars are moving indicating that the vessel is no longer keeping a 000 heading.

Should the participant leave the simulation running without altering the course, the auto pilot alarm would begin to sound at 14 minutes and 56 seconds into the exercise. This would be the final prompt for the participant to alter the course and acknowledge the alteration of heading for the vessel. Should the participant proceed to not alter the course or take control of the vessel by the 20-minute time limit the participant would be given a time score of 540 seconds, the time from the fault start time to the end of the exercise, thus indicating that the participant failed to recognise the fault. The radar plot in Figure 6.2(b) shows what the plot would look like should the vessels control remain untouched throughout the exercise.

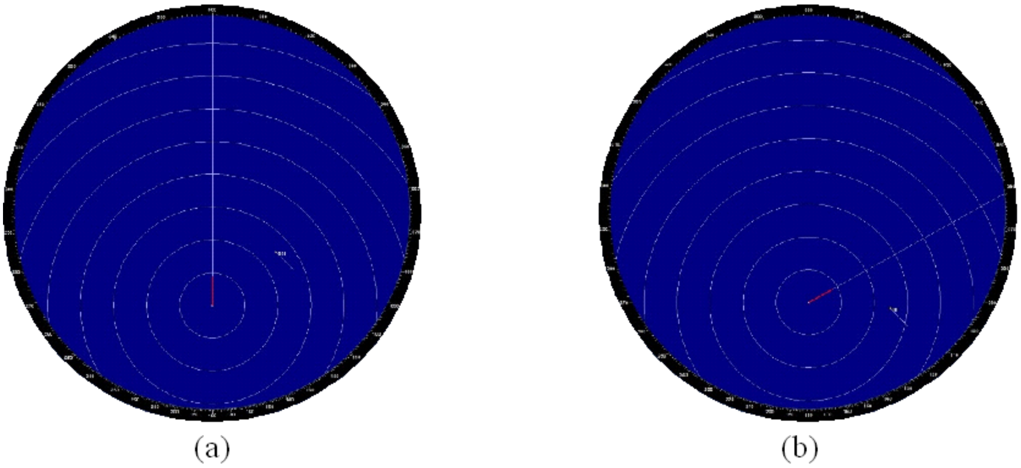

(a) (b)

Figure 6.2: Radar Display Plots ROF

6.3.1.4 Gyro Drift Fault Exercise

When entering the simulator suite, the participant was presented with the radar display shown in Figure 6.3(a). As can be seen in the radar display plots there are three vessels within the proximity of the simulator ship.

The participant would enter the simulator suite to find that the vessel is travelling at a heading of 000 as per the orders of the autopilot. At 9 minutes into the exercise the vessel would begin to experience a GDF. The vessel would begin to deviate from its course at a drift rate of 3 degrees per minute until the vessel reaches an off track limit of 20 degrees.

As the vessel begins to experience the GDF the vessel's magnetic compass would begin to start clicking thus indicating to the participant that the vessel is deviating from its original course. However, as this error has affected the vessel's gyros the heading display and radar readings would deliver an output that the vessel is on a course heading of 000. During this exercise the participant would have to look closely at the positions of the surrounding vessels and use the tracking function on the radar to help them assess the situation. As the bridge is fitted with a backup gyro for redundancy the participant may changeover to the vessel's second gyro and from there, they can clearly see that there has been a course deviation.

Should the participant leave the simulation running without altering the course the auto pilot off track alarm would begin to sound 15 minutes and 54 seconds into the exercise. The sounding of the off track alarm would act as the final prompt for the participant to assess and attempt to correct the error. Should the participant proceed to not alter the course or take control of the vessel by the 20-minute time limit the participant would be given a time score of 660 seconds, the time from the fault start time to the end of the exercise, thus indicating that the participant failed to recognise the fault. Figures 6.3(b) and 6.3(c) show the radar plots of gyros 1 and 2 where gyro 1 shows the error display whereas gyro 2 shows the true course of the vessel.

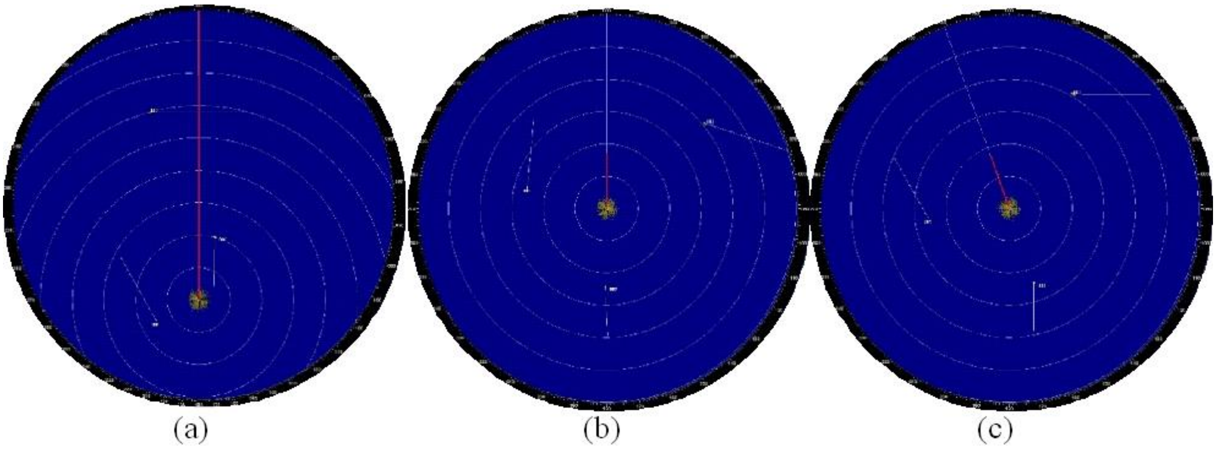

(a) (b) (c)

Figure 6.3: Radar Display Plots GDF

6.3.1.5 Fire Alarm Exercise

When entering the simulator suite, the participant was presented with the radar display as shown in Figure 6.4(a). As can be seen in the radar display there are two vessels in the proximity of the simulator ship.

Upon entering the simulator, the participant would find that the vessel is travelling at a heading of 000 as per the orders of the autopilot. During this exercise the participant would not experience any faults which would put the vessel at risk of harm. At 1 minute and 30 seconds the FA panel would sound a FA in zone 1 of the vessel however upon calling the captain and engine room the participant would be told that there is routine FA testing taking place which would be carried out during the course of this simulation. The participant would then experience alarms sounding every 90 seconds in the exercise thus enhancing the sense of alertness.

Due to there being no deviation from the course the vessel moves as expected. This can be seen from Figure 6.4(b) which displays the final radar plot at the end of the exercise.

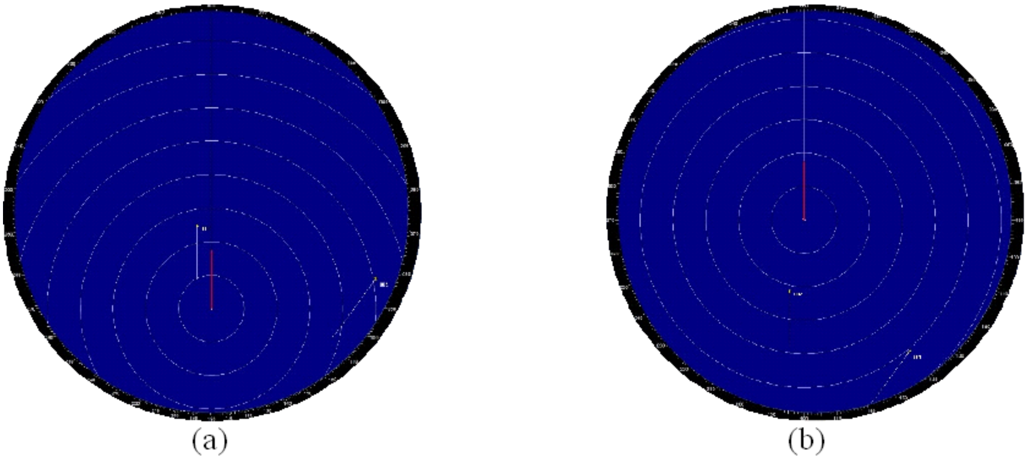

(a)
(b)

Figure 6.4: Radar Display Plots FA

6.3.2 Maritime Officer Questionnaire

The maritime officer questionnaire (MOQ) was disseminated to the test subjects as a part of the debrief for the study. The overall survey was structured to contain 18 individual sections; sections 1 to 13 of the survey assess the demographic information of the individual, including previous seagoing experience. Once the participant has completed the background information, they would be presented with various questions invoking a response from the participant which they would have to consider carefully when answering. The questions require the participant to express their views on autonomy, their past experiences with automated systems and their trust in automated systems. Within this study the questions that were analysed, focusing on the participant’s trust in automated systems and to discover if the participant had any further training beyond what is mandatory as per the minimum requirements of STCW Certificates and

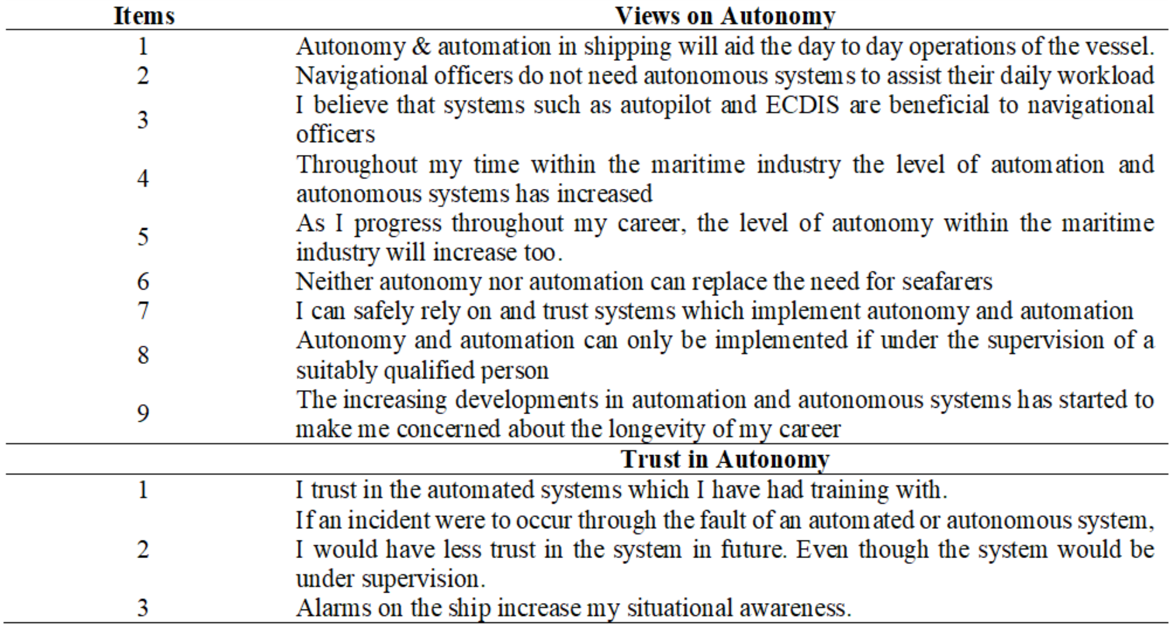
Requirements for Officer in Charge of a Navigational Watch on Ocean Going & Near Coastal Ships.

The questions were structured under the two following question types:

- Likert Scale – Questions designed to invoke a response from the test subject indicating the how strongly they feel in their opinion regarding the discussed topic in question (Brown, 2011).
- Subjective Dichotomous – Questions which, despite the informative nature of the questioning, could invoke the test subject to answer in a concise manner (Batchelder & Narens, 1977)

For the *"Pilot Study"* all Likert scale questions asked were a given a standard 5-point Likert scale answering method, with 5 being "Highly Agree" and 1 being "Highly Disagree". The aim of using the 5-point Likert scale was to allow the participants to answer the question whilst maintaining a midpoint, so if they felt indifferent to the question, they were not forced to favour one argument side over the other. Despite the *Survey Study* in Chapter 4 using 7 point Likert scales, it was felt that a 5 point Likert scale simplified the survey which was intended to act as a complimentary exercise to the simulator study. Table 6.4 shows the questions that were posed in the MOQ. Figure 6.5 shows the overall survey map structure and event trees dependent on the participant's response.

Table 6.4: MOQ Survey Questions



Items	Views on Autonomy
1	Autonomy & automation in shipping will aid the day to day operations of the vessel.
2	Navigational officers do not need autonomous systems to assist their daily workload
3	I believe that systems such as autopilot and ECDIS are beneficial to navigational officers
4	Throughout my time within the maritime industry the level of automation and autonomous systems has increased
5	As I progress throughout my career, the level of autonomy within the maritime industry will increase too.
6	Neither autonomy nor automation can replace the need for seafarers
7	I can safely rely on and trust systems which implement autonomy and automation
8	Autonomy and automation can only be implemented if under the supervision of a suitably qualified person
9	The increasing developments in automation and autonomous systems has started to make me concerned about the longevity of my career
	Trust in Autonomy
1	I trust in the automated systems which I have had training with.
2	If an incident were to occur through the fault of an automated or autonomous system, I would have less trust in the system in future. Even though the system would be under supervision.
3	Alarms on the ship increase my situational awareness.

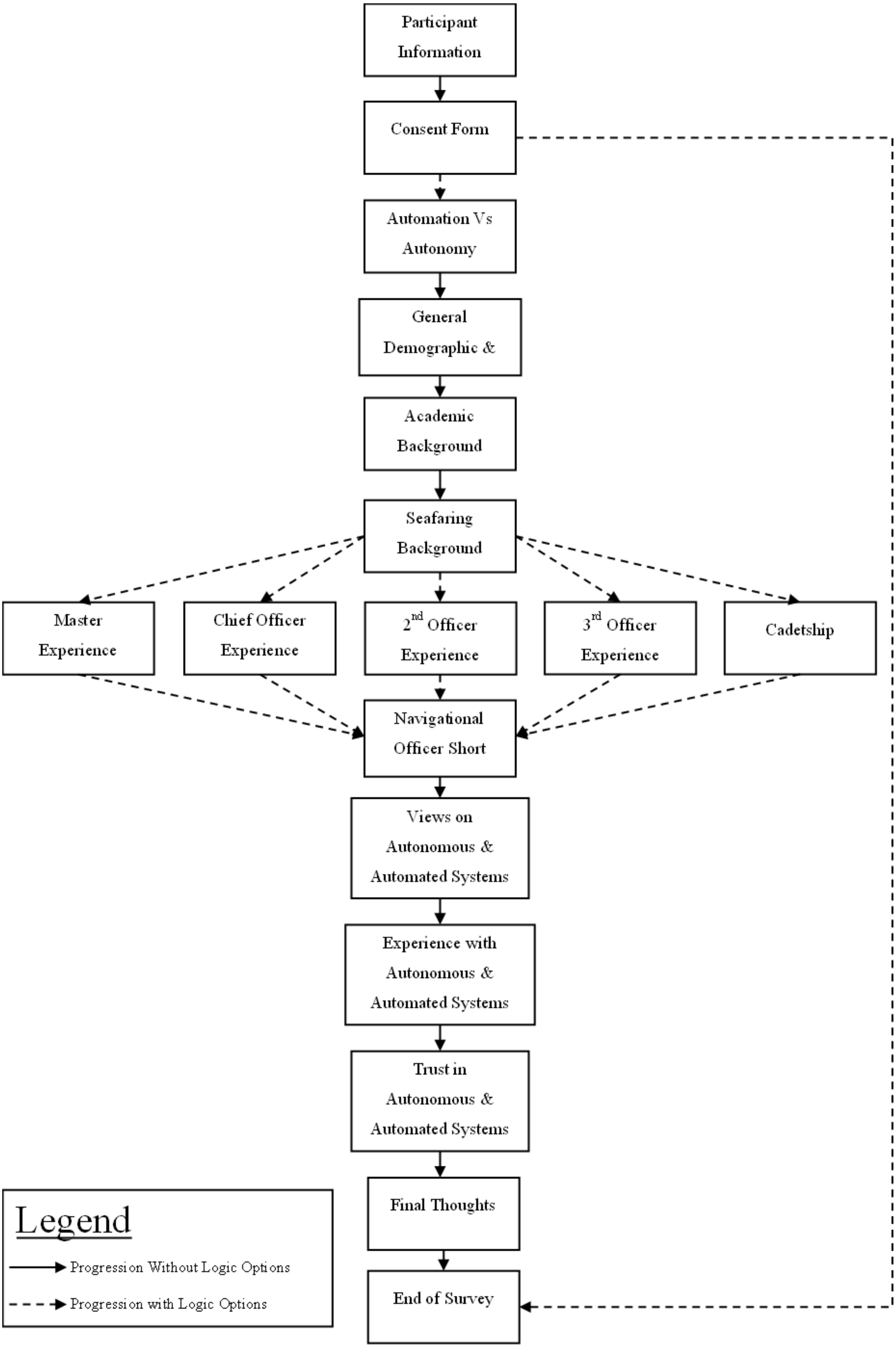


Figure 6.5 Maritime officer questionnaire structure

6.4 Results

Once each of the 50 individuals had been tested, the results were gathered and processed for statistical analysis. The data analysed was the time it took for the participants to react to the fault for the rudder offset and the gyro drift exercises. The statistical analysis was conducted for the following demographics of participants: Age, Rank and Education level. By collating the data into these demographics, it was then possible to analyse the results further. Table 6.5 shows the variety of participants demographics.

Table 6.5: Pilot Study Participant Demographics

Sex	n	Education Level	n	Age Group	n	Rank	n	Nationality	n
Male	49	High School	19	21 & under	16	CP 1	11	British	26
Female	1	Diploma	20	22-25	12	CP 3	3	Nigerian	5
		Degree	11	26-29	14	CP 5	14	Romanian	8
CP – Cadet Phase				30 & over	8	AC	8	Indian	8
AC – Academic Cadet						3/O	6	Irish	1
3/O – 3rd Officer (Qualified Officer)						2/O	8	Australian	1
2/0 – 2nd Officer (Qualified Officer)								Polish	1

To measure the reaction times for each individual participant, the participant was monitored using visual and audio CCTV. This allowed the instructor to record when the participant reacted to the fault of the test station. Each participant was given a reaction time ranging from the start of the fault, 0 seconds, to the end of the exercise, 540 seconds and 660 seconds for the rudder offset and gyro drift exercises respectively.

With the exercises having been set up to operate under the control of an individual test subject, this allowed behavioral observations to be made for each test subject. All test subjects were given the same information; however, this did not stop each test subject taking a unique approach to each exercise. Some subjects would primarily focus on the paperwork as they may have viewed it as necessary. However, by concentrating on the paperwork, subjects would often fail to react to the course deviation. Beyond the paperwork, participants were visually monitored and recorded in the event of the participant beginning to display signs of boredom and restlessness by yawning, checking their watch and checking their phones. Following the conclusion of the simulator exercises, the results were separated into two distinct data sets: Fault Recognition & Fault Diagnosis.

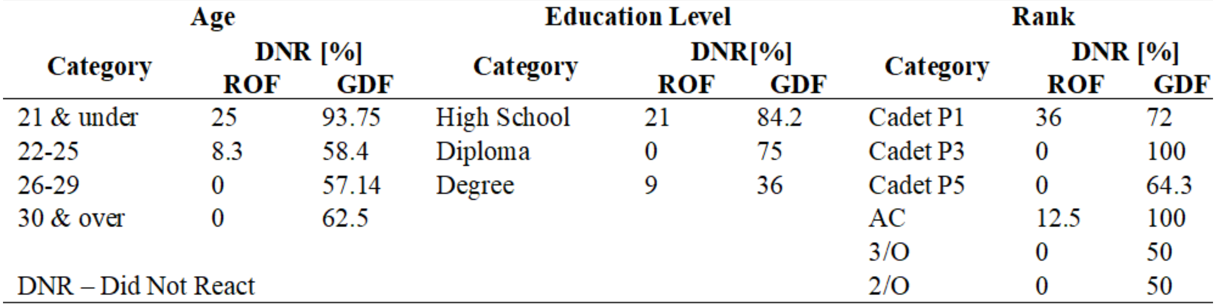
6.4.1 Fault Recognition

Initial analysis of the fault recognition aspect of the study had shown that younger, less experienced and lower educated participants were less reactive to the ROF. However, in general all participant groups reacted appropriately to the ROF, as shown in Table 6.6.

Conversely, all demographic groups experienced difficulties in reacting to the GDF. Table 6.6 shows the variety of participants in terms of the aforementioned demographics.

By conducting further analysis into each of the demographic groupings of participants, it can be seen that younger participants were less competent than their older peers which suggests that older participants are less trusting of automated systems and are more reliant on their skills and knowledge. Furthermore, this initial assessment can be extended to both the Education Level and Rank groupings of the participants as both participants of higher rank and education were more successful in recognising the fault. This may indicate that individuals who have received more education and have more experience, may have encountered such failures while onboard. As such this could equip the individual with the knowledge to be able to recognise both manual and automated failures more successfully. Moreover, the individual demographic groups will be further explored in the subsequent sections of this Chapter.

Table 6.6: Participant Reactions Rates by Group



Age			Education Level			Rank		
Category	**DNR [%]**		**Category**	**DNR[%]**		**Category**	**DNR [%]**	
	ROF	**GDF**		**ROF**	**GDF**		**ROF**	**GDF**
21 & under	25	93.75	High School	21	84.2	Cadet P1	36	72
22-25	8.3	58.4	Diploma	0	75	Cadet P3	0	100
26-29	0	57.14	Degree	9	36	Cadet P5	0	64.3
30 & over	0	62.5				AC	12.5	100
						3/O	0	50
DNR – Did Not React						2/O	0	50

6.4.1.1 Raw Data

The graph displayed in Figure 6.6 shows every participant's individual response time to both the gyro drift and the rudder offset exercises. In the graph, the times at which both exercises finish are highlighted along with the times at which the autopilot off-track alarm begins to sound, 236 seconds after the introduction of the rudder offset fault and 414 seconds after the introduction of the gyro drift fault.

From the graph displayed in Figure 6.6 it can be seen that 52% of the participants who attempted the exercise were successful in reacting to the rudder offset fault, before the signalling of the alarm. The overall percentage of successful participants was anticipated to exceed this value as the participants should have a heightened sense of alertness due to the exercise being conducted in darkness. However, with correct prompting i.e., autopilot off-track alarm, 90% of the participants reacted accordingly and were alert to the fault.

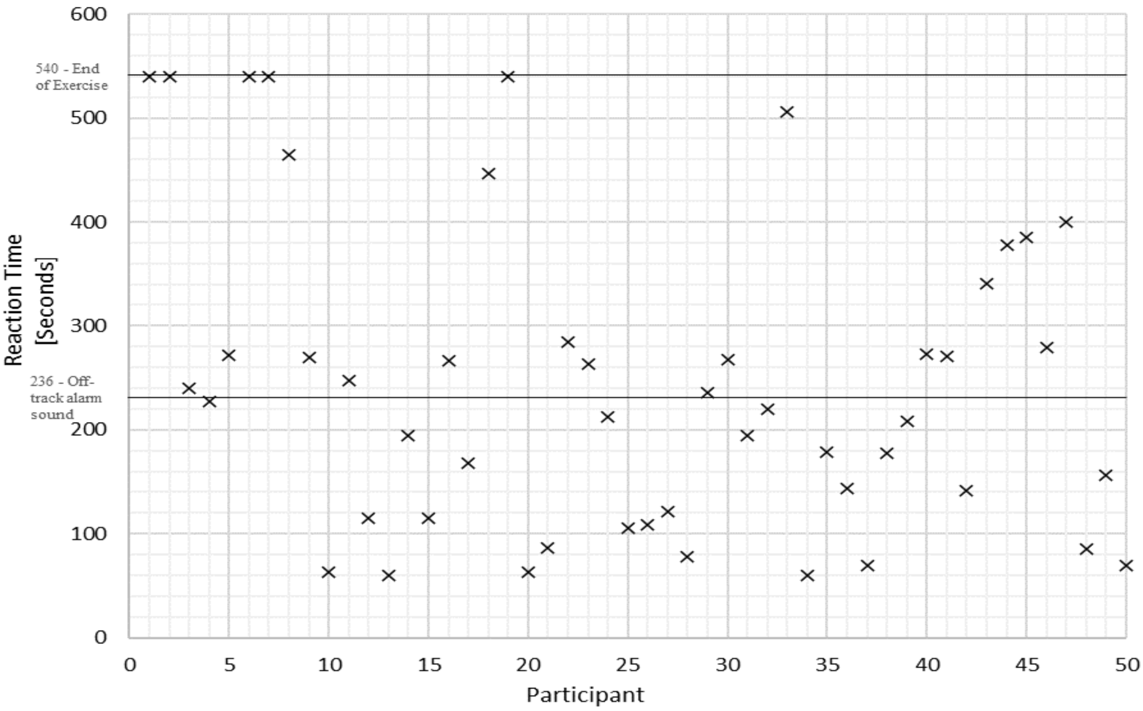


Figure 6.6: Individual Reaction Times for ROF Exercise

Figure 6.7 shows the reaction times for the GDF exercise, and it can be seen that only 16% of the participants responded to the GDF prior to the sounding of the alarm. This low value is of concern. A further 14% of the participants required the alarm to sound before they reacted to the course deviation. Bridge watch navigational alarm systems such as this can be deactivated. The deactivation of such systems can result in hazardous consequences and accidents which have occurred at sea have been attributed to this (Marine Accident Investigation Branch - MAIB, 2019).

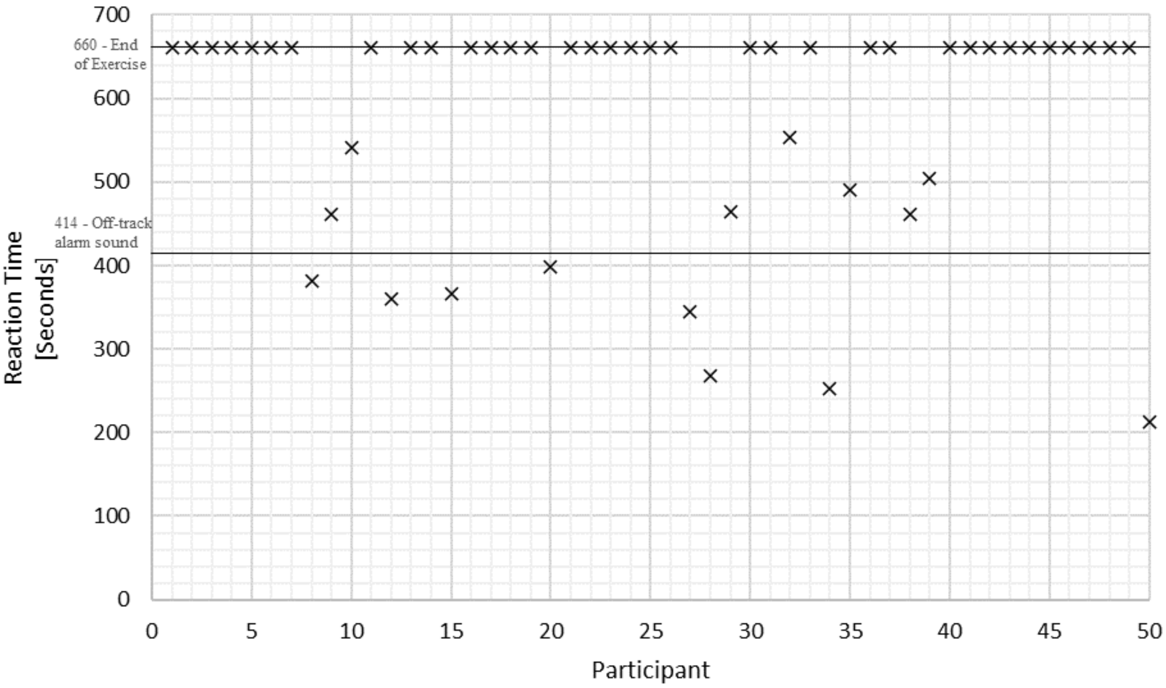


Figure 6.7: Individual Reaction Times for GDF Exercise

6.4.1.2 Age

From the data displayed in Figure 6.7, it is evident that the percentage of successful attempts by participants was far greater on the exercise with the ROF when compared with the gyro drift exercise. It can be seen that 90% of the participants successfully responded to the rudder offset fault, whereas only 30% of participants successfully reacted to the GDF. Additionally, Figure 6.7 illustrates the fastest, slowest and average reaction times for each participant age pool, for the rudder offset exercise. The fastest and slowest reaction times came from the 21 & Under group, with times of 60 seconds and 506 seconds respectively. With regards to the rudder offset fault only 5 participants failed to react to the fault, with four of those participants belonging to the "21 & Under" group and one participant belonging to the 22-25 group.

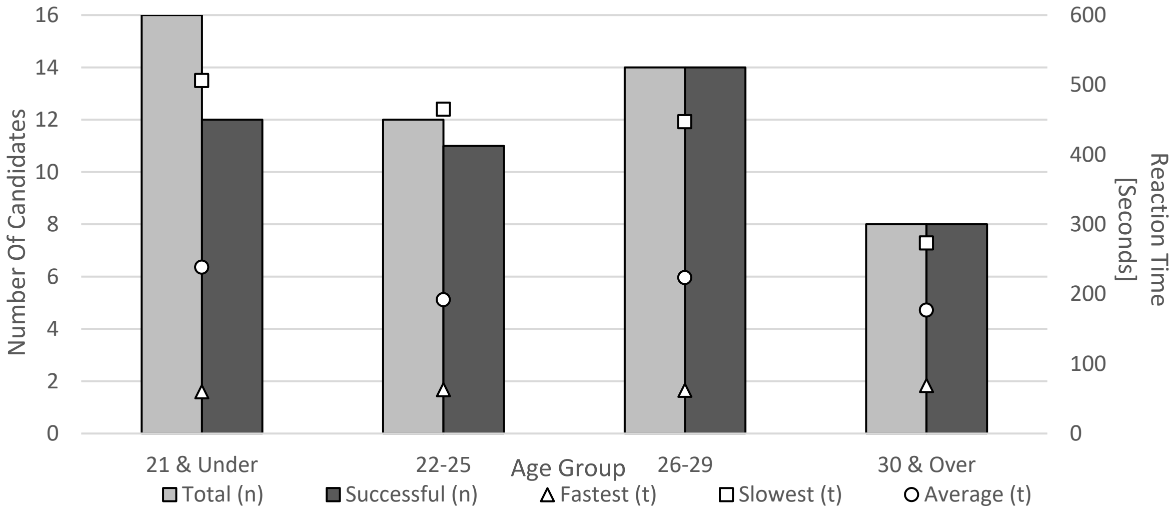


Figure 6.8: Reaction Times for ROF Exercise by Age Group

Conversely the data displayed in Figure 6.9 shows the fastest reaction time for the gyro drift exercise was attributed to the 22-25 group with a reaction time of 213 seconds and the slowest to the 26-29 group, with a reaction time of 553 seconds. It should also be noted that for both the rudder offset and gyro drift exercises the largest number of unsuccessful attempts belongs to the 21 & Under group. However, this can be expected as the age of the participants should correlate to the overall experience each participant has onboard vessels i.e. it is assumed that the younger the participant is, the less navigational officer experience they have. This assumption may also be strengthend as the slowest reaction times of the 30 & Over group are quicker than all other groups for the rudder offset and are quicker than both the 22-25 and 26-29 groups for the gyro drift. However, the percentage of partcipants, from both the 22-25 and 26-29 groups, who successfully recognised the GDF was higher than those in the 30 & Over group. This suggests that the SA of an OOW can not be determined by an individual's age. As such, the age of an OOW does not efficiently correspond to the fault finding skills of an individual.

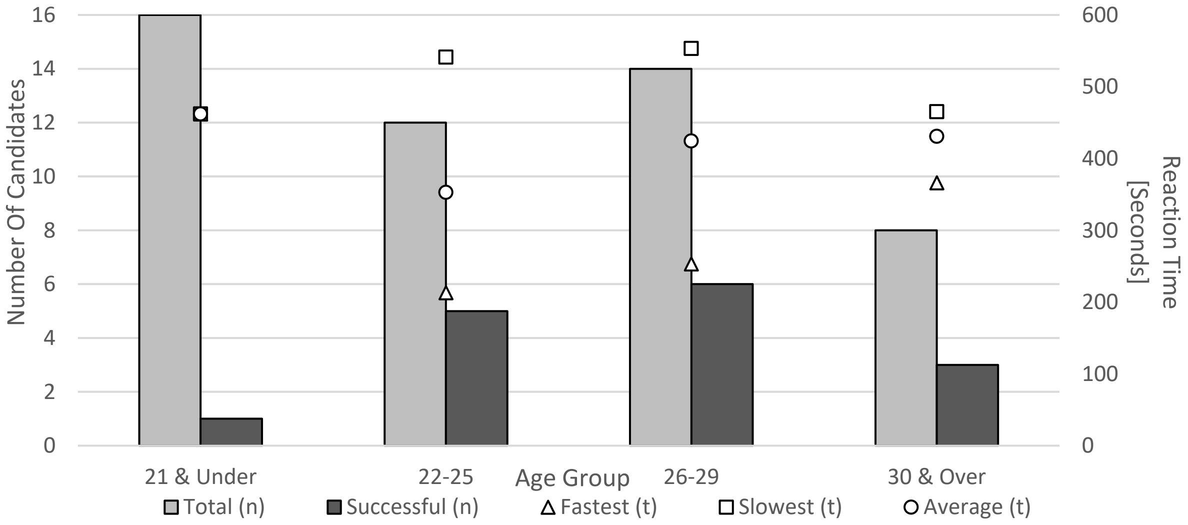


Figure 6.9: Reaction Times for GDF Exercise by Age Group

6.4.1.3 Rank

From the analysis of the graph displayed in Figure 6.10 it is apparent that the largest number of unsuccessful participants for the rudder offset came from the phase 1 cadet group, with four participants failing to react to the fault, and the second largest can be attributed to the academic cadet group, with one participant failing to react to the fault. This was to be expected due to the unfamiliarity of the non-seagoing cadets with the wheelhouse. It should also be noted that the fastest reaction times came from the phase 5 cadet group, at 60 seconds. However, the slowest successful reaction time also came from the phase 5 cadet group, with 506 seconds. Additionally, it should be noted that all qualified officers performed as expected with the majority of officers reacting to the rudder offset within 200 seconds of the fault occurring.

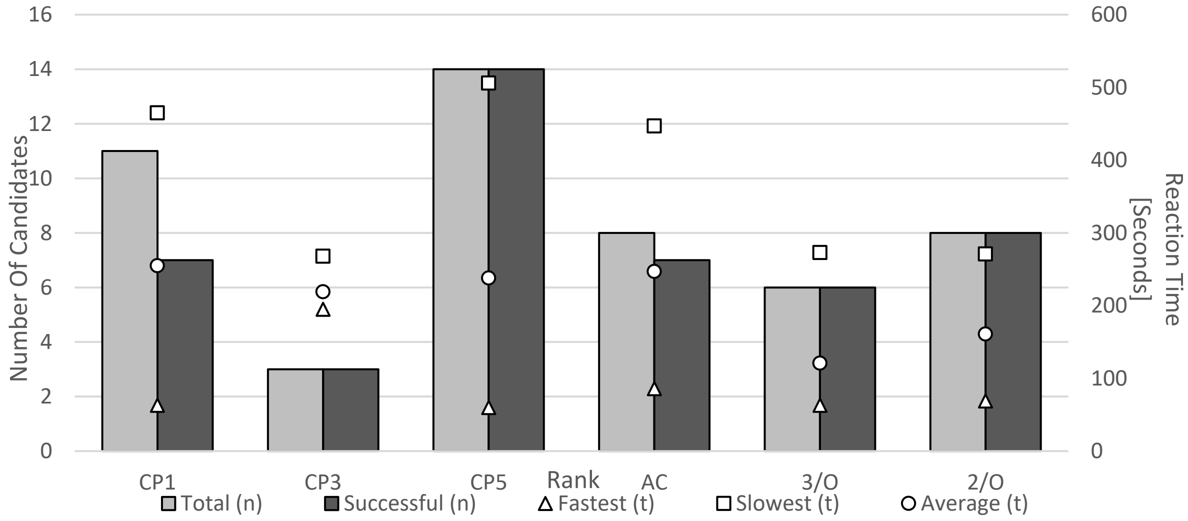


Figure 6.10: Reaction Times for ROF Exercise by Rank

From the graph depicted in Figure 6.11, it can be seen that the majority of unsuccessful attempts came from the cadet groups, however, with that being said, 50% of both 2nd and 3rd officers failed to react to the fault within the allotted timeframe. It should also be noted the fastest reaction time overall came from a 2nd officer who had completed the NAEST management course, prior to attempting the exercise. Therefore, it was to be expected that this participant performed to a higher standard than other participants at the same rank.

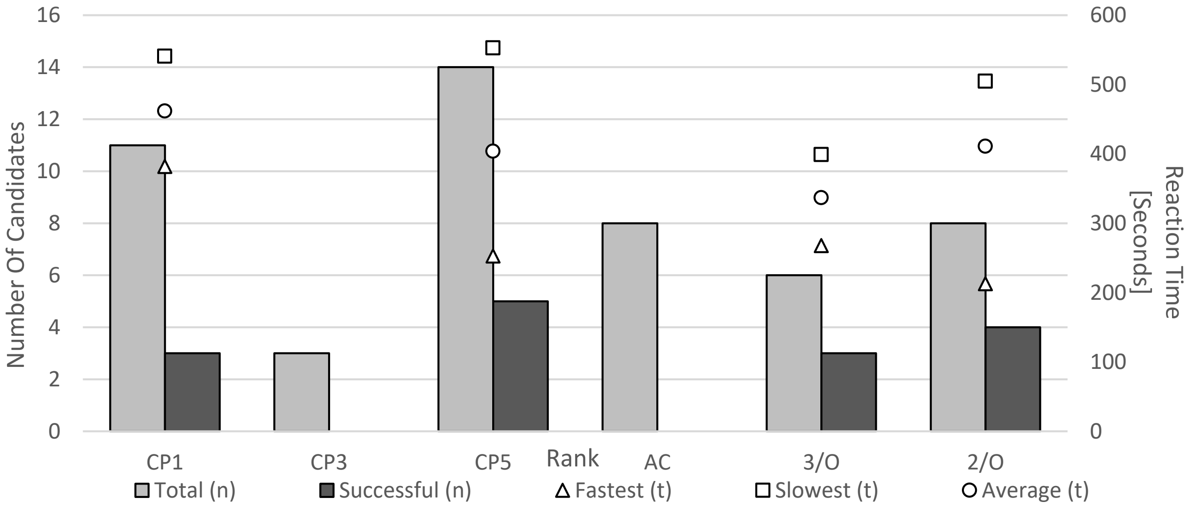


Figure 6.11: Reaction Times for GDF Exercise by Rank

6.4.1.4 Education Level

Due to the wide variation in the participants' levels of education, the data was confined to the following demographic pools: High School, Diploma and Degree. As seen from the graph in Figure 6.13 the only pools to have unsuccessful attempts were High School and Degree levels, with 3 and 1 respectively. As a larger portion of participants with Diploma and Degree level of education reacted to the faults, it was assumed that the participants with a higher level of education had greater bridge watchkeeping experience and therefore were more observant and reactive when presented with a fault, as seen in the rudder offset exercise.

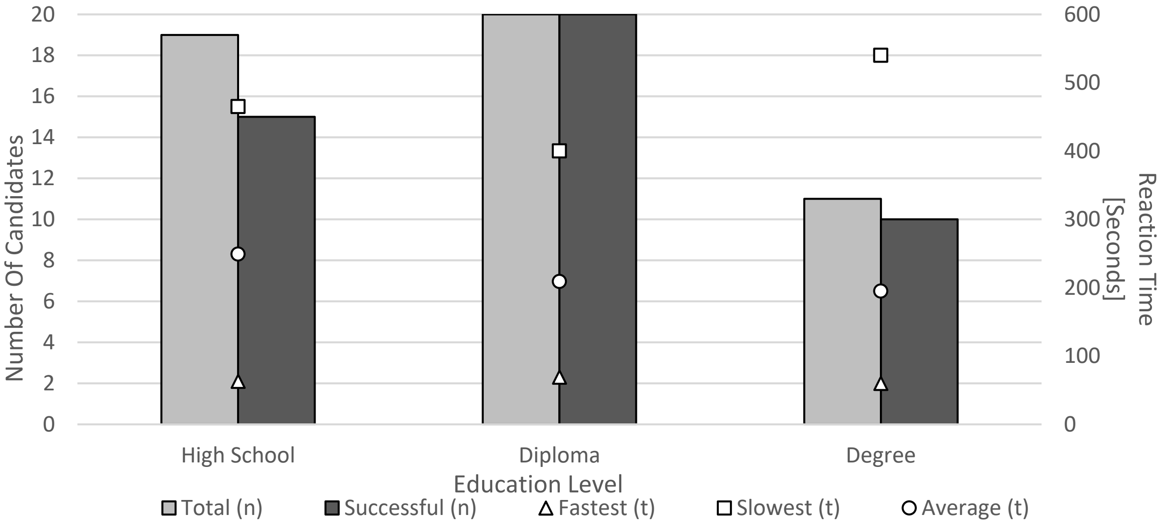


Figure 6.12: Reaction Times for ROF Exercise by Education Level

As shown in Figure 6.14, for the gyro drift exercise, the largest pool of successful participants was from the Degree level, with seven individuals, whereas the High School group provided the lowest number of successful participants, with three individuals. It should be noted that this group also contained the slowest reaction time, 553 seconds. However, the fastest reaction time belonged to the Diploma pool, 213 seconds.

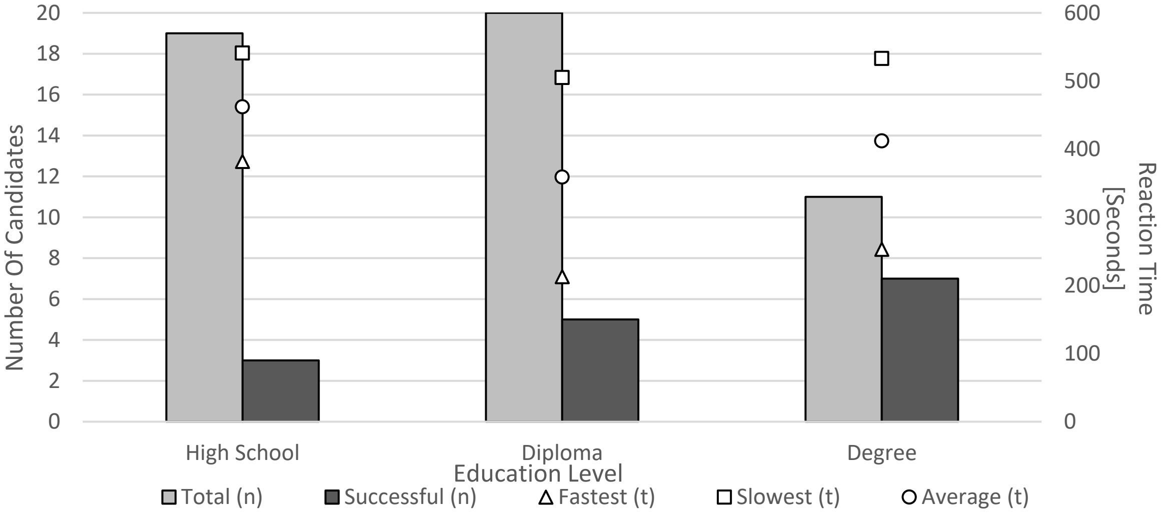


Figure 6.13: Reaction Times for GDF Exercise by Education Level

6.4.2 Fault Diagnosis

The use of human test participants created a multitude of event pathways that were created in detecting the various faults. Therefore, an ETA was conducted for each exercise, enabling each possible outcome and its probability to be analysed. The use of an ETA allows a logic diagram to be designed to analyse the sequential events deriving from the initial fault. Each diagram highlights the frequency of occurrence of each individual event (Punnoose, 2018). A standard event tree is shown in Figure 6.14.

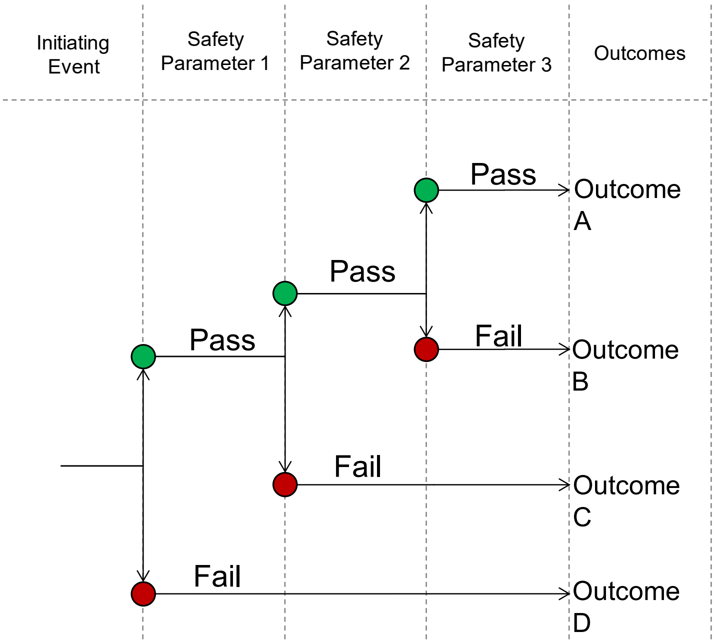


Figure 6.14: Standard Event Tree Logic Diagram

Each ETA shows an accidental event which can be defined as a significant deviation from the expected situation resulting in an unwanted consequence, therefore leaving the participant with multiple outcomes depending on their decision making. Each exercise consisted of a variety of safety barriers that assisted the participant, similar to what the participant would expect when conducting a navigational watch. The combinations of results from the ETA provide an insight into the variety of failure modes located within each exercise.

For each individual exercise, the following method was conducted to ensure that the ETA was constructed accurately and therefore highlighting the safety barriers and outcomes:

- Define the initial event that may cause an undesirable outcome
- Define the safety barriers installed to negate unwarranted consequences
- Design the event tree using the safety barriers and outcomes in sequential order
- Identify the number of participants that took the specified course of action in diagnosing the fault.

6.4.2.1 Fire Alarm

As shown in Figure 6.11 the event which most participants struggled with was turning the FA panel to test mode. By putting the FA panel into test mode, the participant would have been able to complete their work and conduct their watch safely without the constant distraction of having to silence alarms individually.

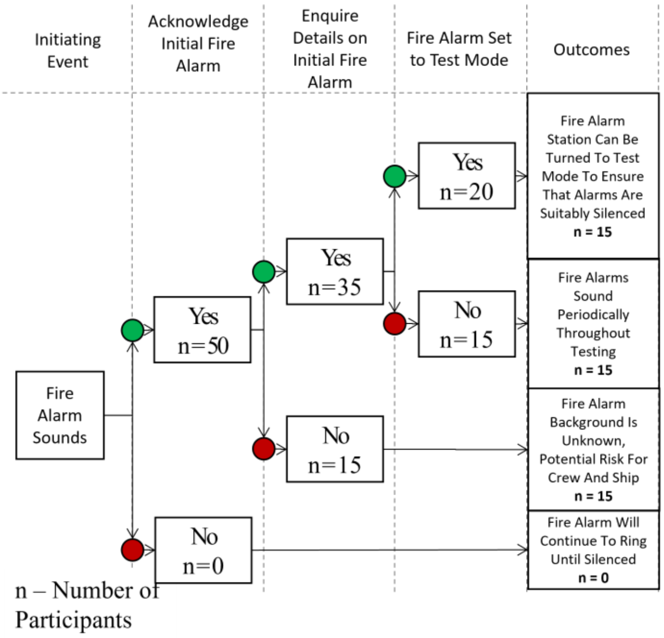


Figure 6.15: Event Tree for FA Exercise for All Participants

When assessing the participants with an onboard rank of OOW, it was found that all OOW participants successfully reacted and requested further details on the FA, as can be seen in Figure 6.16. Moreover, the majority of OOW participants successfully switched the FA panel into fire test mode, thus acknowledging subsequent alarms.

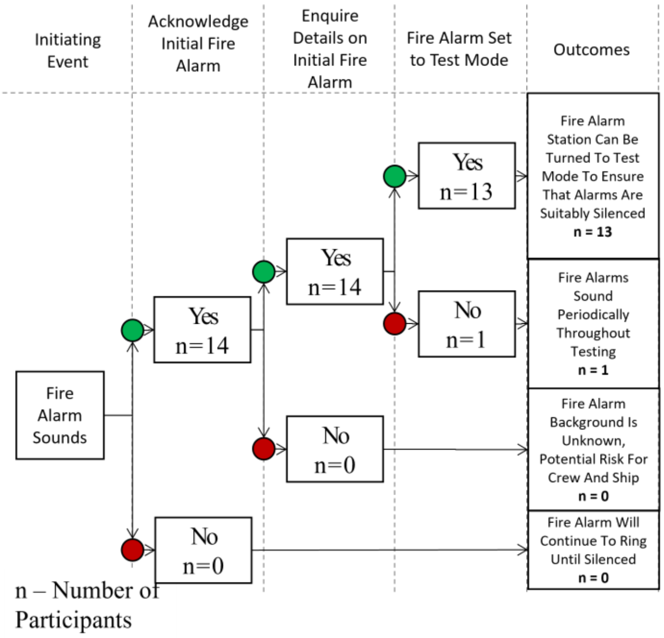


Figure 6.16: Event Tree for FA Exercise for Qualified Participants

6.4.2.2 Rudder Offset

It can be seen from Figure 6.17 that a large proportion of participants failed to carry out a main engine slowdown. Had the participant conducted a main engine slow down then the resultant outcome would have been reduced and the course deviation would have been minimised, thus resulting in a successful yet non-desirable result.

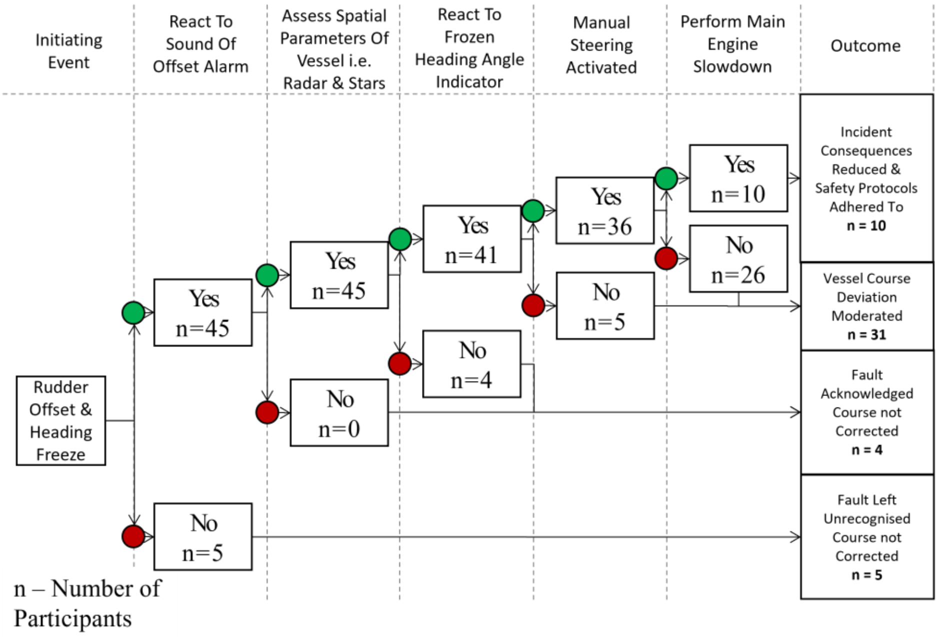


Figure 6.17: Event Tree for ROF Exercise for All Participants

When looking at the qualified officers only, it can be seen in Figure 6.18 that all of the OOW participants successfully overcame all the safety barriers preceding activating the manual steering. However, it can be seen that the qualified officers faced difficulties when performing a main engine slowdown to assess the fault.

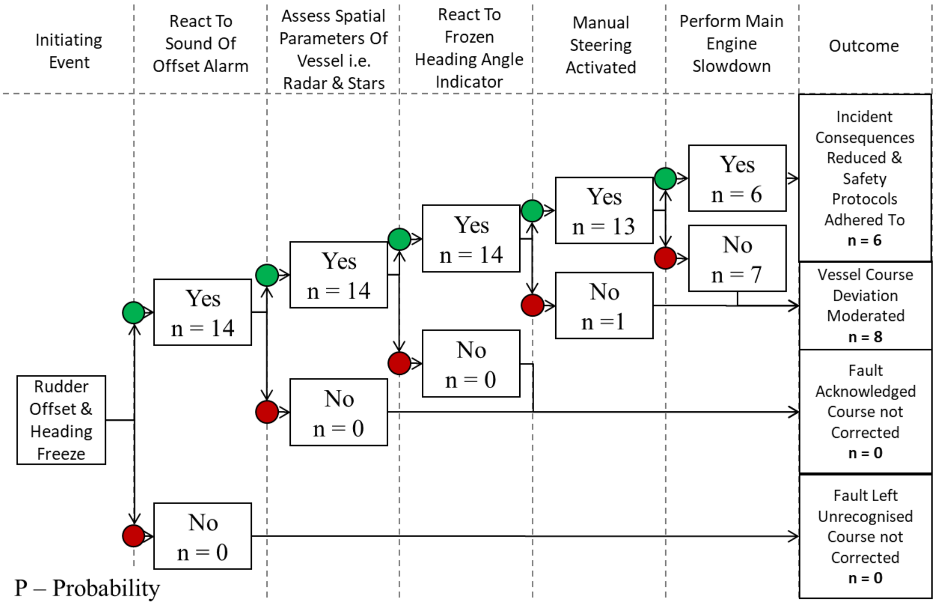


Figure 6.18: Event Tree for ROF Exercise for Qualified Participants

6.4.2.3 Gyro Drift

As seen in Figure 6.19, as the participants progressed through the exercise the number that were successful in diagnosing the gyro drift fault greatly reduced through the occurrence of each successive event. Six participants navigated the exercise by choosing the correct, safest pathway for both crew and vessel.

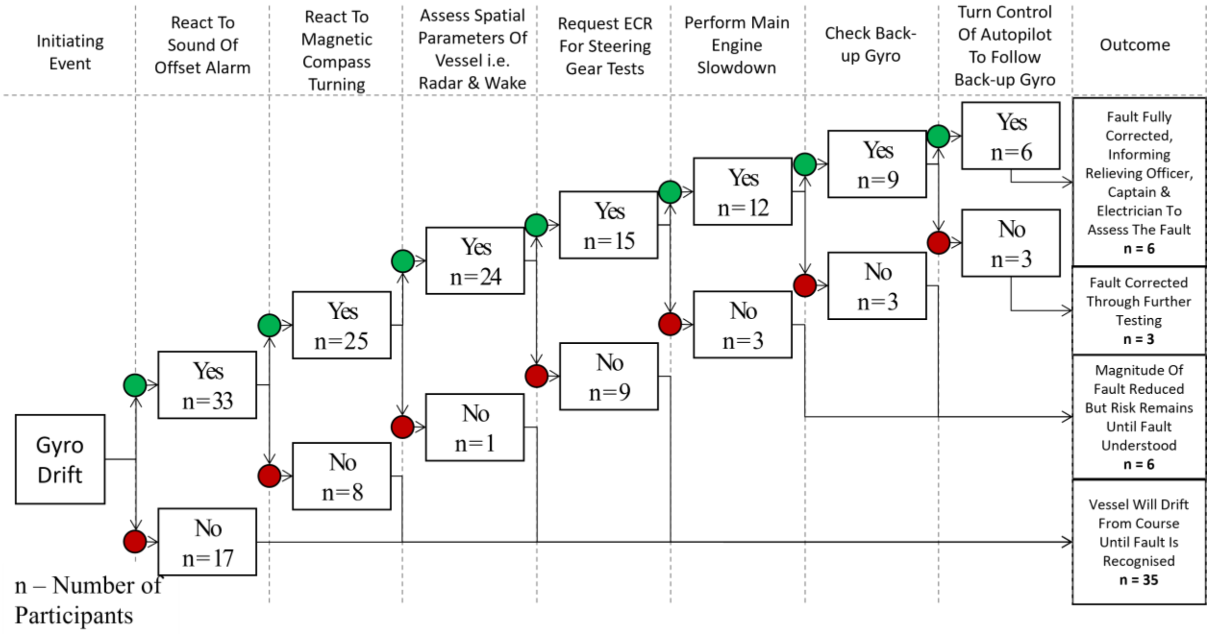


Figure 6.19: Event Tree for GDF Exercise for All Participants

As seen in Figure 6.20 all OOW participants performed successfully until reacting to the spatial parameters of the exercise. The participants began to falter in requesting steering gear tests and assessing the back-up gyro, both safety barriers which would have aided the diagnosis of a gyro drift.

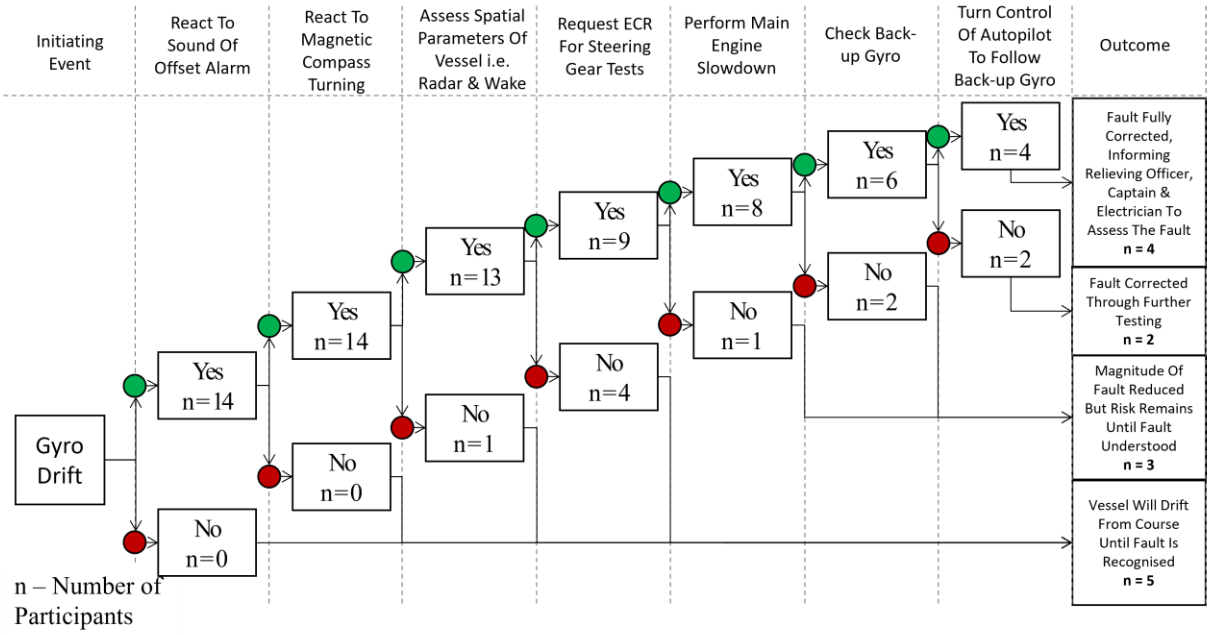


Figure 6.20: Event Tree for GDF Exercise for Qualified Participants

6.4.3 Maritime Officer Questionnaire

The responses from the MOQ provided a deeper insight into the participants’ knowledge base on autonomous shipping as well as providing the participants with a platform to express their personal views and opinions on autonomous shipping. By adopting a similar approach to the statistical analysis discussed in Chapter 4, it was possible to identify areas of interest in the results of the seafaring questionnaire. To analyse the Likert scale questions the statistical analysis that was opted for was a table of means.

6.4.3.1 Overview

In addition to the Likert scale questions, a different approach was taken to allow the participants to display their understanding of autonomous shipping and systems. As shown in Table 6.7 almost half of the participants have experienced an automated fault on the bridge and have an understanding on what autonomy is, whereas the vast majority of participants have undergone a form of alarm management training in their career.

Table 6.7: Participant Responses to Automation Experience Questions

Questions	**n**	
	Yes	**No**
Have you experienced a fault or error from any automated system on the bridge?	22	28
Have you undertaken alarm management training	40	10
Are you aware of the differences between autonomy and automation?	24	26

6.4.3.2 Age

When isolating the participants' age as the independent variable, it was found that age did not greatly factor into reasoning for the participant's response as all age groups tended to respond in a similar manner. The table of means shown in Table 6.8, displays the mean value of the Likert scale per question by age group.

Table 6.8: Participant Response to MOQ by Age Group

Question	**Views on Autonomy**			
	21 & under	**22 – 25**	**26 – 29**	**30 & over**
1	4.4	3.8	4.1	3.8
2	2.9	3.1	2.9	2.8
3	4.6	4.5	4.5	4.9
4	3.3	3.5	4.3	4.5
5	4.3	4.4	4.6	4.3
6	3.8	4.2	3.8	3.8
7	3.9	2.8	2.9	3.3
8	4.4	4.6	4.1	4.6
9	3.2	3.5	2.9	3.3
	Trust in Autonomy			
1	4.0	3.3	3.5	3.8
2	3.3	3.9	3.1	3.1
3	4.1	4.0	3.7	3.8

6.4.3.3 Rank

Isolating the participants' rank as the independent variable delivered the most diverse mean score among the responses. As can be seen in Table 6.9, lower ranked participants tended to be more receptive to the introduction of autonomous shipping from questions 1 and 7 of "*Views* *on Autonomy"*, whereas participants of higher rank answered in a manner that delivered a more undecided view on autonomous systems.

Table 6.9: Participant Response to MOQ by Rank

Question	CP1	CP3	CP5	AC	3/O	2/O
	Views on Autonomy					
1	4.5	4.3	4.2	4.1	4.0	3.1
2	2.5	4.3	2.8	3.4	2.5	3.1
3	4.4	4.7	4.6	4.9	5.0	4.3
4	3.3	3.3	3.5	4.1	4.3	4.6
5	4.1	5.0	4.2	4.8	4.7	4.4
6	3.4	5.0	3.7	4.6	4.0	3.6
7	3.7	3.3	3.1	3.8	3.3	2.5
8	4.1	4.3	4.6	4.0	4.8	4.8
9	3.4	3.3	3.2	2.6	3.0	3.5
	Trust in Autonomy					
1	3.7	3.0	3.8	4.1	3.3	3.4
2	3.3	2.3	3.5	2.9	3.8	3.6
3	4.0	3.3	3.8	4.9	4.0	3.3

6.4.3.4 Education Level

Table 6.10 shows the variation in mean score of responses from the participants, according to education level. As shown from this table of means, participants with high school education level were more receptive to the introduction of autonomous systems. However, all participant groups answered favourably towards autonomous systems, in both views and trust in autonomy sections.

Table 6.10: Participant Response to MOQ by Education Level

Question	High School	Diploma	Degree
		Views on Autonomy	
1	4.5	3.8	3.9
2	3.1	3.2	2.3
3	4.5	4.6	4.8
4	3.4	4.4	3.4
5	4.4	4.6	4.0
6	4.0	3.7	4.1
7	3.7	3.0	3.0
8	4.3	4.4	4.5
9	3.2	3.4	2.9
		Trust in Autonomy	
1	3.8	3.5	3.6
2	3.1	3.5	3.6
3	4.1	4.0	3.5

6.5 Findings

With the direction of the maritime industry tending towards autonomous operations, similar studies have been conducted using small sample pools (Pazouki, et al., 2018). It was crucial for this study to develop a rich participant pool with a diverse demographic. Additionally, a key element of the study was to ensure that the participants had a fundamental knowledge of navigational operations as with the previous studies within this thesis and past research. From the 50 participants assessed, 90% successfully recognised and acted on a mechanical fault which was causing a course deviation. However, only 30% of participants successfully reacted to the course deviation stemming from an automated fault. Nevertheless, it may be argued that if the participants were given longer to acknowledge the fault, then more subjects could have recognised it and reacted accordingly.

In addition to the gyro displaying a fault on the vessel's radar, the participants would have also seen that the indicator read the same heading, indicating that there was nothing wrong with the course which the vessel was undertaking. The majority of participants completed their work packages following the successful passage of the oncoming vessel, only briefly looking at the radar to validate their actions and trusting that the autopilot system was operating correctly. Thus, the participants became vulnerable to automation complacency, defined as a degradation of human detection of automated system malfunctions (Parasuraman and Manzey 2010).

The inclusion of the MOQ, as a complimentary study allowed for a further dimension to be analysed in comparison to the SJQs designed for Chapter 4. Aspects such as trust in autonomy were apparent through both in the simulator exercises and the participants' responses to the MOQ. Moreover, it can be seen from the MOQ that participants value the position of the OOW and the consensus among participants favoured the idea that *"Neither autonomy nor automation can replace the need for seafarers"* however, the results of the automated fault in the simulator highlighted that there is a bias towards automation.

Of the 15 participants who successfully reacted to the course alteration caused by the automated fault, only 8 reacted to the fault prior to the sounding of the off track autopilot alarm. Among the participants who reacted successfully, a common trait was to change the control of the vessel to manual operation, correct the course and then turn the control of the vessel back to the ship's autopilot. As seen in the case of the grounding of the Lauren Hansen, if a fault with the vessel's autopilot system is overlooked or not repaired, then the consequences could result in an incident as serious as the vessel running aground or worse (Australian Transport Safety Bureau, 2018). The ship's autopilot and navigational systems only operate as efficiently as the operator in control of the system.

As previously highlighted within Chapter 4, Table 4.4, it was found that there was a positive correlation between the Rank, Age and Educational Level of an individual, suggesting that older participants were higher in rank and education. Nevertheless, it was critical to understand if such demographic variables were pertinent to success of the individual in recognising the failures within each exercise. As such, the findings from the ROF exercise, shown in Figures 6.6, 6.8, 6.10 and 6.12 have shown that the younger participants with less education and of a lower rank were less successful. However, in general all participant groups performed adequately and recognised the failure. Whereas the GDF exercise findings, shown in Figures 6.7, 6.9, 6.11 and 6.13, highlighted that to recognise an automated failure, the demographic variables had some influence in the participants success. This suggests that there is a link between the success in fault recognition and the Age, Rank and Education Level of a participant. As such this link will be further explored within Chapter 7, however due to the positive linear correlation between the variables only the participants Rank will be further analysed.

By implementing the ETA, it was possible to further analyse the detail of how each candidate performed during the exercises. Due to the complexity of each exercise, using ETA allowed for a greater understanding of how candidates performed when confronted with different safety barriers which they had to overcome. Additionally, the ETA charts in Figures 6.15 – 6.20 show that despite there being a variety of potential outcomes, an understanding can be developed of which event path was the most common among the candidates. The GDF and ROF exercises highlight that even qualified officers are still susceptible to making similar mistakes to the less experienced candidates.

The aim of this study was to utilise independent variables identified within Chapter 4 such as Educational Level, Age, Sea Experience and Rank. However, when testing each of these variables against the fault recognition of participants, it was found that the participants’ rank was the most influential demographic variable. Therefore, by using this as a foundation for future research it would be possible to assess the methods of training for participants.

6.6 Methodological Implications

While at sea operators are expected to work for two 4 hour watches within a 24 hour period. As these exercises were each 20 minutes, they do not offer a full perspective of how operators may react, when presented with an issue, over the course of a standard 4 hour navigational watch. Maritime simulators, while proving to be a beneficial training tool, can be limited in their capacity due to the operator being in a simulated environment versus a real-world scenario. Additionally, had the candidate pool been larger it would have been possible to gain a greater understanding of the possibility of SA being more apparent in different candidate demographics.

One potential issue with an experiment such as this could be the overall time limit of the exercises. It can be argued if participants were given a longer period of time to react to an issue, then it may be possible that they could correct it. However, a counter to that would be that malfunctions are not regular and tend to crop up at the most inopportune of times. Furthermore, an error such as this may appear at any point throughout an officer’s watch.

Recording the reactions of each participant presented a challenge due to the various simulator exercises being conducted simultaneously. This could be improved for future research by developing a response workbook for each participant prior to entry into the simulator. However, the value of this study should not be overlooked as it has allowed for the design of such items for supporting further studies within this thesis.

Ultimately, the MOQ may have failed to capture the participants’ true opinions of autonomy due to the location of the MOQ station in the study, as aspects of the other simulator exercises may have influenced the results of MOQ. Moreover, by creating questions with a 5 point Likert scale, the responses from participants did not offer as rich a data set as the 7 point Likert scale questions, designed for Chapter 4, had done. Therefore, the Likert scale questions for the ensuing study will be designed using a 7 point answering scale.

6.7 Chapter Conclusion

Developing a simulator-based study, allowed for the researcher to identify concerns with the fault recognition and diagnosis skills of navigational officers. These skills could ultimately define how impactful the introduction of autonomous systems is on the maritime industry. This study aimed to answer research questions presented in Chapter 1, which aided in the construction of the hypotheses for this study. Fundamentally this study has shown that participants, despite their age, rank or educational background, are susceptible to relying on the automated system when distracted on the bridge. With autonomous shipping being introduced it is expected, as introduced in Chapter 5, that the OOW role will evolve to a more supervisory role, which this study has shown will prove to be another hurdle for the industry to overcome.

This chapter detailed the work that, using previous research ideas and studies within this thesis, allowed for the development of a simulator based human factors study. While this study has provided an insight into the SA of the OOW, it also identified that further work is needed with regard to training packages and automated faults. Chapter 7 will therefore utilise the studies conducted within Chapters 4, 5 and 6 to develop a final simulator study that focuses on automated faults and the impact of training.

Chapter 7. Final Study

7.1 Introduction

The following chapter introduces and details the fourth and final study conducted for this thesis. The chapter details the development preparation, execution, findings, and statistical analysis of the results of the final simulator study. As with all studies in this thesis, the individuals chosen to participate within this study were to have a seafaring background and have accumulated a minimum of 12 months navigational bridge watchkeeping time. For this chapter, participants were requested to undergo a bridge watchkeeping simulation exercise and PES. Following the analysis of the study, this chapter will address the remaining research questions that were identified in the thesis and the impact that the design and findings of the study will have on the maritime industry. Furthermore, this chapter will conclude with the methodological limitations and how the study could be improved for future research.

As the maritime industry looks to implement autonomous systems within the foreseeable future, navigational officers must be equipped with the knowledge of how to utilise future systems and how to successfully diagnose and troubleshoot faults which may arise. Autonomy may lead the way towards unmanned vessels, which could result in the extinction of one of man’s oldest professions. Therefore, the maritime industry must do what is necessary to aid the current and future workforce of the industry to develop their skills to allow the seafaring profession to continually develop.

The *Survey Study* identified multiple opinions and concerns that seafarers have regarding autonomous shipping. From career worries to opinions on modern day automation technology the participants of the *Survey Study* delivered a rich data set which was used as a foundation in the development of the subsequent PES that was utilised to compliment this simulator study. Because a similar question set was implemented, it was possible to adopt the statistical tests utilised in the *Survey Study* to analyse the results of the PES.

The *Interview Study* highlighted the intrigue and enthusiasm, that both seafarers and industry experts have towards autonomous shipping. The development of autonomous shipping will look to evolve the seafaring profession and develop new jobs within the industry for young people. With the industry looking to adopt one of its most impactful transitions since the introduction of the diesel engine, the participants of the *Interview Study* appear to have a welcoming response towards autonomous shipping. However, the interest was not without apprehension. The *Interview Study* introduced themes such as the MET sector and reliance on technology. Prior to the introduction of autonomous shipping, the MET must address issues with the current navigational officer curriculum, including outdated subjects such as celestial navigation and paper chartwork. Moreover, seafarers are aware of various factors that can influence the success of a navigational watch. From external pressures such as working in isolation and paperwork, in addition to human factors impacting automation and autonomy such as bias, complacency, alarm fatigue and an over reliance in decision making technology; there are multiple difficulties that the OOW can encounter during their watch. Therefore, the final simulator study will look to address the topic of training, by developing two different training videos to understand what subjects can be of benefit to the fault recognition skills of an individual. Additionally, creating a fault with the autopilot system in the simulator will aim to highlight the human factors issues raised by participants of the *Interview Study*, as it is expected that a number of participants of the *Final Study* will encounter the trials and tribulations of the human factors highlighted from the *Interview Study*.

The *Pilot Study* defined multiple simulator exercises for participants to undertake. The findings of the *Pilot Study* identified that while individuals were proficient in acknowledging a manual based fault, the introduction of an automated fault would ultimately cause uncertainty and result in the majority of participants disregarding visual and auditory cues that indicated the existence of a fault. Therefore, the *Final Study* will aim to develop a deeper study using the same automated gyro drift fault as the *Pilot Study* as the foundation for the simulator exercise. Adapting the exercise to allow the participants more time, increasing the participant pool and introducing stringent participant selection criteria will result in an extensive study which the maritime industry can review, in time, preceding the introduction of autonomous shipping.

Concurrently this study intends to utilise the findings of the previous studies to develop a final simulator study that will endeavour to identify a training method that can benefit seafarers. This chapter looks to answer the research questions specific to this study, with the main body of this chapter outlining the procedure, describing the data analysis, and documenting the findings of this study. The chapter will then conclude with the impact that this study can have for the maritime industry and how the use of simulators can benefit MET in the introduction of autonomous shipping.

7.2 Study Design

Each chapter prior to this study identified various themes and topics that it is recommended the maritime industry addresses prior to the introduction of autonomous shipping. The gyro drift exercise of the *Pilot Study* has then been used as the basis for the simulator exercise in the *Final Study*.

The aim of the *Final Study* is to develop a simulator exercise that may be used as a foundation for the maritime industry to help train and teach both current and future navigational officers about autonomous shipping. The exercise implemented a fault within a perceived to be reliable automated system, the autopilot, during a standard navigational watchkeeping exercise and documented the actions of participants during the exercise. Additionally, participants received a training video package prior to entering the simulator suite to develop an understanding of whether the training that an individual receives prior to the exercise can influence the skills being assessed. Use of a training video package allowed participants to be split into two groups, one which received a behavioural video package and the other which received a technical training package. Following the conclusion of the exercise, participants were issued with a PES to allow individuals to document their findings should any action go unnoticed in the exercise.

The design process of this study identified multiple hypotheses, which allowed this study to answer both RQ4 and RQ6 of this thesis. Introducing the following hypotheses would shape the direction and design of the study and develop a foundation exercise that could be used for future training courses to be developed by the maritime industry.

- Hypothesis 1 – The inclusion of multiple alarms and work will result in various distractions for the human operator and be detrimental to the individual’s fault recognition and diagnostic skills.
- Hypothesis 2 – Participants receiving the behavioural video training package will be more receptive to the exercise fault, resulting in an increased number of individuals recognising and successfully diagnosing the fault in comparison to the participants receiving the technical video training package.
- Hypothesis 3 – Participants who are successful in recognising the automated fault will experience an increased workload during the exercise in comparison to the participants who did not recognise the fault.
- Hypothesis 4 – Participants of a higher rank will be more alert in recognising and diagnosing the automated system fault.

7.3 Method

With other studies highlighting the impact that behavioural traits, such as AB, complacency, and SA (Lee & See, 2004), have within the human automation relationship, it was key to develop an exercise that identified whether such behavioural traits were present among a larger cohort of participants. Therefore, the final simulator study was designed with the aim to assess whether behavioural traits affected the watchkeeping skills of individuals of varying ranks.

Additionally, it was imperative to identify the behavioural impact of different training packages and their effect on an individual prior to a navigational watch.

For the study, it was important that all participants had sailed and acquired a minimum of 12 months navigational watchkeeping. This would then allow all participants to come into the bridge watchkeeping simulator and conduct a watch in accordance with Marine Guidance Notice (MGN) 315: Keeping a Safe Navigational Watch. The final simulator study consists of two main components:

- The simulator exercise
- Post exercise survey

7.3.1 *Materials*

The aim of the *Final Study* was to assess whether automated navigational systems, deemed to be highly reliable by seafarers and the maritime industry, provide the trained operator with a significant amount of reassurance, such that, should the system begin to fail it would go unnoticed by the operator. By using the *Pilot Study* as a foundation, the GDF was used as the fault for the *Final Study*. Figure 7.1 shows a block diagram of the systems that interact with the vessel’s autopilot. As can be seen from the diagram the vessel’s autopilot can be altered through the gyro compass, which is powered through batteries and a magnetron. In the event of a faulty magnetron the gyro compass will begin to display a weakened heading reference which will cause a course deviation.

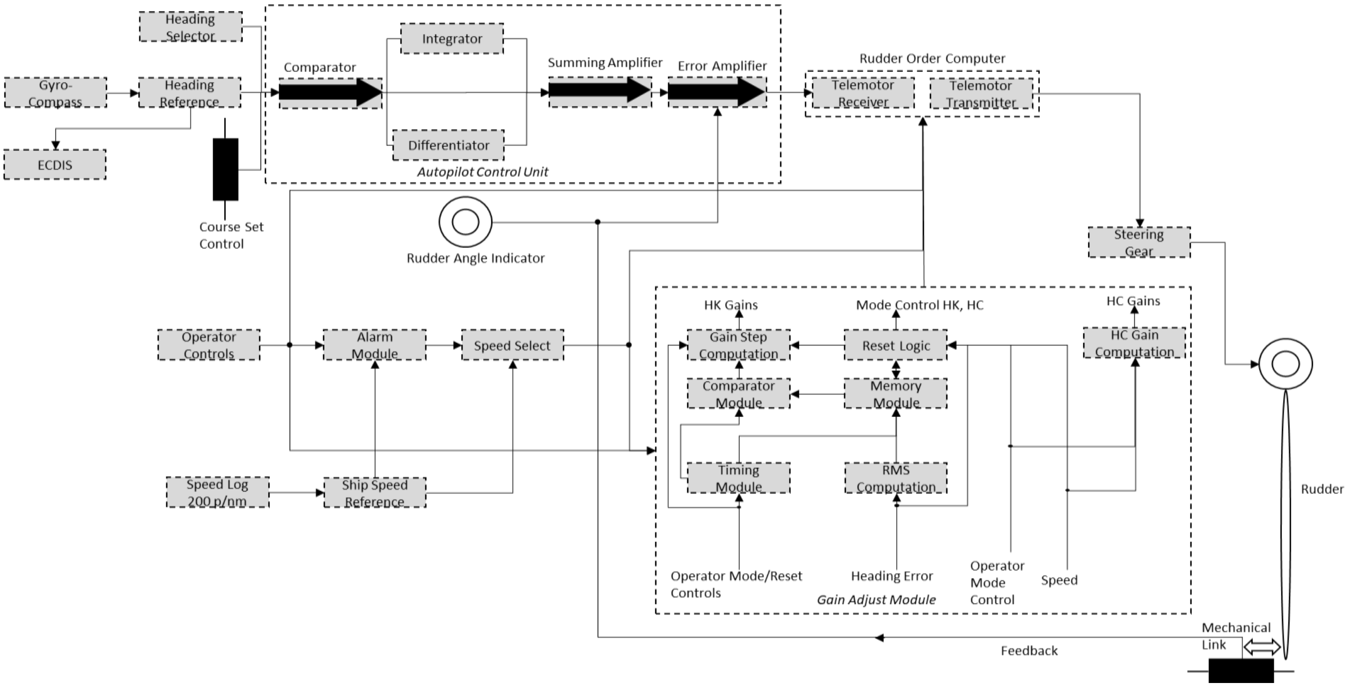


Figure 7.1: Autopilot System Block Diagram

Due to the difficulties faced by the participants in the *Pilot Study,* a fault tree analysis (FTA) as conducted to identify the root cause of a course deviation. From the FTA shown in Figure 7.2, various aspects can attribute to a course deviation. Many of the outcomes from the FTA are devised through the inclusion of AND/OR logic gates. However, it should be noted that the symptom leading to the error is not limited to the logic gate preceding the fault. For example, when looking at the “Weakened Alertness” it can be seen that the symptoms preceding this fault is a combination of “Distractions” and “Fatigue”. As it is understood, both symptoms individually can contribute to the “Weakened Alertness” fault however combining the symptoms will increase the chance of the fault occurring. From the *Pilot Study* the GDF proved to be the challenging fault to recognise and diagnose. Henceforth the FTA identifies the circumstances that cause the GDF, and it can be seen that a course deviation can transpire from a transmission error, which would develop from a faulty magnetron. This pathway is highlighted in red in Figure 7.2.

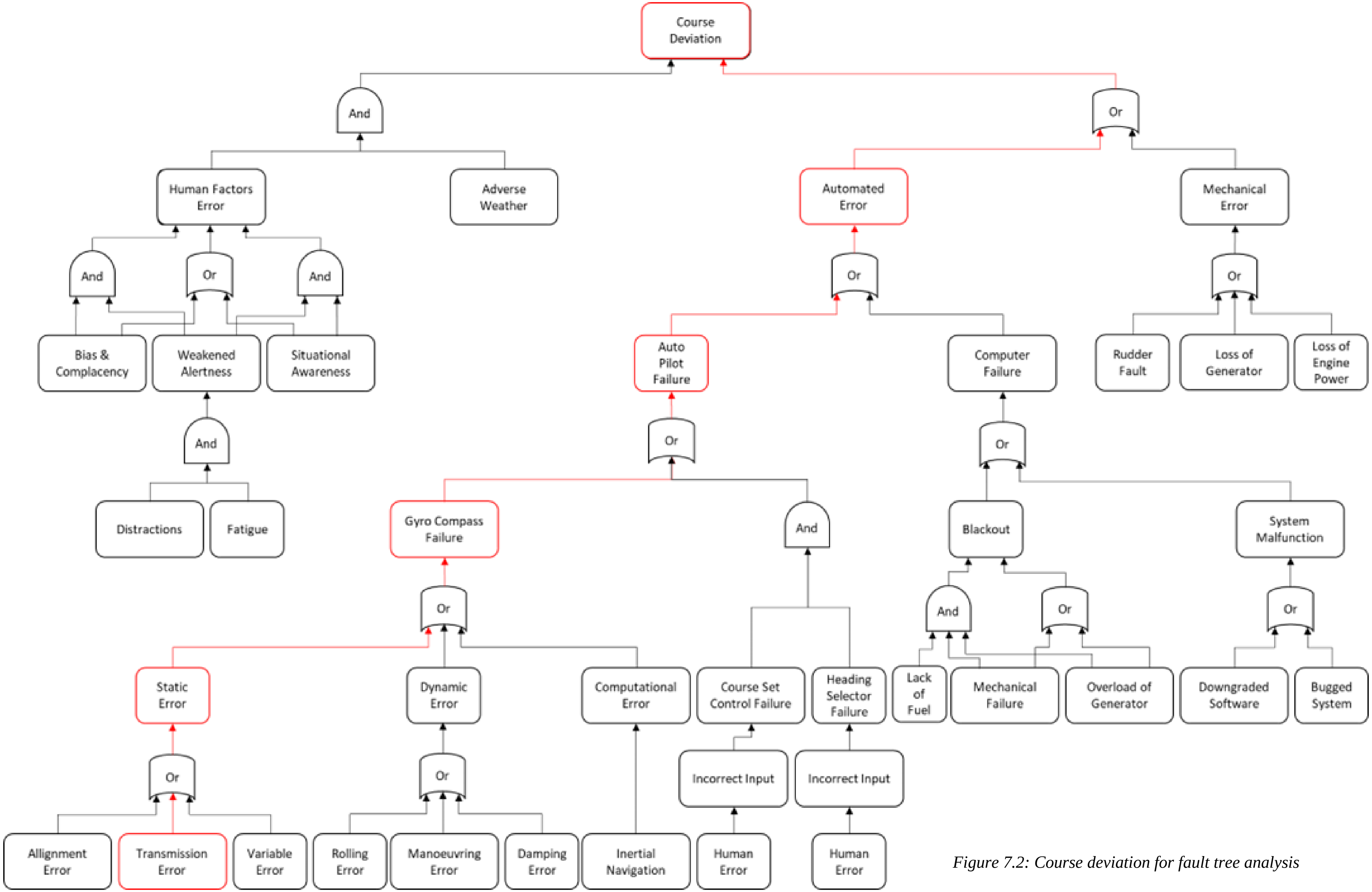


Figure 7.2: Course deviation for fault tree analysis

Once the main fault had been identified for the exercise, it was then important to ensure that the bridge watch simulator set up closely simulated a working bridge watchkeeping environment. Therefore, various alarm sounds, including echo sounder alarms and doppler log alarms, were added to the simulation.

Beyond the set-up of the bridge simulator, all participants would be issued a work pack containing the following items:

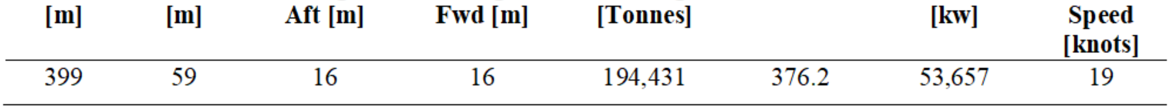
- Non-descriptive quizzes to imitate wheelhouse based paperwork;
- A ship particulars worksheet;
- A vessel logbook.

Issuing the work pack would simulate daily routine paperwork expected to be completed by officers on their watch. The work pack simulated onboard paperwork, thus increasing the fidelity of the simulation as it recreated an immersive environment. The intention of the work pack was to analyse the participant’s prioritisation of their work, i.e., the emphasis placed on completing the work pack verses the concentration given to ensure that the watch is as safe as possible. The key objective of the navigational watchkeeping simulation exercises was to understand whether the onboard autopilot system affects the judgement of the participant with regard to their abilities to conduct a safe navigational watch as per the requirements of MGN 315.

The structure of the exercise closely followed the previous exercises created for the *Pilot Study*. One of the identified methodological implications that was considered was the length of the exercise, as some participants had begun to recognise the occurrence of the GDF in the *Pilot Study* towards the end of the exercise, without acting on the failure . As such, the duration of the exercise, for the *Final Study*, was increased from 20 minutes to 30 minutes, to assess whether the fault recognition rate could be improved given a longer exercise time. The exercise was carried out using the same simulator setup as the *Pilot Study*, Kongsberg secondary bridge suites. The only difference in the bridge design was that for this exercise the software used had been upgraded to the Kongsberg K-Sim® Navigation software. The vessel chosen for the exercise was the twin screw Maersk Majestic, 17,000 Twenty-foot Equivalent Unit (TEU) container vessel, which is defined as an Ultra Large Container Vessel (ULCV). By selecting this size of vessel, it ensured that all participants had to be aware of their surroundings due to the vessel being larger than average.

The mission of the vessel throughout the exercise was to maintain a course heading of 270 while travelling at a speed of 18 knots. Additionally, the vessel’s ECDIS had been configured to allow for a cross track limit of 1nm. Table 7.1 shows the ship particulars for the Maersk Majestic:

Table 7.1: Ship particulars for Maersk Majestic



L.O.A [m]	Beam [m]	Draught Aft [m]	Draught Fwd [m]	Deadweight [Tonnes]	L.P.P [m]	Max Power [kw]	Full Speed [knots]
399	59	16	16	194,431	376.2	53,657	19

Participants were given sufficient opportunities to correct any fault which they encountered both aurally, through the clicking of the magnetic compass and alarms ringing, and visually, through cloud patterns moving and vessels deviating from traffic positions. Throughout the exercises, the participants had full communication access to the control station, which they could use if they began to encounter difficulties. Additionally, every participant was monitored using CCTV and microphones which were active throughout each exercise. For each participant, a watch handover was conducted during the mission brief. The handover consisted of telling the participants about the ship's position, traffic density and the weather conditions. Throughout the exercise, the participant was the only person present in the simulator suite, unless they requested the presence of a look out. The parameters for both traffic vessels encountered in the exercise are shown in Table 7.2.

Table 7.2: Parameters of traffic vessels encountered in Final Study exercise

Vessel	Distance [Nm]	Bearing	Speed [knots]	Heading
001	7	045	20	110
002	18	300	12	240

7.3.2 Procedure

Upon entering the simulator suite, the participant would find a pilot card and ship particulars list on the workbench that would allow them to fill in their paperwork over the duration of the exercise. Once the exercise had begun, the vessel would be under autopilot control and the participant would then be allowed to alter the position of the vessel to suit their watch. Alarms were scheduled to sound every 5 minutes to replicate the sounds that the participant can expect on the bridge. However, after 12 minutes and 30 second the vessel would begin to deviate from its course due to a GDF. From the start of the failure the vessel would drift to port at 1 degree per minute until it achieved a 20 degree course deviation. If left unaltered the vessel would then sound an alarm at 25 minutes into the exercise to alert the participant that the cross track limit had been exceeded, prompting the participant to investigate the fault. Should the participant identify or correct the fault then the time for the participant would be recorded as the number of seconds from the fault initiation to fault correction. Hence should a participant fail to identify the fault then that participant would receive a time score of 1050 seconds.

Figure 7.3 shows the radar plot at a range of 12nm delivered by the gyro compass. As can be seen, the vessel's trajectory is set to travel along a course of 270 degrees and with one traffic vessel within it proximity.

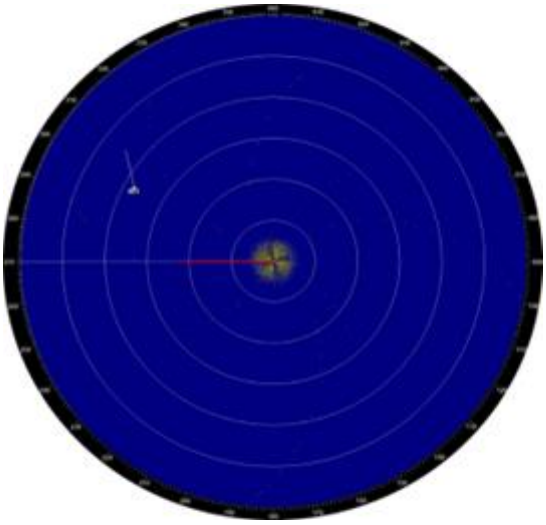
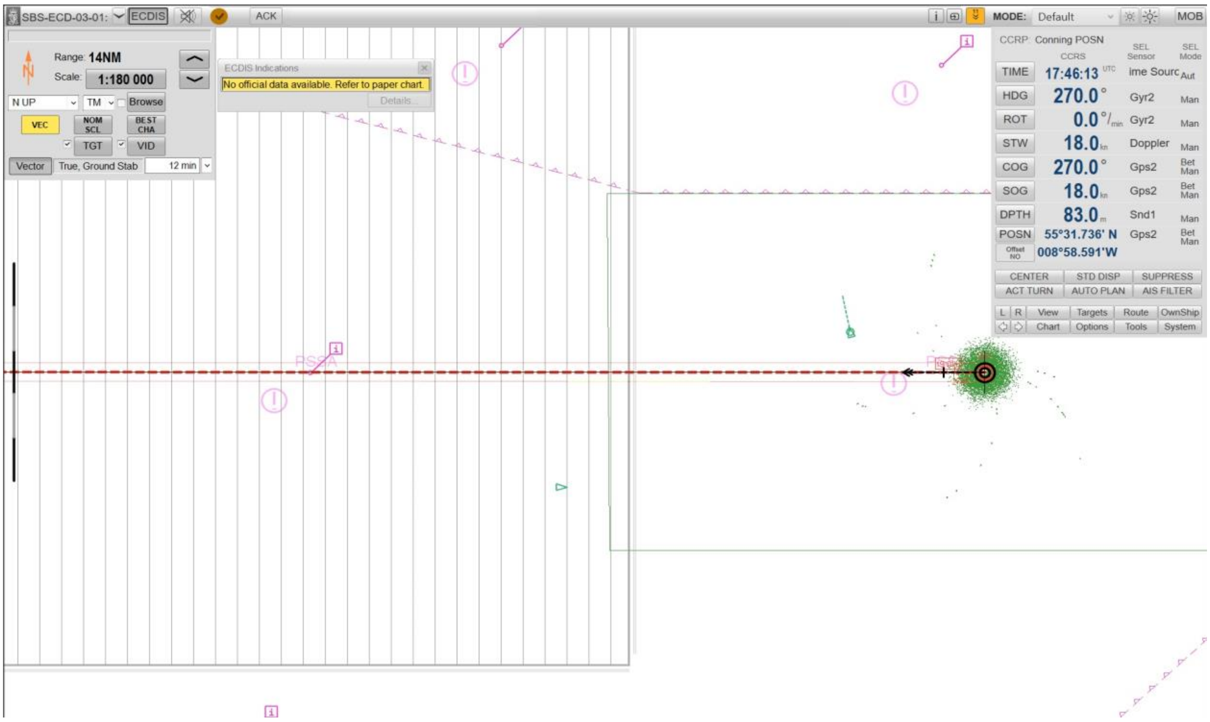


Figure 7.3: Radar Plot at Exercise Start

Furthermore, this is corroborated with the ECDIS view, at a range of 14nm, detailed in Figure 7.4. The ECIDS view details the speed of the vessel, the heading of the vessel with regard to the gyro compass positioning and the GPS readings.



SBS-ECD-03-01:

Range: 14NM

Scale: 1:180 000

N UP

TM

Vector True, Ground Stab 12 min

ECDIS Indications

No official data available. Refer to paper chart.

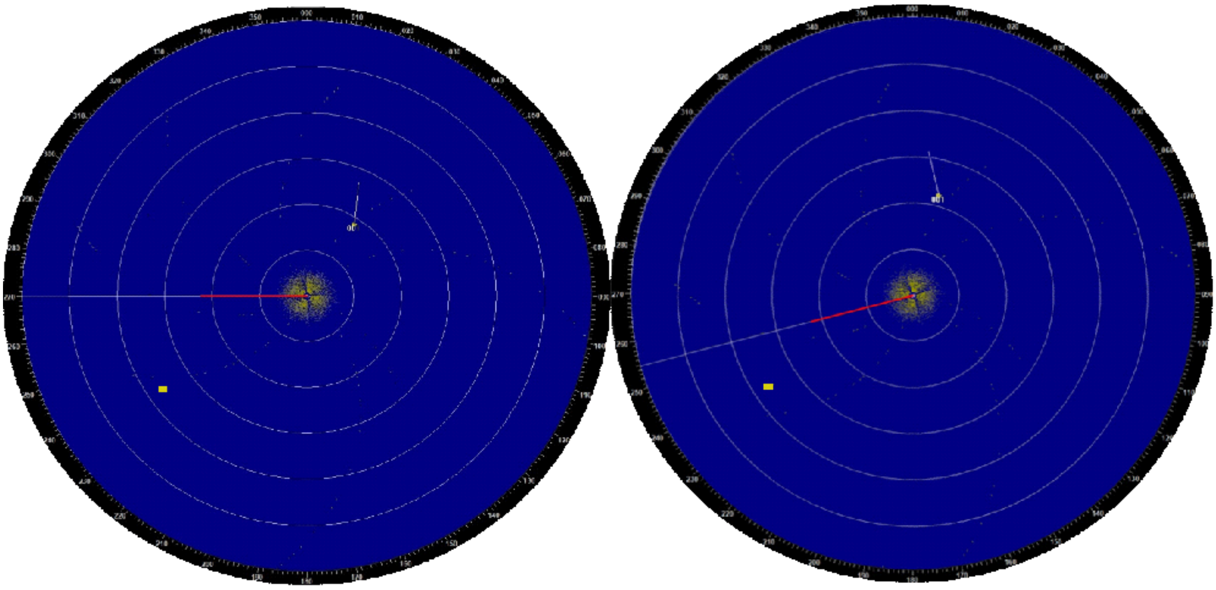
MODE: Default

CCRP: Conning POSN

	CCRS	SEL Sensor	SEL Mode
TIME	17:46:13 UTC	ime Sourc	Aut
HDG	270.0 °	Gyr2	Man
ROT	0.0 °/min	Gyr2	Man
STW	18.0 kn	Doppler	Man
COG	270.0 °	Gps2	Bet Man
SOG	18.0 kn	Gps2	Bet Man
DPTH	83.0 m	Snd1	Man
POSN	55°31.736' N 008°58.591'W	Gps2	Bet Man

Figure 7.4: ECDIS View at Exercise Start

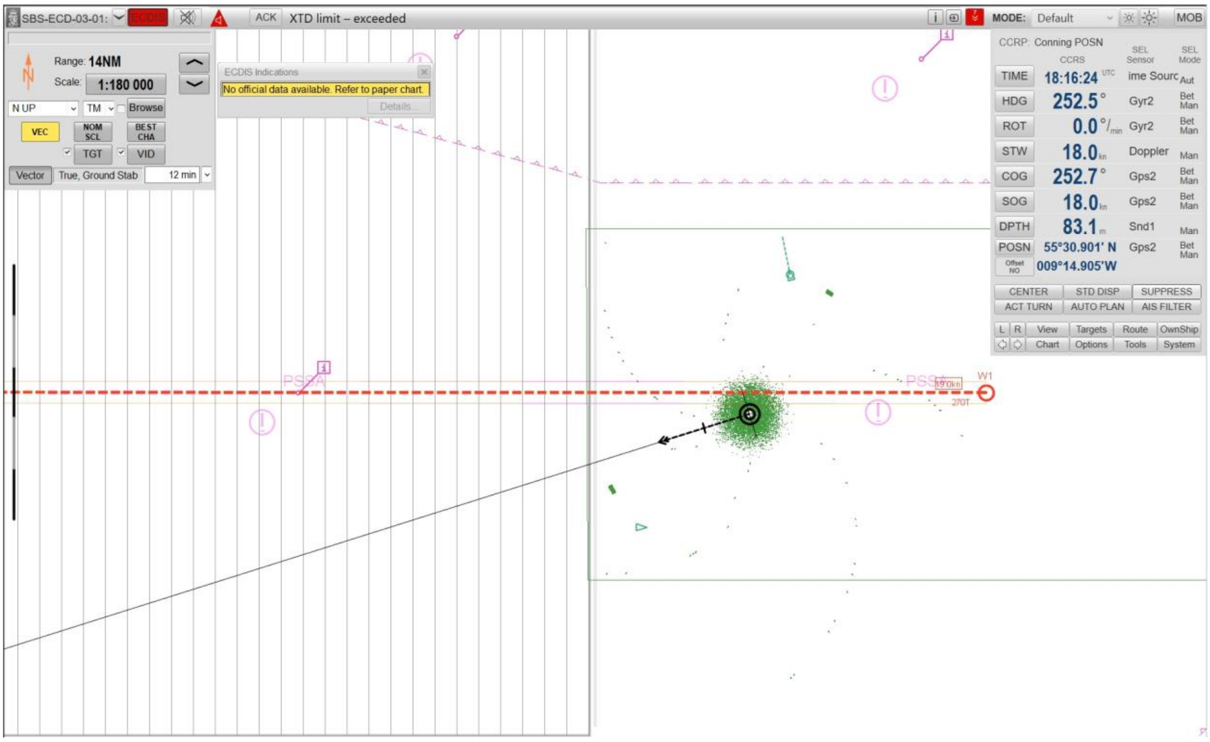
Figure 7.5 shows radar plots for the malfunctioning case, Gyro 1 {Figure 7.5 (a)}, and the working gyro compass, Gyro 2 {Figure 7.5 (b)}. As can be seen from Gyro 2, if the participant does not correct the gyro drift fault the vessel will have altered its course to a new heading of approximately 253 degrees. Moreover Gyro 1 shows the radar display for what the participant can see if they did not alter the view to show Gyro 2, which would indicate to the participant that the vessel is still maintaining a 270 degree heading.



(a) (b)

Figure 7.5: Radar Plots at Exercise End

The ECDIS plot shown in Figure 7.6 correlates to Gyro 2 from Figure 7.5 (b). From the ECDIS view it can be seen that the vessel has deviated from its intended course to a new heading of 252.7 degrees. Additionally, no other parameters would be altered if left untouched by the participant.



SBS-ECD-03-01:

XTD limit – exceeded

ECDIS Indications

No official data available. Refer to paper chart.

Range: 14NM

Scale: 1:180 000

N UP

TM

Vector True, Ground Stab 12 min

MODE: Default

CCRP: Conning POSN

	CCRS	SEL Sensor	SEL Mode
TIME	18:16:24 UTC	ime Sourc	Aut
HDG	252.5 °	Gyr2	Bet Man
ROT	0.0 °/min	Gyr2	Bet Man
STW	18.0 kn	Doppler	Man
COG	252.7 °	Gps2	Bet Man
SOG	18.0 kn	Gps2	Bet Man
DPTH	83.1 m	Snd1	Man
POSN	55°30.901' N 009°14.905'W	Gps2	Bet Man

Figure 7.6: ECDIS View for Exercise End

7.3.2.1 Training packages

The introduction of autonomous shipping and onboard systems has the potential to revolutionise the maritime industry, including the MET sector. Therefore, the intent of the design of the *Final Study* was to determine whether the fault recognition and diagnostic skills of seafarers can be improved by altering the training received prior to beginning the exercise.

For this study, two different types of training were delivered:

- Behavioural Training – A training package which includes information regarding the behavioural skills that will need to be developed for autonomous navigation. The main topics delivered within this training package include:
    - Situational Awareness – What SA is, how it can impact autonomy and how it can be improved.
    - Automation Bias – What AB is and how to combat AB.
    - Complacency – The dangers associated with complacency and how not to fall victim to it.
- Technical Training – A training package which includes information regarding the modern-day automated systems that may be used as the foundation for autonomous navigation. The main topics delivered within this training package include:
    - Autopilot – How the autopilot may be adapted for autonomous navigation.
    - ECDIS – How ECDIS can benefit future navigational autonomous systems.
    - Radar – The development of radar over time and how it can be adapted into a tool for autonomous shipping.

Once the training packages had been outlined, two 5-minute videos were developed using Microsoft PowerPoint to cover each training package, the contents of which are found in Appendices B and C. Following the recruitment of all participants, it was then imperative to ensure that they were categorised by rank and then issued one of the aforementioned training videos. By categorising the participants by rank it was then possible to ensure that the number of participants that received each video was split evenly among the ranking groups. Table 7.3 shows the variation of participants by rank and which training the individual received.

Table 7.3: Training video groups by rank

Participant Rank	Training Video Behavioural	Technical
Master	2	0
Chief Officer	3	5
2nd Officer	8	8
3rd Officer	2	2
Cadet	9	6
Rating to Officer	6	9
Total	30	30

7.3.3 Post Exercise Survey

Following the completion of the simulator exercise, participants were then issued a PES to assess the level of understanding that the individual had regarding the fault and requirements of the exercise. Figure 7.7 shows the overall survey structure map.

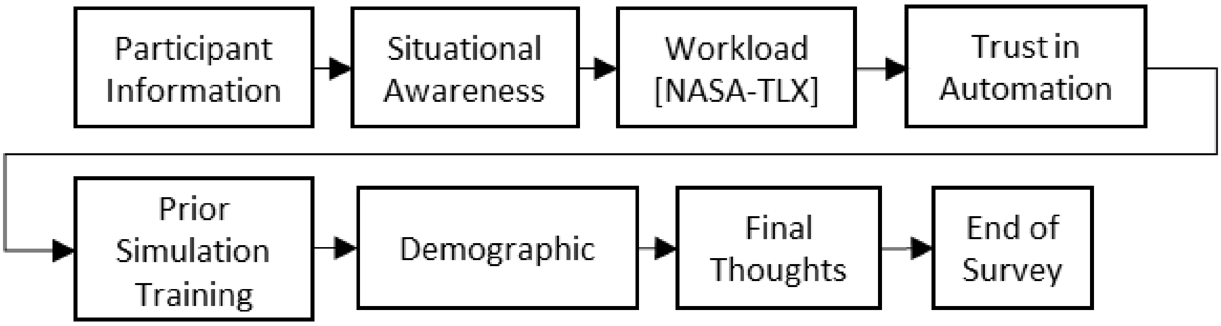


Figure 7.7: Post exercise survey structure

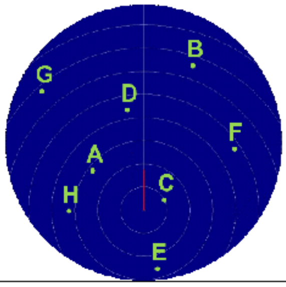
The PES was developed using the “Online Surveys” software and the data sets for the PES were recorded and collected using this platform. The aim of the PES was to analyse the individual in terms of a deeper level of understanding on autonomy. This was achieved by questioning the participant on the following research areas:

- Situational Awareness Section – The level of self-awareness that each participant showed throughout.
- Workload [NASA-TLX] section – How they perceived the workload of the exercise.
- Trust in Automation section – Whether their opinions of autonomy had changed following the conclusion of the exercise.

7.3.3.1 Situational Awareness

The SA section was introduced into the *Final Study* to analyse the participants’ knowledge of the mission they were tasked with. Due to the nature of the fault, there is the possibility of accidentally discovering, or correcting, the gyro drift with no further knowledge of the fault that is occurring. Furthermore, depending on the reaction speed of the participant it is possible that they had mentally acknowledged the fault with the intention to investigate it at a later stage in the exercise. Therefore, the SA section of the PES allowed the participants to detail their understanding of the exercise. The SA section of the PES contained questions asking the participant the speed and heading of their vessel, the number of traffic vessels that they encountered within the exercise as well as the speed, heading and locations of the vessels, the number of alarms they encountered and whether they recognised any faults within the simulator. The design of the SA section was to ask the question set and subsequently score the participant, on the responses, as shown in Table 7.4. This scoring method would allow the participant to achieve the highest possible score of 9.

Table 7.4: SA Question Set and Score

Question	Maximun Score
Indicate the speed of the vessel at the start of the exercise	1
Indicate the heading of the vessel at the start of the exercise	1
Indicate how many traffic vessels were in a 24 mile vicinity	1
Indicate the speed of any traffic vessels within a 24 mile vicinity	2
Indicate the heading of any traffic vessels within a 24 mile vicinity	2
Indicate the approximate location of any traffic vessels within a 24 mile vicinity 	2

7.3.3.2 Workload

One of the main focal points of the exercise was to gain a deeper understanding the participants' mindset when in the simulator. Therefore, by using the NASA TLX it allowed the participant to express the volume of mental workload they felt they were under when conducting their watch (Hart & Staveland, 1988). The NASA TLX section of the PES consisted of six questions on a 10 point scale ranging from 1 – very low workload to 10 very high workload. The scale would then increase in increments of 0.5. The following six questions were posed to the participant to understand the individual's workload demands:

- Mental Demand – How mentally demanding was the task? Was the task easy or demanding, simple or complex?
- Physical Demand – How physically demanding was the task?
- Temporal Demand – How hurried or rushed was the pace of the task?
- Performance – How successful were you in accomplishing what you were asked to do?
- Effort – How hard did you have to work to accomplish your level of performance?
- Frustration Level – How insecure, discouraged, irritated stressed and annoyed were you throughout the task?

The NASA TLX was administered immediately following the end of the exercise to ensure that the task was not intrusive to the participant. For this study the NASA TLX score would then be averaged among the total values within each participant group. Furthermore, the results of the NASA TLX were given equal weighting across all questions and then averaged to define the participant's final score. The interpretations of the scoring was conducted in a similar manner to that of past research (Prabaswari, et al., 2019) and the values are shown in Table 7.5.

Table 7.5: NASA TLX Score

Workload	**Value**
Low	0 – 12
Medium	13 – 24
Somewhat high	25 – 36
High	37 – 48
Very high	49 – 60

7.3.3.3 Trust in Automation

Having assessed multiple participants on previous studies using these questions, the aim was to understand whether the viewpoints towards the self-perceived trust in automation changes following a simulated automation failure. This section consisted of a six item questionnaire with the same question set as designed for the "Trust in Autonomy" section in the *Survey Study*. The question set was designed to follow the "Trust in Autonomy" section of the *Survey Study* rather than the MOQ section of the *Pilot Study* due to the fact that the extended question set would allow the participant to document their opinions on autonomous shipping in greater detail. Additionally, a 7 point Likert scale was utilised, to be the same as the *Survey Study*, to allow participants a wider response range than the 5 point Likert scale from the MOQ of the *Pilot Study*. Table 7.6 shows the question set issued to participants.

Table 7.6: Trust in Autonomy Question Set of PES

Items	**Trust in Autonomy**
1 – Trained	I trust in the automated systems which I have had training with.
2 – Failure	If an incident were to occur through the fault of an automated or autonomous system, I would have less trust in the system in future. Even though the system would be under supervision.
3 – Alarms	Alarms on the ship increase my situational awareness.
4 – Fatigue	If I were tired or fatigued, I would be more susceptible to trust the vessels automated systems.
5 – Instincts	I would trust my instincts more than the vessel's automated systems.
6 – Monotony	I could be easily distracted during night-time or watches where the vessel is at deep sea.

7.3.4 Participant Pool

Having gained insight from the previous studies it was apparent that, while beneficial to a quantitative study, limiting the selection criteria for participants would increase the effectiveness and quality of the *Final Study*. Therefore, for this study the following criteria were introduced to ensure that participants were:

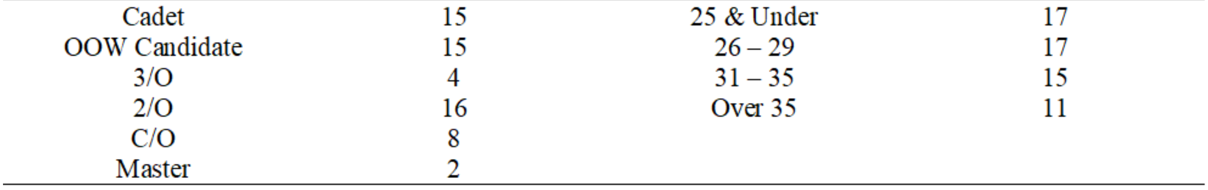
- Aged 18 or over
- Had accumulated a minimum of 12 months as a navigational cadet

To enhance the recruitment process, contact was made with South Tyneside College – South Shields Marine School, via the curriculum leaders, to attract potential participants. Introducing stricter selection criteria for participants enriched the data from the study and also ensured that all participants had accrued sufficient time on the bridge. Additionally, having a minimum requirement of sea time also ensured that all candidates were confident in their abilities to operate as a sole watchkeeper. This also meant that the minimum rank which could be analysed for this study was that of a final phase navigational cadet, however other variables such as age and level of education differed to allow further analysis of the test results. The introduction of a minimum sea time criterion for participants of 12 months, ensured that all individuals had met the sea time requirement to be a qualified navigational officer.

Sixty individuals participated in the *Final Study*. Of these 60, 30 participants were fully qualified officers with 20 junior officers and 10 senior officers. The other 30 participants were unqualified officers with a minimum of 12 months sailing time as a navigational cadet. Most of the participants were set to be promoted within the months succeeding this study. Hence, the final phase navigational cadet participants would be qualified junior officers and junior officers would be promoted to chief mates.

By developing the understanding of the impactful demographics of participants from the preceding studies of the thesis, it was identified that the participants' critical demographic variable was the Rank of the participant. All participants of the study were male and had a minimum of 12 months navigational sea time. The initial collation of the data identified the demographic splits shown in Table 7.7.

Table 7.7: Final Study Participant Demographics



Rank	n	Age Group	n
Cadet	15	25 & Under	17
OOW Candidate	15	26 – 29	17
3/O	4	31 – 35	15
2/O	16	Over 35	11
C/O	8		
Master	2		

The groups were divided to define which received each training video. Participants were organised to ensure that there was an even split of 30 participants each that received the behavioural and technical training videos. By grouping the participants by rank, it can be seen that there are a further two distinct categories that participants can be grouped by and that is as follows:

- Unqualified Participants – Consisting of participants that are yet to achieve their OOW certification (Cadet and OOW Candidate Groups), **n = 30**
- Qualified Participants – Consisting of participants that have already achieved their OOW certification (3/O, 2/O, C/O and Master Groups), **n = 30**

By utilising this grouping method for the participant ranks it was then possible to identify four participant groupings for statistical analysis.

- Behavioural Trained, Qualified OOW (BQ) – **n = 15**
- Technical Trained, Qualified OOW (TQ) – **n = 15**
- Behavioural Trained, Unqualified OOW (BU) – **n = 15**
- Technical Trained, Unqualified OOW (TU) – **n = 15**

7.3.5 Data collation and analysis

To record the actions taken by participants in the simulator, a drop down selection sheet was designed using Microsoft Excel. The selection sheet was designed using the various actions taken by the participants of the *Pilot Study* which then defined the location of the participant, alarm status, work pack location, vessel control and activity list all of which were recorded every 30 seconds during exercise. This allowed faster and more accurate recording of the events occurring in the simulator. The decision form that allowed for the creation of the drop selection sheet is shown in Table 7.8. Following the completion of the exercise, the CCTV footage was rewatched to ensure that every intrinsic detail of the actions of the participant was recorded.

Table 7.8: Decisions for drop down selection sheet

Location of Candidate	Activity List
Aft Window	Altering Course Heading
Alarm Panel	At Alarm Panel
Control Panel	At Steering Console
Forward Window	Changing Speed of Vessel
Radar Table	Checking Bridge Controls
Steering Console	Checking ECDIS
Workstation	Checking Radar
Alarm Status	Completing Work
	Controlling Binoculars
Accepted	Controlling Speed of Vessel
Silenced	Looking at Phone
Sounding	Looking Out of Window
Work Location	Making a Cup of Tea
	Making Call to Captain
Alarm Panel	Making Call to ECR
Control Panel	Making Call to Electrician
Radar Table	Making Call to Steering Gear Room
Steering Console	Moved Work to New Location
Workstation	Moving Around Bridge
Vessel Control	On Phone
	Silencing ECDIS Alarm
Autopilot	Silencing Fire Alarm
Manual	Switching to Back Up Gyro
	Writing in Logbook

7.4 Results

The statistical analysis of the data, such as ANOVA testing and Fisher Exact Tests were conducted using the IBM SPSS Statistics 27 software package. Following the conclusion of the study, the results were collected and subsequently processed for data analysis. With various individual aspects of the study being analysed independently, it was key to differentiate the overarching aim of the study to allow for the efficient analysis of the data. This led to statistical analysis being conducted on the participants' workbooks, PES, fault recognition times and fault diagnosis.

7.4.1 Fault Recognition

Initial analysis of the data was conducted to identify whether the inclusion of different training videos impacted on the success rate of participants in terms of fault recognition skills. By separating the rank and training received by each participant, it would be possible to identify whether different training can have an impact on participants irrespective of their rank. A Fisher Exact test with a Freeman Halton extension was conducted on the participant groupings to identify if there was any statistical significance between the groups. By conducting the Fisher Exact test, the categorical data of the participants could be analysed to assess if there were any statistically significant relationships arising from the training and rank of the participant and whether the participant successfully reacted to the fault. Using the Freeman Halton extension, allowed for the analysis of the data in a 4x2 contingency table metric. Table 7.9 shows the number of participants that recognised the course deviation fault versus the participants that did react to the course deviation fault in the simulator exercise.

Table 7.9: Fault Recognition Chi-Square Test

Fault Recognised	**Group**				**Chi-Square Tests**	**P Value**
	BQ	**TQ**	**BU**	**TU**		
Yes	10	3	5	0	Pearson Chi-Square	16.825*
No	5	12	10	15	Likelihood Ratio	20.101*
Total	15	15	15	15	Fisher Freeman Halton Exact Test	17.082*

* Sig < 0.05

Furthermore, when comparing the groups' success in fault recognition against each other it was found that many groups displayed signs of statistical significance. Further analysis of the data, as displayed in Table 7.10, shows that relationship of the BQ group was statistically significant from both the TQ and TU groups and the BU group displayed statistical significance from the TU group. The data therefore suggests that there were differences between participants receiving behavioural training to technical training. Moreover, participants who had received the behavioural training were more alert and reactive to fault than the participants that received technical training, irrespective of the individual's rank.

Table 7.10: Fault Recognition Fisher Exact Test Group Comparison

Group	**BQ**	**TQ**	**BU**	**TU**		**Technical**	**Unqualified**
BQ	-	0.0253*	0.1431	0.0002*	**Behavioural**	0.0015*	-
TQ	-	-	0.6817	0.2241	**Qualified**	-	0.047*
BU	-	-	-	0.0421*			
TU	-	-	-	-			

* Sig < 0.05

The fault recognition time, for participants started at 0 seconds when the fault initiated and then stopped when the participant recognised the fault. In the event of the participant not recognising the fault they would be issued with a time score of 1050 seconds.

The graph displayed in Figure 7.8 shows the time scores and volume of workbook completed for all participants of the simulator exercise. As a final prompt for all participants in the simulator, a cross track alarm would sound 750 seconds after the fault had started, this has been denoted on the graph. As shown in Figure 7.8, half of the participants that had recognised the fault did not need the aid of the cross track alarm. The analysis of the individual groupings of the participants shows that the participants of the BQ group were more attentive, with 60% of the successful BQ participants reacting to the fault without the aid of the cross track alarm. However, for the TQ and BU groups, 40% and 33.3% of participants reacted to the fault prior to the sounding of the alarm. Furthermore, it can be seen that the fastest and slowest reaction times to the fault both belonged to the BQ group with time scores of 399 seconds and 1005 seconds, respectively. When analysing the participants as a homogenous group it can be seen that 30% of all participants were successful in recognising the fault.

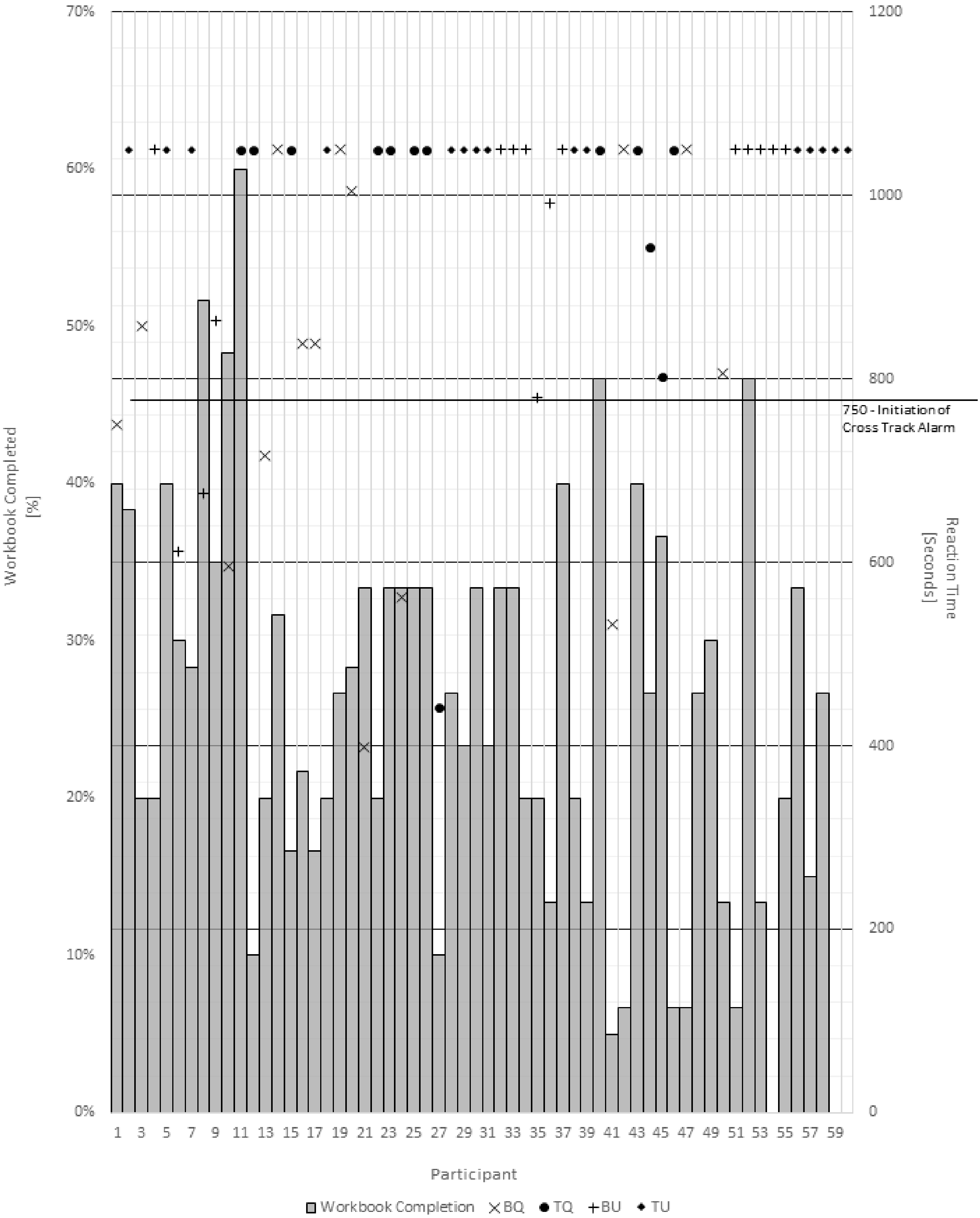


Figure 7.8: Fault Recognition Rates for Final Study

Following the conclusion of the exercise all participants' workbooks were collected to assess the quantity of the tasks completed for each participant. The collation of the workbook data indicated the level of detail that participants recorded. However, as shown in Figure 7.8, the volume of workbook completed did not appear to have a connection to fault recognition success. However, One way ANOVA testing was conducted on the data from the workbook to gain a greater understanding of whether there is any relationship between the volume of workbook completed and the success in recognising the fault. Additional One way ANOVA testing was conducted to assess the relationship between volume of workbook completed and the "Training Package vs Rank" groups that participants were categorised by. The findings of the ANOVA, as shown in Table 7.11, identified that there was no statistical significance between the volume of workbook completed and the fault recognition success. However, the ANOVA test did identify a statistically significant relationship between the volume of workbook completed and the "Training Package vs Rank" groups.

Table 7.11: Workbook Completion ANOVA Test

Variable		Sum of Squares	Degrees of Freedom	Mean Square	F Value
Fault Recognised	Between Groups	5.656	22	0.257	1.370
	Within Groups	6.944	37	0.188	
	Total	12.600	59		
Training Package vs Rank	Between Groups	44.472	22	2.021	2.450*
	Within Groups	30.528	37	0.825	
	Total	75.000	59		

7.4.2 Fault Diagnosis

Conducting an ETA, similar to the *Pilot Study*, allowed a greater understanding of the thought processes of each participant. With the various pathways being created in the ETA, it was possible to identify the actions taken by the participants and decipher whether the participants understood the fault and to which event they progressed. The main aim of this study was to identify whether the type of training had an impact on how an individual would conduct their watch. The inclusion of the drop down selection sheet allowed for additional events to be included in the ETA over those identified in the *Pilot Study*.

Figure 7.9 shows the complete event tree for the simulator exercise. Within Figure 7.9 it can be seen that the participants have been split into their groups depending on the training package they had received prior to entering the simulator. The initial alarms at events 2 and 3 of the doppler log and echo sounder, allowed the participants to immerse themselves in a simulation similar to a working wheelhouse. The participants that had received the technical training package were more responsive in both alarm accounts. Event 4 indicates the initiation of the fault. At event 5, nearly two thirds of the behaviourally trained participants had been proactive in addressing the course deviation, whereas only one third of the technically trained group had taken an initial course of action. Progressing through the exercise to event 9, this allowed participants to formally acknowledge the instance of a malfunction and document their findings of the exercise. From event ten, participants would then have the opportunity to call the captain and alert them to the ongoing situation. As shown in the ETA, 15 and three participants from the behaviourally and technically trained groups, respectively, successfully navigated the exercise to this event. All participants that had successfully addressed event 10 were considered to be successful in identifying the fault. However, both events 11 and 12 allowed the participant to further explore the fault with the aim to correct it. At event 11, five and three participants from the behaviourally and technically trained groups, respectively, successfully changed over the autopilot control from gyro compass 1 to gyro compass 2. However, it may be assumed that by the participants alerting the captain to the malfunction, it would ultimately be identified at a later point in a longer watch. Ultimately, from the cohort of 60 participants, two participants from the behaviourally trained group and one participant from the technically trained group were successful in their actions at event 12, resulting in a total of three participants following the correct procedures in diagnosing the fault.

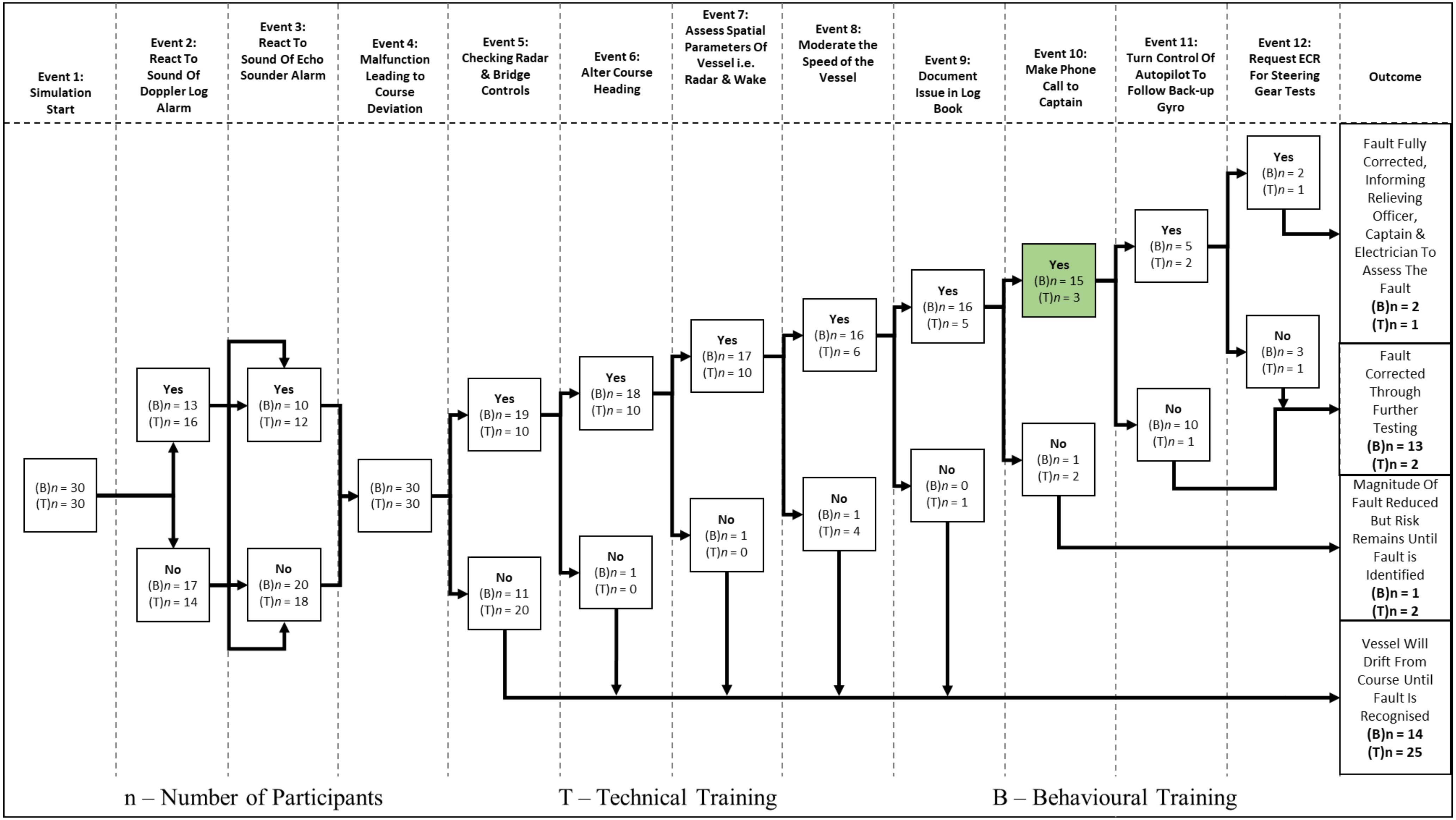


Figure 7.9: Event Tree Analysis for Final Study

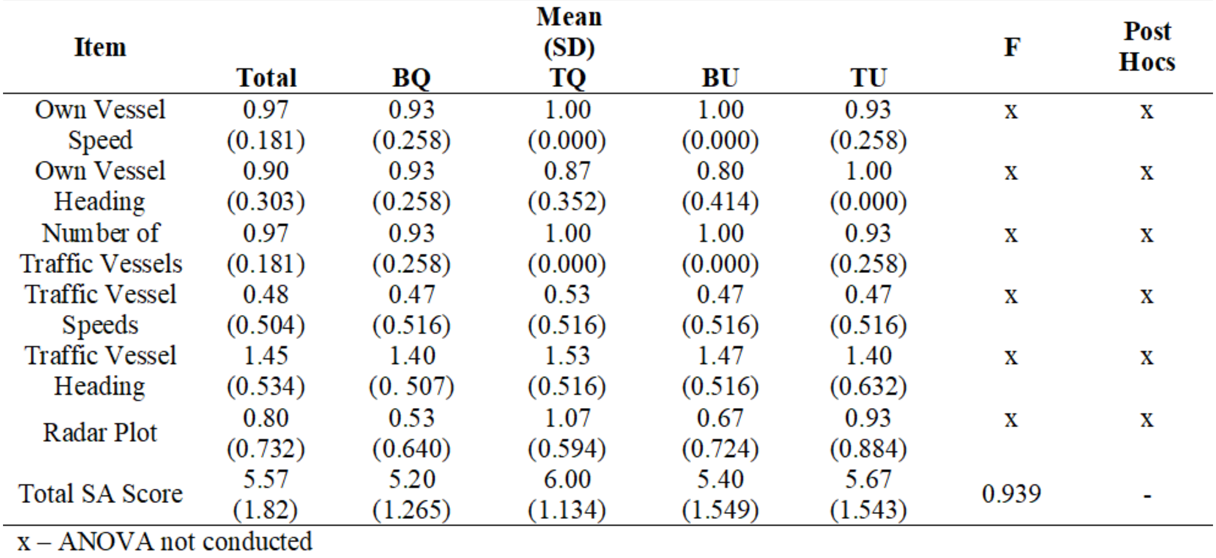
7.4.3 *Post Exercise Survey*

For the PES the key aspects that were analysed were as follows; the SA section, NASA TLX and Trust in Automation section. Each section was analysed against both the “Training Package vs Rank” and whether or not the participants successfully recognised the fault. The statistical analysis was conducted using One way ANOVA testing with a Tukey HSD Post Hoc test to analyse the data between groups for the Training package vs Rank participant group. All testing was conducted using a statistical significance value of $p < 0.05$.

7.4.3.1 Situational Awareness

For each question in the SA section of the PES a participant could score 1 point for every correct response, with 2 points being allocated to the questions regarding the traffic vessels. Participants could score a maximum score of 9 for the SA section. Due to the size of the scores, individual ANOVA tests could not be conducted, nevertheless seven 1x4 ANOVA tests were conducted on the total SA score, for the SA section for the “Training Package vs Rank” participant group, with the aim to identify if there were any statistically significant relationships emerging from the data. As can be seen from Table 7.12 all groups scored on average over 5 points, suggesting that the participants were aware of their surroundings and only when questioned about the parameters of the traffic vessels did participants begin to struggle to answer. However, no results produced from the ANOVA showed any statistically significant relationships.

Table 7.12: Statistical Tests for “Training Package vs Rank” of the SA Section of PES



Item	**Mean (SD)**					**F**	**Post Hocs**
	Total	**BQ**	**TQ**	**BU**	**TU**		
Own Vessel Speed	0.97 (0.181)	0.93 (0.258)	1.00 (0.000)	1.00 (0.000)	0.93 (0.258)	x	x
Own Vessel Heading	0.90 (0.303)	0.93 (0.258)	0.87 (0.352)	0.80 (0.414)	1.00 (0.000)	x	x
Number of Traffic Vessels	0.97 (0.181)	0.93 (0.258)	1.00 (0.000)	1.00 (0.000)	0.93 (0.258)	x	x
Traffic Vessel Speeds	0.48 (0.504)	0.47 (0.516)	0.53 (0.516)	0.47 (0.516)	0.47 (0.516)	x	x
Traffic Vessel Heading	1.45 (0.534)	1.40 (0. 507)	1.53 (0.516)	1.47 (0.516)	1.40 (0.632)	x	x
Radar Plot	0.80 (0.732)	0.53 (0.640)	1.07 (0.594)	0.67 (0.724)	0.93 (0.884)	x	x
Total SA Score	5.57 (1.82)	5.20 (1.265)	6.00 (1.134)	5.40 (1.549)	5.67 (1.543)	0.939	-

x – ANOVA not conducted

For the analysis of the Fault Recognition groupings in the SA section, seven One way ANOVA tests were conducted. When analysing the data computed through the ANOVA tests it was found that participants, who failed to react to the fault had scored slightly better than those who had acted to correct the fault. Furthermore, it was found that there were no statistically significant relationships among any of the questions. The results of the ANOVA are shown in Table 7.13.

Table 7.13: Statistical Tests for Fault Recognised Groups of the SA Section of PES

Item		Mean (SD)		F
	Total	Fault Recognised n = 18	Fault Unrecognised n = 42	
Own Vessel Speed	0.97 (0.181)	1.00 (0.000)	0.95 (0.216)	0.870
Own Vessel Heading	0.90 (0.303)	0.94 (0.236)	0.88 (0.328)	0.551
Number of Traffic Vessels	0.97 (0.181)	0.95 (0.216)	1.00 (0.000)	0.870
Traffic Vessel Speeds	0.48 (0.504)	0.50 (0.506)	0.44 (0.511)	0.151
Traffic Vessel Heading	1.45 (0.534)	1.44 (0. 511)	1.45 (0.550)	0.003
Radar Plot	0.80 (0.732)	0.61 (0.502)	0.88 (0.803)	1.734
Total SA Score	5.57 (1.82)	5.44 (1.247)	5.62 (1.447)	0.198

7.4.3.2 NASA TLX

The introduction of NASA TLX questions allowed participants to document their mindset towards the simulator exercise. Each NASA TLX question was scored on a scale of 0 to 10 in increments of 0.5. The scores of the NASA TLX section were then totalled to give the participants a score out of 60.

Table 7.14 shows the results of the seven 1x4 ANOVA tests that were conducted on the Training package vs Rank participant groups. From the data shown it can be seen that most participants felt that the exercise did not require much mental output and was not overly frustrating. Furthermore, participants expressed that they had felt that they had given a middling effort in the exercise. Conversely, the Post Hoc analysis identified that within the temporal and physical questions of the NASA TLX section, there were statistically significant relationships between the BU group and both the TQ and BQ groups respectively. This indicated that the participants from the BU group felt that the task was more physically demanding and felt more hurried than the TQ and BQ groups respectively.

Table 7.14: Statistical Tests for "Training Package vs Rank" of the NASA-TLX Section of PES

Item	**Mean (SD)**					**F**	**Post Hoc**
	Total	**BQ**	**TQ**	**BU**	**TU**		
Mental	4.93 (2.497)	5.13 (2.774)	4.53 (1.959)	5.27 (2.764)	4.80 (2.597)	2.54	-
Physical	2.35 (2.335)	1.73 (2.086)	1.33 (1.633)	3.53 (2.416)	2.80 (2.624)	3.056*	BU > TQ
Temporal	3.75 (2.542)	2.60 (1.682)	3.80 (2.883)	5.00 (2.752)	3.60 (2.324)	2.414*	BU > BQ
Performance	4.43 (3.005)	5.20 (3.427)	3.80 (2.859)	5.13 (2.560)	3.60 (3.043)	1.217	-
Effort	5.00 (2.731)	4.60 (2.586)	4.13 (2.416)	5.67 (3.200)	5.60 (2.613)	1.160	-
Frustration	3.20 (2.927)	2.87 (2.774)	3.73 (3.595)	3.00 (2.591)	3.20 (2.883)	0.244	-
Total NASA TLX Score	23.67 (9.775)	22.13 (7.954)	21.33 (8.406)	27.60 (12.397)	23.60 (9.493)	1.232	-

A further seven One way ANOVA tests were performed on the NASA TLX questions for the Fault recognition grouping of participants. As shown in Table 7.15 all participants responded in a similar manner for all aspects of the NASA TLX section. Moreover, the results of the ANOVA tests identified that there were no statistically significant results within this data set.

Table 7.15: Statistical Tests for Fault Recognised Groups of the NASA-TLX Section of PES

Item	**Mean (SD)**			**F**
	Total	**Fault Recognised n = 18**	**Fault Unrecognised n = 42**	
Mental	4.93 (2.497)	5.17 (2.503)	4.83 (2.517)	0.22
Physical	2.35 (2.335)	1.67 (1.847)	2.64 (2.477)	2.249
Temporal	3.75 (2.542)	3.44 (2.175)	3.88 (2.698)	0.368
Performance	4.43 (3.005)	4.56 (3.294)	4.38 (2.913)	0.42
Effort	5.00 (2.731)	4.67 (2.951)	5.14 (2.656)	0.379
Frustration	3.20 (2.927)	2.72 (2.675)	3.40 (3.037)	0.681
Total NASA TLX Score	23.67 (9.775)	22.22 (9.777)	24.29 (9.826)	0.557

7.4.3.3 Trust in Automation

The Trust in Automation section questions had been extracted from the *Survey Study*. In correspondence with *Survey Study*, this section employed a 7-point Likert scale for each question, with 1 being in favour of manual control and 7 being in favour of autonomous control. Thus, resulted in a maximum score of 42.

Table 7.16 shows the responses of the seven 1x4 ANOVA tests that were conducted on the Training package vs Rank participant groups, for the Trust in Autonomy section. The data shows that most participants answered in a similar manner and were favourable towards autonomy in most aspects of the questionnaire. The Post Hoc testing shows a statistically significant relationship between the TU and TQ groups for the question *"Alarms on the ship increase my situational awareness."* As shown in the data, participants from the TU groups responded more favourably to this question than those in the TQ group.

Table 7.16: Statistical Tests for "Training Package vs Rank" of the Trust in Automation Section of PES

Item			**Mean (SD)**			**F**	**Post Hocs**
	Total	**BQ**	**TQ**	**BU**	**TU**		
Trained	4.95 (1.443)	4.60 (1.682)	5.33 (1.175)	4.47 (1.598)	5.40 (1.121)	1.760	-
Failure	5.05 (1.431)	4.67 (1.633)	5.47 (0.834)	4.87 (1.807)	5.20 (1.265)	0.916	-
Alarm	5.85 (1.516)	5.67 (1.397)	4.93 (2.017)	6.13 (1.302)	6.67 (0.488)	4.077*	TU > TQ
Fatigue	4.03 (1.868)	4.67 (1.877)	3.87 (1.846)	4.07 (1.981)	3.53 (1.767)	0.973	-
Instincts	5.50 (1.610)	5.80 (1.424)	5.27 (1.335)	5.47 (1.959)	5.47 (1.767)	0.272	-
Monotony	3.38 (1.795)	3.80 (1.821)	3.73 (1.944)	3.47 (1.995)	2.53 (1.187)	1.643	-
Total Score	28.77 (4.131)	29.20 (4.507)	28.60 (4.501)	28.47 (3.815)	28.80 (4.057)	0.086	-

To analyse the Trust in Autonomy section against the Fault recognition groups a further seven One way ANOVA tests were completed, the results of which are shown in Table 7.17. From here it can be seen that the ANOVA tests identified a statistically significant relationship between the groups. Participants who successfully recognised the fault were less favourable towards autonomy than those who failed to react to the fault, as shown from the responses from the question *"I trust in the automated systems which I have had training with."*. Furthermore, the ANOVA test identified a statistically significant relationship between the participant groups for the question *"If I were tired or fatigued, I would be more susceptible to trust the vessels automated system."*. This question showed that participants that recognised the fault were more favourable towards autonomy than those who failed to react.

Table 7.17: Statistical Tests for Fault Recognised Groups of the Trust in Automation Section of PES

Item	Mean (SD)			F
	Total	Fault Recognised n = 18	Fault Unrecognised n = 42	
Trained	4.95 (1.443)	4.33 (1.782)	5.21 (1.20)	5.016*
Failure	5.05 (1.431)	5.00 (1.815)	5.07 (1.257)	0.031
Alarm	5.85 (1.516)	5.61 (1.539)	5.95 (1.513)	0.634
Fatigue	4.03 (1.868)	5.06 (1.798)	3.60 (1.740)	8.703*
Instincts	5.50 (1.610)	5.44 (1.688)	5.52 (1.596)	0.030
Monotony	3.38 (1.795)	3.83 (1.886)	3.19 (1.742)	1.633
Total Score	28.77 (4.131)	29.28 (4.637)	28.55 (3.934)	0.390

7.5 Findings

7.5.1 The Effects of Training Programmes

With Maritime 2050 on the horizon, the industry should aim to learn and develop from both ongoing autonomous maritime research and the introduction of autonomous technology in other transportation sectors. With the maritime industry looking to implement autonomous systems in the near future, training the OOW will ultimately influence its success. As such, the development of this study aims to provide the maritime industry with the knowledge of how to adapt future navigational officer training to aid the evolution of the navigational seafaring role.

Research has already identified that the current curriculum contains outdated training aspects such as celestial navigation and paper chartwork and that cadets believe that the educational sector of the industry is not suitably arming them with the knowledge to succeed in the future of shipping (Bogusławski, et al., 2022). The work conducted within this study has identified, with the transition towards autonomy, that behavioural training has the potential to be the most beneficial training method for trainees. When comparing the fault recognition skills of participants, within their respective training groups, it was found that 50% of participants from the behaviourally trained group were successful in recognising the fault, whereas 10% of technically trained participants could find the fault. The results of this study have shown that while the training of officers must be adapted for autonomy to succeed, future topics should focus less on the knowledge of the system and look to employ a more reflective method of education. While the behaviourally trained group were not infallible, the results of this study identify that incorporating aspects such as SA, AB and complacency into the maritime education curriculum can improve the fault recognition skills of participants. Moreover, the results of the Fisher Exact test identified statistically significant relationships between the various participant groups and while the rank provided a strong relationship, the training package that participants received, delivered a stronger relationship. When analysing the groups individually, the BQ and TU groups provided the highest value of statistical significance, which can be expected as the groups had received different training packages and were of different rank. However, The BU and TQ groups showed no level of statistical significance indicating that on a purely statistical plane, both groups behaved in a manner that is not dissimilar from each other. This may be interpreted as the training package being a more influential factor in the participants' success in fault recognition.

As shown in Table 7.10, there was a statistically significant relationship between the participant groups receiving different training packages. Moreover, the intention of the *Final Study* was to ascertain whether altering the training received prior to conducting a navigational watch would impact the success in recognising the fault. As such hypothesis 2 of the *Final Study* was as follows:

- Hypothesis 2 – Participants receiving the behavioural video training package will be more receptive to the exercise fault, resulting in an increased number of individuals recognising and successfully diagnosing the fault in comparison to the participants receiving the technical video training package.

As hypothesised, the participants receiving the behavioural training package outperformed the participants receiving the technical training package, in recognising the fault. Subsequently, when assessing the fault diagnostic skills of the participants it can be seen from Figure 7.9 that participants receiving the behavioural training package were more successful in diagnosing the fault. However, from all of the participants, three individuals successfully diagnosed the fault suggesting that, while behavioural training can benefit the OOW, further training would need to be undertaken to improve an OOW skill set to align with potential autonomous shipping requirements.

7.5.2 The Effect of Rank

Regardless of rank, every participant was given the same conditions and environment to operate in, which included visual and auditory stimuli to aid the participant such as alarms, the vessels wake, the changing of the rudder angle indicator etc. However, by including menial tasks such as paperwork, the participants would divide their focus between completing their paperwork and conducting a safe navigational watch. Distractions such as the sounding of false alarms can impact a participant's mindset and potentially cause alarm fatigue resulting in the participant neglecting to react to future alarms, as seen from the lack of interest in the alarms in the ETA.

Alarm fatigue has long been documented as an issue within human factors and research into reducing alarm fatigue has become prominent with the introduction of autonomous shipping (Fan, et al., 2017; Tam, et al., 2021).

As with all technology, the aim of the autopilot and autonomous systems is to aid the operator and reduce the human workload however, reducing the workload should not eliminate the requirement for the vigilance of the individual (Masalonis, et al., 1999). The results of the ETA identified that from 60 participants, less than half took the initiative to inspect an abnormal occurrence. Furthermore with 30% of participants correctly identifying a fault, the presence of bias towards the autopilot to operate correctly and complacency towards the navigational systems is evident among the cohort tested. With research alluding to the main focus of maritime trainees being to pass exams, it can be assumed that individuals may have subconsciously perceived this exercise in a similar vein to an examination (Gholamreza & Wolff, 2008). With this being a simulated environment, the expectation is that the number of individuals successfully recognising the fault would be greater those compared to a real life situation due to a heightened sense of awareness when entering the simulator. However, 15% of participants recognised the fault without the aid of an alarm, resulting in potentially fewer individuals recognising this fault while in a real-life situation. Nevertheless with 35% of participants documenting the findings of the fault, this could allow the OOW to report it at the watch handover, thus resulting in it being found at a later point of the voyage in a real life setting.

As shown in Table 7.10, there was a statistically significant relationship between the participant groups receiving different training packages. A critical aspect of the *Final Study* was to increase the number of qualified OOW participating in the study in comparison with the *Pilot Study*. Therefore, by gaining an equal number of qualified and unqualified participants, hypothesis 4 could be addressed as follows:

- Hypothesis 4 – Participants of a higher rank will be more receptive in recognising and diagnosing the automated system fault.

While the qualified participants outperformed the unqualified participants, no statistically significant relationships were identified in comparing the BQ to BU groups and the TQ to TU groups. However, the results of the Fisher Exact test identified a statistically significant relationship between the ranking groups of participants therefore suggesting that the hypothesis can be accepted. Interestingly, the study has shown that participants are more alert with regard to fault recognition when receiving the behavioural training than technical training regardless of rank. Moreover, from the results the Fisher Exact test, it can be seen that there is no statistically significant relationship between the BU and TQ groups suggesting that by introducing the behavioural training to unqualified officers an individual's fault recognition skills are similar to those of a qualified officer without the behavioural training. Concurrently, if a seafarer receives behavioural training, the individual will benefit from this more than being a qualified officer.

7.5.3 Success in Automated Fault Finding

The inclusion of the PES provided further depth to the study and gave the participants a platform to express both their understanding of the exercise and their knowledge and opinions towards autonomous shipping. The analysis of the SA section of the PES showed that the majority of participants, from all test groups, were aware of parameters of their own vessels i.e., their own vessel's speed, heading and the number of vessels in a close proximity. However, further analysis showed that all tested groups displayed varying levels of uncertainty with regard to the parameters of the vessels in close proximity. The participants of the technically trained groups outperformed the participants receiving the behavioural training package, which could indicate that participants from the TQ and TU groups retained more information from the exercise. Nevertheless, when assessing the total SA score, all participant groups scored more than 50%. When assessing the groups of participants who did and did not recognise the fault, the responses followed a similar pattern to the analysis of the training vs rank participant groups with the majority of participants being successful in detailing the parameters of their own vessel. However, it was found that the participants who did not react to the fault were more receptive to the locations of the traffic vessels when presented with the radar plots, than those who recognised the fault. Nevertheless, while it can be speculated that the inclusion of multiple alarms and distractions could negatively impact the individual's SA, with no statistical significance arising from the ANOVA test no definitive statements could be concluded from the data. As such, this has rejected the null hypothesis as follows:

- Hypothesis 1 – The inclusion of multiple alarms and work will result in various distractions for the human operator and be detrimental to the individual's situational awareness.

When categorising the participants based on their success in finding the fault, it was found that there was a statistically significant relationship between the groups when questioned on Item 4 *"If I were tired or fatigued, I would be more susceptible to trust the vessels automated systems."*. Participants who recognised the fault answered favourably to this question, which can be highlighted in their vigilance in the simulator. Conversely, item 1, *"I trust in the automated systems which I have had training with."*, also drew a statistically significant response with the participants who did not recognise the fault answering more favourably to this question. Due to the responses gained from the Trust questioning in the PES, it can be seen that findings are ambiguous in nature with as the two statistically significant responses contradict one another. As such it can be concluded that the participants were potentially confused by the nature and wording of the questioning leading to the different responses from the participant groups.

The subjective nature of the NASA TLX allowed participants to reflect on their own perceived workload throughout the exercise. By conducting this it was possible to assess if there were any differences arising between the participant groups for the varying types of workloads experienced. The results of the NASA TLX section of the PES identified that participants of all testing groups, when categorising the participants by their training package vs rank, found the exercise to be of *somewhat high* to *high* workload, as referenced within Tables 7.14 and 7.15. However, when assessing the participants based on their success in finding the fault, it was found that the participants responded in a similar manner with subtle changes throughout each question posed. Moreover, regardless of the participants’ success in finding the fault, the results from the NASA-TLX suggested that all participants had similar experiences throughout the exercise. With both group sets scoring the NASA-TLX in a similar manner this rejects the null hypothesis as follows:

- Hypothesis 3 – Participants who are successful in recognising the automated fault will experience an increased workload during the exercise in comparison to the participants who did not recognise the fault.

7.6 Methodological Implications

The aim of this study was to improve on the limitations that were identified in the *Pilot Study*. Therefore, the simulator exercise in this study was to be longer and include a drop down selection sheet to improve recording efficiency, and the PES was to be improved through the inclusion of aspects such as the NASA TLX and SA sections. However, although the time spent in the simulator was 30 minutes, this does not deliver the complete perspective of a full 4-hour navigational watch. Nevertheless, research has identified the average attention span for a human is approximately 20 minutes (Murphy, 2008). Therefore, the time allocated for this exercise should be suitable for the participants to recognise the fault considering that malfunctions are not scheduled and can develop at any time throughout a 24 hour period.

As highlighted in the *Pilot Study*, while simulators are an incredibly useful tool and will continue to be for the education in autonomous shipping, participants will not react exactly how they would when presented with a real-life scenario. Despite increasing the fidelity of the simulation, the individual still knows that should they fail or deliver an inadequate performance in the simulator there are no real world repercussions for safety of the crew, environment, or vessel.

One key limitation to this study is that all participants were male. However, this is indicative of the current seafaring cohort. It has been reported by the International Chamber of Shipping, that of the 1.89 million seafarers serving in the world merchant fleet, only 1.28% are female (International Chamber of Shipping & BIMCO, 2021). Increasing the number of participants could result in the increase of the female demographic, however it is improbable to attain a suitable demographic split, without assessing a high number of participants to increase the number of female participants.

The modifications to the PES proved successful. The inclusion of the NASA TLX section allowed participants to document their perceived workload and increasing the Likert scaling and the number of questions within the Trust in Autonomy section delivered a richer data pool not dissimilar to the *Survey Study*. However, the SA section requires further development to truly capture and quantify the levels of SA among participants. Moreover, future research could look to adapt the SA section to require the participants to record items such as weather, performing a watch handover or the inclusion of monitoring hardware that would allow for recording of stress levels.

7.7 Chapter Conclusion

The aim of the *Final Study* was to incorporate previous learning and develop a final simulator study that could utilise and build on key findings that had arisen from the supporting studies. The aim was to address the remaining research questions that had been outlined in Chapter 1. These research questions allowed for the development of the hypotheses for the *Final Study*.

As detailed in this chapter, despite both training packages producing a number of participants that successfully reacted to the automated fault. The data suggests that the behavioural training package was more beneficial to the fault recognition skills of the participants, than the technical training package. As such, further developments can be made to optimise the behavioural training package to improve the number of participants successfully recognising the fault. Moreover, the data analysis of the study provided evidence that the success rate is dependent on what training package the individual received, as the BU group outperformed the TQ group. As the maritime industry transitions towards autonomous shipping this study has shown that training is of paramount importance and the key to its success.

The development of this study was to incorporate the findings of the previous studies of this thesis and to develop on the elements that benefitted the simulator study in the *Pilot Study*. Fundamentally, the participant pool for this study needed to be more stringently selected to develop a richer data pool. Analysing the participants without any variables, the findings of this study have shown that of the 60 individuals that undertook the simulator exercises, only 18 participants (30%) were successful in recognising the fault. Three additional participants acknowledged the existence of a fault in their logbook. The additional participants documenting the fault in the logbook may indicate that, while they were not sure of how to address the fault, logging its existence could speed up its correction when compared to the participants that had not recognised it at all.

The comparison of qualified versus unqualified has shown that participants who are qualified OOW are more reactive to fault finding, which is to be expected due to their onboard experiences and longevity in their careers. However, when assessing the participants by training package received, it was found that participants undergoing the behavioural training package were more successful in the fault-finding exercise. Furthermore, despite training having an impact on the fault-finding skills of the participants, it did not have an effect on the perceived SA or the workload of the participants.

Chapter 8will discuss the overall findings of the studies in this thesis and their potential impact on the maritime industry. It will also discuss the research objectives and questions developed, how each of them was addressed and the limitations of the research.

Chapter 8. Discussion

8.1 Chapter Summary

This chapter presents the findings from all four studies as a collective, addressing the defined aim and objectives and the research questions posed in the thesis. The overall structure of this chapter will address each of the research objectives individually and how each objective relates to the corresponding research question. Thereafter, this chapter will address the literature around maritime SA and the impact that technology has on the OOW in comparison to the findings of the thesis. Furthermore, the chapter makes recommendations for the maritime industry in terms of evolving the OOW role, the development of future MET to incorporate additional technological and psychological education into the OOW curriculum and what steps could be taken by the maritime industry to improve the human automation relationship.

8.2 Background

Within the preceding chapters of this thesis, various critical research areas are described detailing the respective stages of research conducted. Chapter 1 identified that the overall aim of this work was to determine whether the modern navigational officer curriculum provided the OOW with the human factors skills to successfully integrate the OOW with future autonomous navigational systems. To achieve this aim, the following research objectives were presented:

1. Determine the level of knowledge and understanding that modern seafarers have regarding autonomy and digitised bridges.
2. Analyse the relationship between modern automated navigational systems and operators.
3. Analyse the seafarer's perspective of the current officer training regime and autonomous shipping.
4. Determine whether situational awareness is a concern among navigational seafarers.
5. Determine the environmental variables that negatively impact a seafarer's situational awareness.
6. Assess whether different training can influence the fault recognition and diagnosis skills of seafarers.

Through the development of the aim and research objectives, the following research questions were created:

RQ1. What is the perception among seafarers of the current training regime, the introduction of autonomous shipping and the human automation relationship?

RQ2. Are modern seafarers equipped with the fault awareness skills suited for supervising autonomous shipping?

RQ3. Do demographic variables such as age, education level, sea experience or rank have an impact on the seafarers' opinions of autonomous shipping?

RQ4. Do seafarers lack the concentration skills to maintain the safety of the vessel?

RQ5. Do demographic variables such as age, education level, sea experience or rank have an impact on the fault recognition and fault diagnostic skills of navigational officers?

RQ6. Can a different training method improve the fault recognition and fault diagnostic skills of seafarers?

The subsequent sections of this chapter will discuss the findings of each of the four studies, both individually and as a collective, to address the research questions.

8.3 Addressing the research questions

The following subsections reintroduce each research question and its respective link to past literature and research. Each research question will then be analysed from the perspective of each study individually and as a collective, with a summary of key findings from the thesis addressing the research questions.

8.3.1 Research Question 1: What is the perception among seafarers of the current training regime, the introduction of autonomous shipping and the human automation relationship?

This question was primarily addressed through the findings of the *Survey Study* presented in Chapter 4. Due to the potential complexities of introducing autonomous navigational systems it was critical to understand MASS from the perspective of the OOW. Subsequently the subsequent surveys conducted in both the *Pilot Study* and *Final Study*, provided additional supporting data to substantiate the initial findings from the *Survey Study*. The *Interview Study* then provided the insight towards MET that allowed this question to be answered.

With aspects of MASS being introduced within this question such as MET, autonomous technologies and the relationship between operator and system, it was critical to devise question sets that would complement each other and act as the initial research area to design deeper studies. Therefore, the findings of the *Survey Study* could be summarised in that the perspective that seafarers have towards autonomous technology is generally positive. Understandably, there are concerns among seafarers ranging from job security to ethical responsibility and vessel safety all of which support the current views identified through research (Kim, et al., 2020; Miyoshi, et al., 2022; Komianos, 2018). Nevertheless, the findings from the *Survey Study* found that seafarers, in general, believe that autonomous technology will benefit the OOW and can aid vessel operations. The participants alluded to the fact that they were comfortable to trust autonomous systems providing that they had sufficient training with the systems and that such sophisticated systems were not given the responsibility to supersede the human operator in the decision making process. Such views were further supported through the supplementary studies conducted from both the MOQ of the *Pilot Study* and the PES in the *Final Study*.

The current curriculum of the MET sector is due to undergo a wide variety of changes to cope with the technological advancement of autonomous shipping (Aboul-Dahab, 2021). Further research has identified that seafaring students understand that the current curriculum for seafarers is outdated and needs to incorporate education and training into topics such as leadership, communication and teamwork that will rapidly aid in the development of future training regimes in autonomous technology (Jo, et al., 2020). This idea that the current seafaring curriculum is outdated is supported through the findings of the *Interview Study*. The *Interview Study* confirmed the view of seafarers of all experiences on the inadequacy of the current syllabus for navigational officers and the urgent need for an overhaul to incorporate autonomous and emerging technology. Moreover, subjects such as critical thinking, SA and communications can aid the OOW in their understanding of their role onboard in addition to the technicalities behind navigation.

The findings of this thesis have determined that in the development of MASS, seafarers have a positive outlook toward autonomous shipping and the human automation relationship. However, there is a theme of ambiguity towards the MET sector with the consensus of participants believing that current training standards lag technology and unless the training regime undergoes an immediate revision, the OOW qualifying in the near future will not be equipped with the skills to successfully integrate themselves in the initial stages of MASS. Moreover, with many seafarers having a positive disposition towards autonomous shipping, it can be deduced that many of the challenges of the introduction MASS may be reduced, as proactive seafarers will aim to develop their skills beyond the assistance of the MET sector. It can be concluded that the seafarers have a positive outlook towards the introduction of MASS. Nevertheless, there remain certain reservations towards job security and ethical decision making responsibilities that have arisen from seafarers.

8.3.2 Research Question 2: Are modern seafarers equipped with the fault awareness skills suited for supervising autonomous shipping?

The findings of all studies within this thesis addressed RQ2. With the IMO looking to implement autonomous supervision in the early stages of MASS (IMO - MSC, 2018), it is critical for the safety of the vessel, crew and environment that the OOW is situationally aware of their personal working environment. With various modern day maritime accidents occurring due to the implications of human factors such as SA, lack of knowledge or communications breakdown (Marine Accident Investigation Branch - MAIB, 2019; Marine Accident Investigation Branch - MAIB, 2017; Japan Transport Safety Board - JTSB, 2021), it can be understood how the forefront of both literature and published statistics emphasise human error as the leading cause of maritime incidents (Russo, et al., 2022; Allianz Global Corporate & Specialty, 2022). Nevertheless, system malfunctions can occur, that also result in maritime incidents (Dutch Safety Board, 2017). The studies presented in Chapters 4 through to 7, were devised and conducted such that various aspects of each of these studies aimed to address this question.

From the three SJQs in the *Survey Study,* it was found that, in a relaxed environment and with all knowledge available to the individual, in general participants were able to successfully identify the most appropriate responses in the event of a system fault. By basing the question on the events of real maritime incidents, it could be seen that the participants successfully identified the actual events that lead to the accident as being the least appropriate response (Australian Transport Safety Bureau, 2018). However, when interviewing participants, the general consensus highlighted that seafarers believe that as sophisticated systems become commercialised, there is a great risk of an over-reliance on the system. Moreover, the participants of the *Interview Study*, believed that the inclusion of the OOW on the bridge would act as a fail-safe if they insert themselves into the decision making loop, the belief is that aspects such as fault diagnostics and fault recognition skills must be more prevalent in future MASS officer skill sets.

As seafarers are understanding of the risks associated with perceived reliable and sophisticated systems, it was then possible to clearly direct the narrative for the subsequent simulator studies presented in Chapters 6 and 7. With research identifying the wide variety of dangers that can be associated with onboard automation failure, the inclusion of both automated and mechanical failures was critical for the design of the *Pilot Study* (Demirel, 2019). Subsequently from the *Pilot Study* it was found that 70% of participants failed to react to the automated fault, GDF, whereas 5% failed to react to the mechanical fault, ROF. The findings from the *Pilot Study* differed from those of prior research, from which the expectation would be that more participants would have reacted to the automated fault (Pazouki, et al., 2018). The *Pilot Study* also identified that despite seafarers being able to correctly identify the fault on paper, as shown in the *Survey Study*, in a dynamic environment setting such as a simulator, seafarers in general will have difficulties identifying an automated fault. This was further supported by the findings of the *Final Study*, where again 70% of participants failed to identify a fault with the automated system. Subsequently, the findings of the *Final Study* identified that while 30% of participants had successfully recognised the fault, only three out of the 60 participants that completed the simulator exercise had exhibited the knowledge and understanding to successfully diagnose the gyro drift fault. Furthermore, the findings of the *Final Study* identified concerns with the practical knowledge levels of seafarers and align with both research and maritime incidents that have occurred due to a lack of understanding or system malfunction (Mallam, et al., 2020; Australian Transport Safety Bureau, 2018).

The findings of this thesis have identified that there is an evident lack of fault awareness skills displayed among seafarers that may negatively impact the development of the introduction of autonomous systems onboard MASS class vessels. The findings have shown that while seafarers can accurately select appropriate responses to text based scenarios, when presented with a dynamic setting seafarers will rely on the navigational system to maintain course headings. Moreover, this thesis has identified that seafarers have an awareness of the human factors challenges surrounding MASS, yet there is no research identifying that the MET sector has taken the steps to update the training regime for the OOW. Furthermore, with the maritime industry looking to develop decision aid technology, skills such as fault diagnosis, recognition and critical thinking will begin to take precedence in the OOW skillset, as such seafarers must hone such skills prior to the commercialisation of autonomous navigational systems.

8.3.3 Research Question 3: Do demographic variables such as age, education level, sea experience or rank have an impact on the seafarers' opinions of autonomous shipping?

To address this question, the findings of the *Survey Study* and *Interview Study* were primarily used. The MOQ and PES, of the *Pilot Study* and *Final Study* respectively, were conducted as supporting studies to provide further information to address this research question. Each study allowed participants to be grouped by the demographic variables stated in the research question. Furthermore, each study then provided further information as to the importance of each demographic variable.

As MASS looks to be integrate with seafaring system operators, for at least the initial stages, the OOW should be aware that such systems do not indicate the extinction of the seafaring career yet imply that the onboard role of the OOW will evolve (Kim, et al., 2019). Research into the maritime human automation relationship has suggested that seafarers are accepting of new technology (Bogusławski, et al., 2022). However, further work needs to be conducted by the maritime industry to educate seafarers on what MASS will mean for the industry and their livelihoods (Kenney, et al., 2022). Furthermore, the introduction of MASS will affect seafarers with a wide variation of backgrounds, experiences and age. As such with research in wider fields having identified that variables such as age have an influencing factor on trust in automation (Mcbride, et al., 2010; Winter, et al., 2014), the development and conduct of the studies aimed to capture a wide variety of participants to assess the variables stated within RQ3.

The findings of the *Survey Study* offered a preliminary insight to develop the foundations that would ultimately shape the subsequent studies of the thesis. The findings of the *Survey Study* had shown that the participants had responded favourably to the introduction of MASS, which contradicts previous research (Theotokatos, et al., 2023). Moreover, when analysing the individual variables, it was found that the results of the *Survey Study* had identified statistical significance between the demographic groupings of participants within *"Views on Autonomy"* Item 3 – Benefit and Item 4 – AHI, in addition to *"Trust in Autonomy"* Item 3 – Alarms, as shown in Table 4.2. However, the *Survey Study* failed to identify a definitive demographic variable that could influence the participants' response that would relate to the trust and opinion on autonomous shipping, from the perspective of the OOW.

The subsequent studies conducted in this thesis offered supporting analysis into the views on autonomous shipping from the seafarers perspective. The findings of the MOQ identified that while the participants were in favour of onboard autonomous systems, the analysis did not identify a definitive influence from the demographic variables of the participants. Subsequently, the findings of the PES had further aligned with the findings of the *Survey* and the *Pilot* studies in showing enthusiasm among both qualified unqualified officer participants towards MASS whereas the studies did not identify any distinguishable difference between the qualification levels of participants. Moreover, despite studies identifying that generally older individuals are more favourable of decision making aids (Lou & Sun, 2021), the studies conducted in this thesis did not support this theory. With the maritime industry looking to implement MASS in the near future, seafarers of all backgrounds had a similar outlook towards autonomous systems.

From research the expectation indicated that demographic variables such as age and education level, in addition to experience, would have had an influencing factor on the opinions that seafarers have towards MASS (Tang, et al., 2020; Mcbride, et al., 2010; Hannaford, et al., 2022). However, it is concluded that while certain experiences with automation differ depending on the rank and length of time spent at sea, the opinions of the OOW are not influenced by demographic variables.

8.3.4 Research Question 4: Do seafarers lack the concentration skills to maintain the safety of the vessel?

In preparation to address this question multiple aspects of all four studies were assessed. The development of all studies was to incorporate the understanding that the modern day OOW has an overwhelming focus on paperwork and administrative tasks resulting in situations that endanger the vessel (The Mission to Seafarers, 2021). With the emphasis on paperwork occupying the mental capacity of seafarers, there is a risk of the OOW losing their SA resulting in endangering the vessel (Baumler, et al., 2020). In the ever changing landscape of technology in addition to an individual's desire to have accessibility to home life, personal technology has become prevalent in the daily life of a seafarer, to the point that personal devices have been acknowledged as a perpetual distraction for seafarers on the bridge (Fan, et al., 2023). Subsequent research into HAT has identified the benefits for the operators' SA that autonomous systems will bring (Demir, et al., 2017). However there remains the risk that, in the event of the humans being out of the decision making loop, the lack of SA can result in further maritime incidents, which is a potential cause of excessive paperwork and similar bridge based distractions.

The *Survey Study* aimed to identify whether the participants were capable of understanding the hierarchy of task priority during a navigational watch. The data analysis of the SJQs conducted in the *Survey Study* identified that the participants would not jeopardise the safety of the vessel by not reacting to a malfunction in favour of completing paperwork, with the majority of participants selecting R1 – Record the fault…as the least appropriate response. Furthermore, the analysis of the *Survey Study* identified that the participants believe alarms can increase their SA yet did not agree that fatigue could influence their trust in automation. Subsequently, the findings of the *Interview Study* highlighted that the interviewees believed that while the are many onboard distractions that an OOW could face during their watch, the individual should not be easily distracted and lose concentration. However, the interviewees expressed their awareness that aspects such as insufficient manning and fatigue can impact the concentration levels of the OOW, which closely aligns with the findings from similar studies (Rajapakse & Emad, 2023).

The knowledge gained from both the *Survey Study* and *Interview Study*, factored into the development of both simulator studies conducted in this thesis. From the *Interview Study* many interviewees had alluded to the idea of keeping the officer in the loop with one interviewee stating "*What we don't want is a situation where something goes wrong with the automation, and it tells the human you take over now. Because the human hasn't been in the loop and isn't* *situationally aware”*. The ideas of both HITL and OOW distractions were incorporated into the subsequent the *Pilot Study* and *Final Study*.

Additionally, by implementing the finer details of a navigational watch, developed from the findings of the *Survey Study* and the *Interview Study*, it was then possible to develop simulator studies that offered an extra dimension of realism to the exercises. The realism aspect of the faults within the simulator exercise was achieved using the SJQ scenarios as a foundation in the design phase of both the *Pilot Study* and *Final Study*. The inclusion of paperwork in the exercises served as a distraction that has been revealed as an overwhelming demand of the OOW occupation (The Mission to Seafarers, 2021).

The findings of the *Pilot Study* highlighted that there was the potential for participants to focus too much on secondary tasks, such as their workbooks, and have an over reliance on the autopilot maintaining a safe navigational course on the participant’s behalf. Moreover, the findings of the *Pilot Study* had shown that out of the 50 participants, only eight participants reacted to the gyro drift prior to the sounding of the cross track alarm. Additionally, with the aid of the cross track alarm a further 7 participants successfully recognised the existence of a fault. Of the 15 participants acknowledging that there was a system fault, only six had accurately diagnosed the gyro drift malfunction. Ultimately, from the findings of the *Pilot Study* alone, it could be concluded that the majority of seafarers are not equipped with the concentration skills to account for an automated malfunction.

This result was supported in the findings of the *Final Study* where a further 70% of seafaring participants failed to react to a gyro drift, despite being given longer to identify the fault. Through the findings of the *Final Study*, it can be seen that the concentration that an individual applies to the workbook is not indicative of their success in recognising the fault, as the participants that had completed the most and least paperwork, both failed to recognise the gyro drift. The findings of both simulator studies have shown that future technologies and navigational systems must introduce aspects of the system that can build on the system design of the wheelhouse BNWAS, which support the theory stated in past research (Rylander & Man, 2016).

8.3.5 Research Question 5: Do demographic variables such as age, education level, sea experience or rank have an impact on the fault recognition and fault diagnostic skills of navigational officers?

The findings of the *Survey Study* and *Pilot Study* were primarily used to address this question. Variables such as age and experience have been defined as possible factors that can impact an individual’s trust in automation (Hoff & Bashir, 2015). From the introduction and integration of autonomous technology in the aviation industry, the age of an operator has been identified as a potential cause for concern due to the complexity of user interfaces. As such, the aviation sector has adapted automated technology to be integrated with a simple to use interface (Kaminani, 2011). With the maritime industry looking to implement autonomous systems onboard future vessels, it is the current cohort of officers that will have to cope with the learning curve of autonomous shipping including developing skills such as fault diagnosis, fault recognition and critical thinking (Aboul-Dahab, 2021).

When analysing the correlation between the demographic variables it was confirmed that there was a positive linear correlation among rank, age, education level and sea going experience, indicating that individuals of a higher rank tend to be older, have more experience at sea and have a higher educational level due the increasing level of study required to be promoted at sea. The SJQ section of the *Survey Study* provided an initial insight into the fault recognition skills of seafarers. However, the findings of the SJQs showed no differentiation between the categorical groupings of the participants, with the vast majority of participants responding in a similar manner for each question. Similarly, the demographic variables of the participants had no impact on the response patterns of the individuals. Subsequently, many opinions of interviewees from the *Interview Study* highlighted that they believed that all OOW, irrespective of demographic variables such as age; education level; nationality; or rank, can have their navigational skills influenced by their circumstances. Additionally, interviewees highlighted that such skills should be continuously trained to overcome the psychological hurdles associated with seafaring.

Through the *Pilot Study*, the demographic variables of participants allowed age, rank and educational level to be analysed. Over three different exercises, the results in fault recognition success varied greatly, with 90% of participants being successful in recognising the mechanical fault whereas only 30% of participants recognised the automated fault. However, the analysis of the demographic variables identified groups that were of a higher rank, older and of a higher education level were more adept in recognising both the mechanical and automated faults. Due to the link between the variables, it can be assumed that younger and less experienced participants had yet to fully develop their fault recognition skill. The fault diagnosis skills of the participants were then analysed using ETA, where it was identified that from all participants, ten individuals were successful in following the appropriate safety protocol and diagnosing the rudder offset fault whereas six individuals correctly identified the gyro drift and followed the appropriate safety procedure. However, of the participants who were fully qualified OOW, six of the 14 participants correctly identified the ROF, and four of the 14 participants diagnosed the gyro drift malfunction. The findings of the *Pilot Study* indicate that, in the event of an automated fault, seafarers in general have difficulty in recognising the fault. However, the findings show that as the rank of an individual increases so do their fault recognition skills. Similarly, the analysis of the fault diagnosis skills, indicated again that the rank of an individual has a positive impact on such skill sets.

The primary focus of the *Final Study* was to assess the impact of the training that participants received. Through the findings of the Fisher Exact tests, it was identified that the behavioural training has been proven to be valuable and improved the individual's success in fault recognition and diagnosis, whereas the effects of rank are not as impactful.

8.3.6 Research Question 6: Can a different training method improve the fault recognition and fault diagnostic skills of seafarers?

To address the final question, the findings of the *Final Study* were primarily used. Additionally, various aspects from both the *Survey Study* and *Interview Study* were used to introduce the perspective of the OOW which ultimately provided the rationale and recommendations for the possible changes to the maritime curricula and syllabi. The global COVID-19 pandemic brought about multiple shifts in the delivery of education and training within the maritime industry, with emphasis being removed from class based learning to introducing technology and practical learning that can benefit OOW students (Abercrombie, 2021). Moreover, the maritime industry has the tools to develop future skills of seafarers by means of ship simulators which allow seafarers to practice their navigational skills in a controlled environment and work on navigational systems and bridge management skills that they would use on board. Going forward into the digitised maritime world this offers a tremendous benefit (Brandsæter & Osen, 2023; Oliveira, et al., 2022). Currently, simulation is not a well-used tool to deliver education, with the primary use of simulators being to develop complex navigational procedures through STCW approved short courses and to supplement sea going time for maritime cadets (Maritime and Coastguard Agency, 2022). However, with the introduction of autonomous shipping firmly within the foreseeable future, the aim of simulator work should not be to replace sea time, due to the wealth of experience gained, but to compliment practical experience by increasing the volume of time for an individual to spend in the simulator (Evidente, et al., 2022). Furthermore, the introduction of autonomous shipping could render subjects such as celestial navigation and paper chartwork extinct in favour of introducing technical subjects focusing on system technology use (Aylward, et al., 2022; Rylander & Man, 2016).

One of the key objectives of the *Survey Study* was to ascertain whether seafarers could consciously express their trust in a system. The findings detailed in the *Survey Study* show that seafarers are wary of automation and autonomous systems, which may be due to the uncertainty behind the design of autonomous systems. However, as autonomous systems are developed, the participants were more comfortable in trusting sophisticated systems providing that they had sufficient training. This matter was further reaffirmed from the opinion that autonomy and automation should only be operated under the supervision of a trained operator which aligns with the narrative detailed from research (Grønsund & Aanestad, 2020). Furthermore, as previously stated in Section 8.3.1, the belief among the interviewees of the *Interview Study* is that future curricula and syllabi should introduce subjects such as critical thinking and SA training that can improve the awareness of the risks of complacency and fatigue for the OOW, with such training taking place in bridge watchkeeping simulators:

"We will need to incorporate more simulation training as this will help develop and sharpen different skills that we use at sea. Also using simulators will let us understand the risks associated with watchkeeping such as complacency and fatigue" (Interviewee 2)

With one of the key findings of the *Pilot Study* being that only 30% of participants were successful in recognising an automated system malfunction, the aim of the subsequent work was to develop a study that compared the success rates, in terms of fault recognition and fault diagnosis skills, of the OOW depending on the training package they had received. Two distinct training packages were developed from the perspective of seafarers gained from the *Survey Study* and *Interview Study*. The *Final Study* used two groups of participants that received one of the two training packages, the behavioural training package (detailing subjects such as SA, AB and complacency) or the technical training package (detailing the technology that will be impacted by autonomy i.e., autopilot, ECDIS and radar), with the intent to understand whether the training an individual receives can impact their fault recognition and diagnosis skills.

The findings of the *Final Study* showed that the training a participant received can have a great influence in recognising the automated fault. Participants that received the behavioural training package had a success rate of 50%, whereas the participants receiving the technical training package (detailing the technology that will be impacted by autonomy i.e., autopilot, ECDIS and radar) had a success rate of 10%. As discussed in Chapter 7, the participants that received the behavioural training pack outperformed the participants receiving the technical training package. However, despite having an improved success rate, the behavioural trained participants were not infallible, despite receiving training that described human factors the participants were not immune to a degradation of SA and resultant complacency.

The Fisher Exact tests identified that behavioural training has a beneficial impact on the fault recognition and diagnosis skills of the participant, more so than technical training or qualification level. A tentative interpretation of the findings may be that the behavioural training improved the fault recognition and diagnosis skills of unqualified participants to the level of the qualified officers receiving technical training, thus negating the effects of qualification level. Moreover, for highly qualified officers, behavioural training still improved their performance in the exercise, indicating that well qualified officers are amenable to the benefits of a more behavioural orientated training package. Nevertheless, as future MET is developed it is apparent that focusing training on subjects such as SA, AB, complacency and critical thinking, can have a positive influence on an individual's fault recognition and fault diagnosis skills set.

8.4 Recommendations for the Maritime Industry

With the research questions addressed, the focus now will be to document how the work conducted in this thesis can impact the maritime industry.

8.4.1 Development of the OOW role

As the maritime industry looks to commercialise and implement autonomous systems, the role of the OOW is set to undergo an evolutionary step towards the future of seafaring. Recent history has seen the maritime industry experience an overwhelming turnover of cadets that has consequently led to a maritime officer shortage and a generational skill loss (Gekara, 2009). Considering the shortage of maritime officers along with the aging cohort of current mariners, it is apparent that the maritime industry must create excitement and enthusiasm in the future to combat the downturn of seafaring roles (Department for Transport, 2022; Bateman, 2009). The findings of this thesis have shown that OOW do have concerns regarding the security of their livelihood. However, through further investigation, it appears that the concerns are more around the safety and design of the system due to the systems being designed with a perceived lack of input from seafarers and potential misunderstanding of the daily work life of the OOW. Furthermore, the seafaring cohort are aware that while there may be fewer seafaring careers in the future, they expect the maritime industry to evolve the role of the OOW to incorporate more technological knowledge and that current seafaring knowledge will still be required in remote control command centres.

For the OOW, the safety of vessel, crew and cargo is critical in daily vessel operations. In the event of accidents occurring there may be catastrophic consequences for the safety of the vessel, global economy and potentially the environment (Forti, et al., 2022). As would be expected, this external pressure can have an impact on the OOW. As autonomy is gradually introduced, the expectation among the participants of this thesis is that crewing numbers will be further reduced. With crew numbers on the decline, due to redundancies, it is critical that seafarer wellbeing is at the forefront of discussions in the everchanging landscape of autonomous shipping (Bateman, 2009; Brooks & Greenberg, 2022). Given the wide variety of potential stressors, it can be understood how maritime accidents can occur due to negligence or complacency (MAIB DMAIB, 2021). Such concerns regarding workload, mental health due to lack of onboard communities and external stressors have been identified by the participants of the studies as further areas of concern for the OOW. Furthermore, the findings of the *Pilot Study* and *Final Study* support the theory that external pressures and stressors can negatively influence an individual's decision making and trust in the system (Dominguez-Péry, et al., 2021). As such the maritime industry should look to improve the working life of seafarers to promote the harmonisation of autonomous navigational systems, which could have a beneficial impact on the morale of the OOW and result in an enhanced level of SA during their watch.

The themes of lack of concentration, distractions and watchkeeping vigilance were analysed throughout the studies of this thesis. Irrespective of the ongoing debate of human error being the leading cause of maritime accidents (Allianz Global Corporate & Specialty, 2022; Wróbel, 2021), the outcome is still consequential of the human operator. The findings of the *Interview Study* have shown that seafarers are understanding of the impact of human error, yet many interviewees disagreed with the simplistic statement that "X% of all maritime accident are caused by human error". Moreover, certain interviewees alluded to human error being symptomatic of a deep rooted failure, whereas other interviewees discussed the lack of events being documented where human intervention rectified system failures. As discussed in Chapter 2, despite the sophistication of automation and autonomous systems, no machine is infallible. Within the maritime environment, systems are susceptible to adverse effects from forces such as vibration, extended use and heat (Łosiewicz, et al., 2019; Johnson & Holloway, 2007). Furthermore, as identified through the *Interview Study*, the majority of work conducted at sea is a form of preventative maintenance thus requiring the presence of seafarers onboard, which supports the outcomes of the scoping exercise conducted by IMO (MSC - IMO, 2018). Moreover, as autonomous systems are introduced, research has identified SA and leadership as critical skills that should be adopted into the OOW skill set (Kim, et al., 2019). Conversely, through the findings of both the simulator studies designed for this thesis and past maritime accidents, the data suggests that OOW have a challenge to overcome to improve their navigational behavioural skills, such as SA, concentration levels and vigilance, to ensure that they are on par or superior to their current navigational seafaring skill set. The data from this thesis suggests that the improvement of the OOW navigational behavioural skill set can positively influence the fault recognition skills of the OOW.

8.4.2 Complimenting education for the OOW skill set

The maritime industry is currently on the cusp of a radical change that will not only impact vessel and port operations but will have a substantial effect on the future of MET (Aboul-Dahab, 2021). Since the COVID-19 pandemic, trainee seafarers and MET facilities have had to adapt to a new method of blended learning through simulation and classroom learning, with some nations opting to use simulation time to supplement sea going experience (Dewan, et al., 2023; Uitterhoeve & Leunen, 2021). While simulators have evident benefits such as being able to hone skills in a safe working environment (Wahl, 2020), the interviewees opposed the theory of allowing simulator work to replace time at sea stating that simulation training should be used to compliment navigational sea time and potentially replace classroom based learning, which supports the response from past research (Evidente, et al., 2022).

The main focus for simulators is to develop the knowledge of seafarers in short courses such as NAEST and Human element leadership and management (HELM) (Maritime and Coastguard Agency, 2022). However, as the maritime industry looks to introduce autonomous systems onboard, human operators will require a safe environment to learn and develop their skills prior to embarking on a vessel. Through both the *Pilot Study* and *Interview Study*, it was identified that seafarers are aware that future systems will require further education, with the expectation that such training would be a mandatory requirement to go to sea and be of a high personal financial expense. Furthermore, many interviewees suggested the idea of increasing training onboard to alleviate the pressures on MET facilities as this potential method of training would require seafarers to undergo short interactive training videos that could improve an individual's navigational behavioural skill set. Nevertheless, the interviewees continuously expressed their enthusiasm to develop competence-based training within the simulator, with many participants believing that an annual simulator based high intensity short course would be the optimum method to educate the seafaring cohort about future technology and SA.

Irrespective of whether autonomous systems will be taught via a short course or not, the long term outlook for the maritime industry will be to integrate subjects into the maritime officer syllabus with the approval of STCW legislation (Emad & Ghosh, 2023). Subsequently, it has been documented that, as the maritime industry has progressed towards the 21st century, MET still educates cadets on outdated subjects, such as celestial navigation and paper chart work, and how to use obsolete tools such as sextants and parallel rulers in favour of systems that an OOW would continuously use onboard (Aylward, et al., 2022). This perspective was shared by the participants of both the *Survey Study* and *Interview Study*, with many individuals believing that there is too little focus on technology within MET and that current cadets are not going to sea to use outdated tools so struggle to educate themselves. However, the findings of the *Final Study* had shown that educating individuals on technical subjects does not have much benefit on the fault recognition skills of an OOW, whereas educating an OOW on behavioural subjects can improve the awareness of an individual to identify a system malfunction. Therefore, future subjects should not solely teach students how to use systems but should also aim to educate future officers on how to combat human factors and improve their watchkeeping skills. Utilising a blended learning method may allow the student to learn topics in the classroom and then consolidate their understanding in the bridge watchkeeping simulator, which supports the theory determined from past research (Nakashima, et al., 2023).

8.4.3 Strengthening the human automation relationship

In the early stages of autonomous shipping, the IMO has already determined that the introduction of MASS will not be an instantaneous event and will require human operators to supervise and work together with such systems (Kim, et al., 2019). Therefore, the maritime industry should look towards research being conducted in HAT, as a foundation to optimise future systems to promote the human automation relationship (Zhang, et al., 2020). Moreover, early maritime projects that featured autonomous shipping looked towards the development of autonomous shipping infrastructure which included the design of remote control command centres to operate vessels within a defined proximity (MUNIN, 2017). As such, both the immediate and distant future of MASS will incorporate some form of OOW and HAT. Moreover, as autonomy becomes more sophisticated, research has identified that the way to improve HAT is by the human operator treating the system as an equal rather than a tool (Ellwart & Schauffel, 2023). The findings of both the *Survey Study* and *Interview Study* identified that seafarers believed that automation and autonomy should only be used under the supervision of a suitably trained operator, which supports the current theories of HAT. The interviewees believed that future systems must implement decision support to enable the seafarer to understand the situation further. However, when requested to monitor the procedures of an automated system and maintain a safe watch in both the *Pilot Study* and *Final Study*, it was shown that seafarers were trusting of a system that they had perceived to be reliable and ultimately suffered from a form of AB by trusting the system over their judgement and knowledge of the situation. As such, future systems should incorporate a simple user interface decision aid technology that prompts the human operator to make a judgement based off their own knowledge set, which would promote the synchronisation of HAT.

Vessel accidents are often avoidable with many incidents occurring over a gradual period of time that gives the officer ample warning to rectify the situation (Marine Accident Investigation

Branch - MAIB, 2019). Moreover, with the potential for autonomous systems to be integrated as part of a blended HAT crew, communication and HITL are critical features that must be addressed in the concept design phase to reduce the likelihood and magnitude of potential incidents (Vagale, et al., 2022; Mišković, et al., 2022). This theory was further supported through the findings of the *Interview Study* with many interviewees highlighting the importance of maintaining the OOW in the decision making loop and one interviewee stating "*The worst case scenario is "a captain's asleep in his room at night. And gets an alarm saying the system just shut down because there's been a problem…and he doesn't know what's happening" because… somebody hasn't been in the loop*" (Interviewee 7). Subsequently, such opinions lead to development of both the *Pilot Study* and *Final Study*, which highlighted the criticality of remaining in the loop despite the possible distractions that an OOW may encounter. As such, the data from this thesis suggests that the key to the success of MASS is dependent on the human automation relationship. Moreover, the way to improve this relationship may be to increase the input from the OOW in the design phase of the autonomous system.

8.5 Chapter Conclusion

This chapter has presented the main findings which correspond to the research questions outlined within Chapter 1. Each question was discussed and addressed from the studies, both individually and as a collective, and their relevance in comparison to current literature. The chapter then provides the recommendations of how to optimise this work with regard to the impact it can have on the maritime industry in relation to the development of the OOW role, how this work can be utilised to improve MET for the OOW and the impact that it will have on the maritime human automation relationship. The following chapter will detail the overall conclusion of the thesis, discuss the direction for future maritime human factors research by utilising the findings of this thesis and present the contribution of the findings in the research field of maritime human factors.

Chapter 9. Conclusion

9.1 Introduction

The current trajectory for the maritime industry has already seen multiple manufacturers begin the development of, and conducting tests on, MASS. Therefore, it can safely be assumed that the dawn of autonomous shipping is on the horizon. As with any technological advancement, the introduction of MASS could potentially create unrest within the seafaring community and require further training to fully optimise the use of such sophisticated systems.

The work conducted in this thesis centred around the investigation of the human factors exhibited by maritime navigational officers. This was achieved through four independent studies that analysed various critical aspects of seafaring that will be impacted as highly sophisticated autonomous systems are introduced. The thesis introduced six research questions that have been answered to aid the development of OOW skills and the integration of autonomous systems.

Following the development of the aforementioned questions this thesis then sought out to deliver the answers to these questions, by introducing four studies associated with this thesis:

- *Survey Study*
- *Interview Study*
- *Pilot Study*
- *Final Study*

Through conducting these studies, it was identified that the current cohort have a lack of problem solving skills that enable them to compliment highly sophisticated automated and autonomous systems, in a HAT environment. With autonomous systems currently in the design phase, this work was conducted using modern automated systems and analysing the human factors that impact the safety of the vessel. The work conducted in this thesis identified areas of concern with the current OOW cohort and their navigational skill set as neither efficiently transfer from manual to autonomously controlled vessels. However, this work has delivered a platform that can benefit future syllabi and curricula for the OOW, by defining the following core subjects to be implemented into the navigational OOW training regime:

- Situational Awareness
- Critical Thinking
- Fault Recognition and Fault Diagnosis

- Hazards Associated with AB and Complacency

Nevertheless, as the maritime industry has its sights focused on the digitisation of navigational systems, it is critical that the standards of training from both MET and shipping companies must be improved to ensure the overall success and limit the potential incidents that may arise with the introduction of autonomous shipping. Ultimately, the work presented in this thesis has provided an insight into smoothing the learning curve for the OOW, while defining the key topics that should be introduced to future OOW training regimes.

9.2 Research Contributions

The maritime industry is currently in the early stages of autonomous shipping and as such is producing a wide variety of literature for the design and implementation of autonomous systems. However, there is a lack of research into maritime human factors. This thesis is one of the first substantial pieces of work in the maritime human factors research field for the autonomous navigational sector. As such this thesis has developed a platform for future work, from both academic and industrial research whilst providing six key contributions to the research field of maritime human factors.

Contribution 1: Defined subjects that should be introduced to curricula.

The work from this thesis has discussed many potential subjects that may be introduced to future navigational officer training regimes. Past research has determined various subjects such as leadership, fault diagnosis and critical thinking should be incorporated to future curricula (Aboul-Dahab, 2021; Kim & Mallam, 2020). However, as new regimes are defined, the inclusion of behavioural training including topics such as SA, AB and complacency is critical for the success of the OOW in the autonomous age of shipping.

Contribution 2: Identified that seafarers must undergo further training to acclimatise to MASS.

The transition to autonomous unmanned vessels will not be an instantaneous event. Therefore, there will be a requirement for human operators at sea for the foreseeable future, considering the current initiative by IMO being to gradually introduce complex autonomous systems and over time transition to autonomous vessel operations (MSC - IMO, 2018). This has promoted research concepts such as HAT and HITL to have a lasting impact within the industry (Zhang, et al., 2020; Grønsund & Aanestad, 2020). As such, many future onboard systems may utilise an advance form of decision making aids and technology, however research has detailed the potential degradation of navigational skills with advanced technology (Lou & Sun, 2021). The findings of this thesis have identified that seafarers currently have a lack of SA through the use of modern automated systems. It is critical for seafarers to undertake further training now so that in the event of technology advancing to the next phase of autonomy and automation, the OOW is equipped with the skills to correct possible malfunctions.

Contribution 3: Highlighted that the rank of an OOW impacts their trust.

The findings of this study have suggested that while age may be linked to variables such as education level, rank and sea experience, it was found that the rank of the individual was the most influencing factor towards trust and SA, with individuals of a higher rank being less trusting of the automated system and having greater SA. However, as statistics have shown, the majority of officers currently holding the rank of Chief Officer or higher are over the age of 40, therefore the expectation is that many of these officers will reach the retirement age within the next 10 – 15 years (Department for Transport, 2022). Without changes to the OOW training regime, the industry will be succeeded by a cohort of seafarers in high ranking positions that are of high risk to over reliance and trusting highly sophisticated systems.

Contribution 4: Determined that seafarers will be welcoming of autonomous systems.

With cadet wastage being a concern for the maritime industry, there is the danger that the industry could potentially lose vital skillsets of seafarers (Gekara, 2020). However, despite the potential loss of seafaring careers that may accompany autonomous shipping, the industry may see an increase of career pathways opening up to combat the current wastage of cadets (Lušić, et al., 2019). The findings of this thesis have delivered data that suggests the introduction of autonomous shipping has created an aura of excitement among the seafaring community. Additionally, this work has shown that many seafarers believe that autonomous shipping has the potential to create new careers requiring the baseline knowledge and skills that young people currently have, which would then benefit the maritime industry as it progresses to the digitised age of shipping.

Contribution 5: Provided a foundation for future autonomous shipping short courses to be developed.

With the current OOW training regime focusing on aspects such as celestial navigation and paper chart work, it can be assumed that there will be a plan to revolutionise the current syllabus of navigational officers to incorporate more simulation and system understanding training (Aylward, et al., 2022). With the development of short courses such as the NAEST Operational and Management courses, the use of simulators have become a method to enable students to develop core skills in a safe working environment (Maritime and Coastguard Agency, 2022; Røds & Gudmestad, 2019). The findings of this PhD have suggested that seafarers believe that the use of bridge watchkeeping simulators must be better utilised in the navigational OOW training regime. The findings of this thesis have suggested that short courses on aspects such as SA can be developed by testing students using a multitude of system failures.

Contribution 6: Provided knowledge about the problem solving skills gap of an OOW.

With the introduction of autonomous shipping comes the conundrum of the industry attempting to identify the various topics that should be taught to seafaring students in future syllabi. By looking at past systems, for example ECDIS, the development of which was underway by the 1990s (Greer, 1994), there are still continual issues that result in maritime incidents due to a lack of understanding with the system (Marine Accident Investigation Branch - MAIB, 2013; Marine Safety Investigation Unit, 2018). However, over the course of the next four decades many maritime accidents have been attributed to the lack of knowledge with the system and due to the multiple designs of the system there is a lack of familiarity (MAIB DMAIB, 2021; Žuškin, et al., 2023). Tempering the expectations of autonomy and improving the understanding of technology for current officers offers the potential for a smoother transition to MASS. Beyond educating the OOW on future systems that currently have yet to be designed, the industry can focus on educating students on the behavioural aspect of seafaring, offering many officers the opportunity to hone skills such as fault recognition; fault diagnosis; and SA, in addition to learning about the hazards of AB; and complacency, resulting in a cohort of seafarers equipped with the problem solving skills to compliment autonomous shipping.

9.3 Future Research

As the maritime industry looks to implement MASS, multiple aspects of the seafaring role and MET sector must be addressed prior to commercialisation. The findings of this thesis have presented the foundation for future simulator studies to be conducted. Despite the findings of this thesis identifying a multitude of factors that will aid the development and implementation of autonomous navigation systems, there are still a variety of factors surrounding autonomous shipping that either remain unanswered or have arisen through the development of this thesis. The key recommendation for future research would be to develop future simulator based studies on an international scale.

The main body of this work has been conducted primarily with British based navigational OOW, the UK based maritime officer training regime and UK Merchant Navy training sector. Therefore, the work has limited itself to a UK merchant navy bias. However, this research is highly transferable between the training regimes developed for other countries therefore, for future research it is recommended that work should be expanded to understand the subtle differences within the MET sector for different nations. Replicating this research for other nations may result in the recognition of deficiencies with the fault recognition and fault diagnostic skills of OOW of other nationalities or it may identify optimal training methods that could benefit the OOW in the introduction of autonomous shipping and which should be implemented globally.

This research has shown the positive impact that a 5-minute training package, on OOW behavioural traits can have on the fault recognition skills of participants. Therefore, this has suggested that the OOW may be susceptible to being influenced by the training package. As such, while short training packages may be beneficial prior to the OOW undertaking a navigational watch, a critical recommendation for future research would be to increase the duration of the training package. Additionally, it is recommended for future research to improve the quality of the training package to include cognitive response exercises, prior to undertaking a simulated exercise, to understand if the refinement of the training package can significantly improve both the fault recognition and fault diagnosis skills of the OOW.

Despite the evident benefit shown by the participants of the Final Study, one area that would be advantageous to assess is the impacts of a combined training package comparative to no training received. In doing so, there may be further findings that could identify the optimum training topics that could improve the fault recognition and diagnostics skills further.

Autonomous systems currently are in a conceptual phase with IMO, flag states and classification societies developing rules and guidance, hence no studies could be conducted for this thesis using autonomous technology. However, the transition to MASS will not immediately occur and to achieve degree 4 of autonomy (Unmanned) it will be a long process that must include the evolution of the OOW role. As such, this research has been conducted to ensure that the paradigm shift towards autonomous shipping flows as effortlessly as possible since the SA level is dependent on the human operator. Fundamentally from the findings of this thesis if there is no change to the training regime then, as systems increase in sophistication and complexity so will the reliance of the OOW on the system, resulting in a potentially catastrophic accident occurring, which may limit the development of autonomous shipping.

References

Abdushkour, H., Turan, O., Boulougouris, E. & Kurt, R. E., 2018. *Comparative Review of Collision Avoidance Systems in Maritime and Aviation.* Istanbul, The 3rd International Symposium On Naval Architecture And Maritime.

Abercrombie, J., 2021. *Seafarer Training in the Age of Autonomy.* Durban, Springerlink.

Abila, S. et al., 2023. Empowering Seafarers as Agents of Their Mental Health: The Role of Information and Communication Technology in Seafarers' Well-Being. *Inquiry: A Journal of Medical Care Organization, Provision and Financing,* Volume 60.

Aboul-Dahab, K. M., 2021. *The Readiness of the Maritime Education for the Autonomous Shipping Operations.* s.l., Social Science Research Network.

Abramowicz-Gerigk, T., Hejmlich, A. & Wilczyński, P., 2018. Human and operational factors in the risk assessment of ship-to-ship operations. *Scientific Journals Zeszyty Naukowe of the Maritime University of Szczecin,* 56(128), pp. 73-77.

Alessi, S. M., 1988. Fidelity in the design of instructional simulations. *Journal of Computer-Based Instruction,* 15(2), pp. 40-47.

Alfheim, H. L. et al., 2018. Development of a Dynamic Positioning System for the ReVolt Model Ship. *IFAC-PapersOnLine,* 51(29), pp. 116-121.

Allen, R. W., Park, G. D., Cook, M. L. & Fiorentino, D., 2007. *The effect of driving simulator fidelity on training effectiveness.* Iowa City, National Advanced Driving Simulator.

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

Alop, A., 2019. *The challenges of the digital technology era for maritime education and training.* Tallinn, s.n.

Alsos, O. A., Hodne, P., Skåden, O. K. & Porathe, T., 2022. Maritime Autonomous Surface Ships: Automation Transparency for Nearby Vessels. *Journal of Physics: Conference Series,* Volume 2311.

Alsos, O. A. et al., 2022. NTNU Shore Control Lab: Designing shore control centres in the age of autonomous ships. *Journal of Physics: Conference Series,* Issue 2311.

American Bureau of Shipping, 2022. *Autonomous Vessels,* Houston: s.n.

American Bureau of Shipping, 2023. *Rules for Building and Classing Marine Vessels.* [Online] Available at: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://ww2.eagle.org/content/dam/eagle/rules-and-guides/current/other/1-rules-building-classing-marine-vessels-2023/1-mvr-part-4-jul23.pdf
[Accessed 8 July 2023].

Anderson, E., Fannin, T. & Nelson, B., 2018. *Levels of Aviation Autonomy.* London, IEEE.

Andrei, D. M., Griffin, M. A., Grech, M. & Neal, A., 2020. How demands and resources impact chronic fatigue in the maritime industry. The mediating effect of acute fatigue, sleep quality and recovery. *Safety Science,* Volume 121, pp. 362-372.

Australian Transport Safety Bureau, 2017. *ATSB Transport Safety Report - Grounding of the ABFC Roebuck Bay,* Canberra: Australian Transport Safety Bureau.

Australian Transport Safety Bureau, 2018. *Grounding of the landing craft Lauren Hansen,* s.l.: Australian Government.

Aylward, K. et al., 2022. Navigators' views of a collision avoidance decision support system for maritime navigation. *The Journal of Navigation,* 75(5), pp. 1035-1048.

Balyan, R. & Dhankher, D., 2023. Analyzing the Effective of Training Needs Analysis in Shipping Industry. *International Journal Of Innovations In Engineering Research And Technology,* 10(3), pp. 85-95.

Bao, J. et al., 2021. Key factors affecting the quality of maritime education and training: empirical evidence from China. *The Journal of Navigation,* 74(2), pp. 396-408.

Baric, M., Grbić, L., Pericin, L. & Jelic, R., 2023. The Role of the ECDIS on the Development of Situational Awareness – a Study on Grounding Accidents. *TransNav - The International Journal on Marine Navigation and Safety of Sea Transportation* , 17(1), pp. 219-225.

Bartolucci, A., Casareale, C. & Drury, J., 2021. Cooperative and competitive behaviour among passengers during the costa concordia disaster. *Safety Science,* Volume 134.

Batalden, B.-M., Leikanger, P. & Wide, P., 2017. Towards autonomous maritime operations. *IEEE International Conference on Computational Intelligence and Virtual Environments for Measurement Systems and Applications,* pp. 1-6.

Batalden, B.-M. & Sydnes, A. K., 2013. Maritime safety and the ISM code: a study of investigated casualties and incidents. *WMU Journal of Maritime Affairs,* Volume 13, pp. 3-25.

Batchelder, W. H. & Narens, L., 1977. A CRITICAL EXAMINATION OF THE ANALYSIS OF DICHOTOMOUS DATA. *Philosophy of Science,* Volume 44, pp. 113-135.

Bateman, S., 2009. Maritime security implications of the international shipping recession. *Australian Journal of Maritime and Ocean Affairs,* 1(4), pp. 112-120.

Bauldauf, M. et al., 2016. Multidimensional simulation in team training for safety and security in maritime transportation. *Journal of Transportation Safety & Security,* 8(3), pp. 197-213.

Baumler, R., Bhatia, B. S. & Kitada, M., 2020. Ship first: Seafarers' adjustment of records on work and rest hours. *Marine Policy,* Volume 130.

Baum-Talmor, P. & Kitada, M., 2022. Industry 4.0 in shipping: Implications to seafarers' skills and training. *Transportation Research Interdisciplinary Perspectives,* Volume 13.

Baylon, A. & Santos, E., 2015. Attractions, Problems, Challenges, Issues and Coping Strategies of the Seafaring Career: MAAP Seafarers Perspectives. *Safety of marine transport: Marine navigation and safety of sea transportation,* pp. 21-30.

Bogusławski, K., Gil, M., Nasur, J. & Wróbel, K., 2022. Implications of autonomous shipping for maritime education and training: the cadet's perspective. *Maritime Economics & Logistics,* 24(Special Issue - Autonomous Shipping), pp. 327-343.

Bolbot, V. et al., 2020. *Paving the way toward autonomous shipping development for European Waters – The AUTOSHIP project.* London, The Royal Institution of Naval Architects.

Boysen, N., Briskorn, D. & Rupp, J., 2023. Optimization of two-echelon last-mile delivery via cargo tunnel and a delivery person. *Computers & Operations Research,* Volume 151.

Brandsæter, A. & Osen, O. L., 2023. Assessing autonomous ship navigation using bridge simulators enhanced by cycle-consistent adversarial networks. *Proceedings of the Institution of Mechanical Engineers, Part O: Journal of Risk and Reliability,* 237(2), pp. 508-517.

Brandt, S. L., Lachter, J., Russell, R. & Shively, R. J., 2017. *A Human-Autonomy Teaming Approach for a Flight Following Task.* Los Angeles, Springer Link.

Bratić, K., Pavić, I., Vukša, S. & Stazić, L., 2019. Review of Autonomous and Remotely Controlled Ships in Maritime Sector. *Transactions on Maritime Science,* 8(2), pp. 253-265.

Braun, V. & Clarke, V., 2006. Using thematic analysis in psychology. *Qualitative Research in Psychology,* Volume 3, pp. 77-101.

Brčić, D., Žuškin, S. & Barić, M., 2017. *Observations on ECDIS Education and Training.* Gdynia, s.n.

Brooks, S. K. & Greenberg, N., 2022. Mental health and psychological wellbeing of maritime personnel: a systematic review. *BMC Psychology,* 10(139).

Brooks, S. K. & Greenberg, N., 2022. Mental health and wellbeing of seafaring personnel during COVID-19: Scoping review. *Journal of Occupational Health,* 64(1).

Brown, J. D., 2011. Likert items and scales of measurements?. *SHIKEN: JALT Testing & Evaluation SIG Newsletter,* 15(1), pp. 10-14.

Bryman, A., Clark, T., Foster, L. & Sloan, L., 2021. Interviewing in qualitative research. In: E. Vacchelli, ed. *Bryman's Social Research Methods.* s.l.:Oxford University Press, pp. 425-451.

Bureau Veritas, 2019. *Guidelines for Autonomous Shipping.* [Online] Available at: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://erules.veristar.com/dy/data/bv/pdf/641-NI_2019-10.pdf
[Accessed 16 June 2023].

Canepa, M., Ballini, F., Dalakis, D. & Vakili, S., 2021. *Assessing the effectiveness of cybersecurity training and raising awareness within the maritime domain.* s.l., INTED2021 Proceedings.

Cao, A., Chintamani, K. K., Pandya, A. K. & Ellis, R. D., 2009. NASA TLX: Software for assessing mental workload. *Behaviour Research Methods,* 41(1), pp. 113-117.

Carey, L., 2017. *All Hands Off Deck? The Legal Barriers to Autonomous Ships.* Singapore: NUS Law Working Paper No. 2017/011.

Carter, N. et al., 2014. The use of triangulation in qualitative research. *Oncology Nursing Forum,* 41(5), pp. 545-547.

Chae, C.-J., Kim, K. H. & Kang, S. Y., 2021. Limiting Ship Accidents by Identifying Their Causes and Determining Barriers to Application of Preventive Measures. *Journal of Marine Science and Engineering,* 302(9), pp. 1-27.

Chen, S. et al., 2013. A Human and Organisational Factors (HOFs) analysis method for marine casualties using HFACS-Maritime Accidents (HFACS-MA). *Safety Science,* Volume 60, pp. 105-114.

Data Protection Act, 2023. *Data Protection Act 2018, c. 12..* [Online] Available at: https://www.legislation.gov.uk/ukpga/2018/12/contents [Accessed 22 August 2023].

Demirel, E., 2019. Possible Dangers Of Automation Failures On Board And Measures To Avoid The Negative Effects Of These Failures. *Scientific Bulletin of Naval Academy,* 22(2), pp. 22-35.

Demir, M., McNeese, N. J. & Cooke, N. J., 2017. Team situation awareness within the context of human-autonomy teaming. *Cognitive Systems Research,* 46(Situation awareness in human-machine interactive systems), pp. 3-12.

Department for Transport, 2019. *Maritime 2050 Navigating the future,* London: Department for Transport.

Department for Transport, 2022. *Seafarers in the UK Shipping Industry: 2022,* London: Department for Transport.

Det Norske Veritas - Germanischer Lloyd, 2018. *Remote-controlled and autonomous ships in the maritime industry,* Oslo: s.n.

Dewan, M. H. et al., 2023. Immersive and Non-Immersive Simulators for the Education and Training in Maritime Domain-A Review. *Journal of Marine Science and Engineering,* 11(147).

Dominguez-Péry, C., Vuddaraju, L. N. R., Corbett-Etchevers, I. & Tassabehji, R., 2021. Reducing maritime accidents in ships by tackling human error: a bibliometric review and research agenda. *Journal of Shipping and Trade,* 6(20).

Dutch Safety Board, 2017. *Digital navigation: old skills in new technology - Lessons from the grounding of the Nova Cura,* The Hague: Dutch Safety Board.

Ellwart, T. & Schauffel, N., 2023. Human-Autonomy Teaming in Ship Inspection: Psychological Perspectives on the Collaboration Between Humans and Self-Governing Systems. *Smart Ports and Robotic Systems* , pp. 343-362.

Emad, G. R., Enshaei, H. & Ghosh, S., 2022. Identifying seafarer training needs for operating future autonomous ships: a systematic literature review. *Australian Journal of Maritime & Ocean Affairs,* 14(2), pp. 114-135.

Emad, G. R. & Ghosh, S., 2023. Identifying essential skills and competencies towards building a training framework for future operators of autonomous ships: a qualitative study. *WMU Journal of Maritime Affairs.*

Endsley, M., 2017. From here to autonomy: Lessons learned from human-automation research. *Human factors: The journal of the human factors and ergonomics society,* 59(1), pp. 5-27.

Endsley, M. R., 1995. Toward a Theory of Situation Awareness in Dynamic Systems. *Human Factors,* 37(1), pp. 32-64.

Esteves, J. & Pastor, J., 2003. Using a Multimethod Approach to Research Enterprise System Implementations. *Electronic Journal of Buisness Research Methods,* 2(2), pp. 69-82.

Evidente, L. G. et al., 2022. The effect of preparatory bridge simulator training on development of situation awareness skills of watchkeepers. *Russian Journal of Water Transport,* 73(4), pp. 226-242.

Fan, L. et al., 2017. A QFD-Enabled Conceptualization for Reducing Alarm Fatigue in Vessel Traffic Service Centre. *Advances in Transdisciplinary Engineering,* Transdisciplinary Engineering: A Paradigm Shift(5), pp. 821-828.

Fan, S. et al., 2023. Incorporation of seafarer psychological factors into maritime safety assessment. *Ocean & Coastal Management,* Volume 237.

Felski, A. & Zwolak, K., 2020. The Ocean-Going Autonomous Ship—Challenges and Threats. *Journal of Marine Science and Engineering,* 8(41).

Fernandez, R. et al., 2007. Using a Human Patient Simulation Mannequin to Teach Interdisciplinary Team Skills to Pharmacy Students. *American Journal of Pharmaceutical Education,* 71(3), p. 51.

Fisher, D. L. et al., 2002. Use of a fixed-base driving simulator to evaluate the effects of experience and PC-based risk awareness training on drivers' decisions. *Human Factors,* 44(2), pp. 287-302.

Forti, N. et al., 2022. Maritime Anomaly Detection in a Real-World Scenario: Ever Given Grounding in the Suez Canal. *IEEE Transactions on Intelligent Transportation Systems,* 23(8), pp. 13904-13910.

Galieriková, A., 2019. The human factor and maritime safety. *Transportation Research Procedia,* Volume 40, pp. 1319-1326.

Gekara, V., 2009. Understanding attrition in UK maritime education and training. *Globalisation, Societies and Education,* 7(2), pp. 217-232.

Gekara, V. O., 2020. Can the UK Tonnage Tax Minimum Training Obligation Address Declining Cadet Recruitment and Training in the UK?. *The World of the Seafarer,* Volume 9, pp. 37-49.

Ghazizadeh, M., Lee, J. D. & Boyle, L. N., 2012. Extending the Technology Acceptance Model to assess automation. *Cognition, Technology & Work,* Volume 14, pp. 39-49.

Gholamreza, E. & Wolff, M. R., 2008. Contradictions in the practices of training for and assessment of competency: A case study from the maritime domain. *Education + Training,* 50(3), pp. 260-272.

Golightly, D., Wilson, J. R., Lowe, E. & Sharples, S., 2010. The role of situation awareness for understanding signalling and control in rail operations. *Theoretical Issues in Ergonomics Science,* 11(1-2 Situational Awareness), pp. 84-98.

Gombolay, M., Bair, A., Huang, C. & Shah, J., 2017. Computational design of mixed-initiative human–robot teaming that considers human factors: situational awareness, workload, and workflow preferences. *The International Journal of Robotics Research,* 36(5-7), pp. 597-617.

Gouraud, J., Delorme, A. & Berberian, B., 2017. Autopilot, mind wandering, and the out of the loop performance problem. *Frontiers in Neuroscience,* Volume 11.

Greer, R. A., 1994. *The United States Navy Electronic Chart Display and Information (ECDIS) development project.* Las Vegas, IEEE.

Grønsund, T. & Aanestad, M., 2020. Augmenting the algorithm: Emerging human-in-the-loop work configurations. *The Journal of Strategic Information Systems,* 29(2).

Guest, G., MacQueen, K. M. & Namey, E. E., 2011. *Applied Thematic Analysis.* s.l.:SAGE.

Hannaford, E. & Hassel, E. V., 2021. Risks and Benefits of Crew Reduction and/or Removal with Increased Automation on the Ship Operator: A Licensed Deck Officer’s Perspective. *Applied Sciences,* Issue 11, p. Paper 3569.

Hannaford, E., Maes, P. & Hassel, E. V., 2022. Autonomous Ships and the Collision Avoidance Regulations: A Licensed Deck Officer Survey. *WMU Journal of Maritime Affairs,* Volume 21, pp. 233-266.

Hanzu-Pazara, R. et al., 2008. Reducing of maritime accidents caused by human factors using simulators in training process. *Journal of Maritime Research,* 5(1), pp. 3-18.

Hart, S. G. & Staveland, L. E., 1988. Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. *Advances in Psychology - Human Mental Workload,* Volume 52, pp. 139-183.

Hasanspahić, N., Vujicic, S., Francic, V. & Čampara, L., 2021. The role of the human factor in marine accidents. *Journal of marine science and engineering,* 9(261), pp. 1-16.

Haughton, C., 2011. *STCW leadership development and management training in practice. Is leadership training a waste of money?.* Manilla, Haughton Maritime.

Hayes, N., 2000. *Doing Psychological Research.* Open University Edition ed. New York: McGraw Hill.

Hjelmervik, K., Nazir, S. & Myhrvold, A., 2018. Simulator training for maritime complex tasks: an experimental study. *WMU Journal of Maritime Affairs,* Volume 17, pp. 17-30.

Hoff, K. A. & Bashir, M., 2015. Trust in automation: Integrating empirical evidence on factors that influence trust. *Human Factors,* 57(3), pp. 407-434.

Ho, G., Wheatley, D. & Scialfa, C. T., 2005. Age differences in trust and reliance of a medication management system. *Interacting with computers,* 17(6), pp. 690-710.

Hwang, T., Youn, I.-H., Lee, S. & Kim, I., 2022. Efficiency Comparison between Audible and Buzzle Alarms of Electronic Chart Display and Information System Alarm under the Simulated Environment. *Journal of Marine Science and Engineering,* 10(2).

IACS, 2019. *International association of classification societies: Position paper - MASS.* [Online]
Available at: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://iacs.org.uk/media/8673/iacs-mass-

position-paper-rev2.pdf
[Accessed 18 May 2023].

IACS, 2022. *Cyber resilience of on-board systems and equipment (E27),* s.l.: IACS.

IACS, 2022. *Cyber resilience of ships (E26),* s.l.: IACS.

IMO - Maritime Safety Committee, 2022. *Development of a Goal-Based Instrument for Maritime Autonomous Surface Ships (MASS),* London: IMO.

IMO - MSC, 2018. *IMO MSC 99 Meeting Summary,* London: Liberian Registry.

International Chamber of Shipping & BIMCO, 2021. *Seafarer Workforce Report,* s.l.: Witherbys.

Issa, M., Ilinca, A., Ibrahim, H. & Rizk, P., 2022. Maritime Autonomous Surface Ships: Problems and Challenges Facing the Regulatory Process. *Sustainability,* 14(23), p. 15630.

Jamil, M. G. & Bhuiyan, Z., 2021. Deep learning elements in maritime simulation programmes: a pedagogical exploration of learner experiences. *International Journal of Educational Technology in Higher Education,* 18(18).

Janssen, T., Baldauf, M. & Claresta, G., 2023. From Ship to Shore – Studies Into Potential Practical Consequences of Autonomous Shipping on VTS Operation and Training. *TransNav - The International Journal on Marine Navigation and Safety of Sea Transportation ,* 17(2), pp. 383-390.

Japan Transport Safety Board - JTSB, 2021. *Marine Accident Investigation Report - Collision Between APL Pusan and Shoutokumaru ,* s.l.: JTSB.

Jensen, O. C. et al., 2006. Working conditions in international seafaring. *Occupational Medicine,* 56(6), pp. 393-397.

Johansen, K., 2023. Challenges regarding digital distance learning of operationally- oriented professions, due to Covid-19 pandemic. *International Journal of Educational Research Open,* 4(100225).

Johnsen, S. O., Hoem, Å., Jenssen1, G. & Moen, T., 2019. Experiences of main risks and mitigation in autonomous transport systems. *Journal of Physics: Conference Series,* 1357(International Maritime and Port Technology and Development Conference and International Conference on Maritime Autonomous Surface Ships 13–14 November 2019, Trondheim, Norway).

Johnson, C. & Holloway, M., 2007. *A Longitudinal Analysis of the Causal Factors in Major Maritime Accidents in the USA and Canada (1996-2006).* Bristol, Springer.

Johnson, R., Onwuegbuzie, A. & Turner, L., 2007. Toward a definition of mixed methods research. *Journal of Mixed Methods Research,* 1(2), pp. 112-133.

Jokioinen, E., 2016. *Advanced Autonomous Waterborne Applications (AAWA) Initiative, Rolls-Royce Marine MESA's "The Connected Ship and Shipping".* Brussels, Rolls Royce.

Jones, T. L., Baxter, M. A. J. & Khanduja, V., 2013. A quick guide to survey research. *Annals Royal College of Surgeons of England,* 95(1), pp. 5-7.

Jo, S., D'agostini, E. & Kang, J., 2020. From Seafarers to E-farers: Maritime Cadets' Perceptions Towards Seafaring Jobs in the Industry 4.0. *Sustainability* , 12(19).

Jurdana, I., Lopac, N., Wakabayashi, N. & Liu, H., 2021. Shipboard Data Compression Method for Sustainable Real-Time Maritime Communication in Remote Voyage Monitoring of Autonomous Ships. *Sustainability,* 13(15).

Kaber, D. B. & Endsley, M. R., 1999. Level of automation effects on performance, sintuation awareness and workload in a dynamic control task.. *Ergonomics,* Volume 42, pp. 462-492.

Kaminani, S., 2011. *Human computer interaction issues with touch screen interfaces in the flight deck.* s.l., IEEE.

Kari, R., Gausdal, A. H. & Steinert, R. M., 2022. EEG Based Workload and Stress Assessment During Remote Ship Operations. *TransNav - The International Journal on Marine Navigation and Safety of Sea Transportation.,* 16(2), pp. 295-305.

Kavallieratos, G., Katsikas, S. & Gkioulos, V., 2019. *Cyber-attacks against the autonomous ship.* Barcelona, Springer Link.

Kenney, M., Gardner, N., Palmajar, E. & Sivori, H., 2022. *Seafarers in the Digital Age - Prioritising the Human Eement in Maritime Digital Transformation,* s.l.: Inmarsat.

Kim, J. et al., 2023. Identifying Optimal Approaches for Sustainable Maritime Education and Training: Addressing Technological, Environmental, and Epidemiological Challenges. *Sustainability,* 15(10).

Kim, M., Joung, T.-H., Jeong, B. & Park, H.-S., 2020. Autonomous shipping and its impact on regulations, technologies, and industries. *Journal of International Maritime Safety, Environmental Affairs, and Shipping* , 4(2), pp. 17-25.

Kim, T.-e. & Mallam, S., 2020. A Delphi-AHP study on STCW leadership competence in the age of autonomous maritime operations. *WMU Journal of Maritime Affairs,* Volume 19, pp. 163-181.

Kim, T.-e.et al., 2021. The continuum of simulator-based maritime training and education. *WMU Journal of Maritime Affairs,* Volume 20, pp. 135-150.

Kim, T.-E., Sharma, A., Gausdal, A. H. & Chae, C.-j., 2019. Impact of automation technology on gender parity in maritime industry. *WMU Journal of Maritime Affairs,* 18(4), pp. 579-593.

Klauer, K. M., 1997. Examining the concept of total fidelity flight simulation. *CSERIAC Gateway,* 8(2), pp. 13-15.

Klein, N., Guilfoyle, D., Karim, M. S. & McLaughlin, R., 2020. Maritime Autonomous Vehicles: New Frontiers In The Law Of The Sea. *International & Comparative Law Quarterly,* 69(3), pp. 719-734.

Koen van de Merwe, C Mallam, ., Øystein Engelhardtsen & Salman Nazir , 2023. Operationalising Automation Transparency for Maritime Collision Avoidance. *TransNav - The International Journal on Marine Navigation and Safety of Sea Transportation,* 17(2), pp. 333-339.

Komianos, A., 2018. The Autonomous Shipping Era. Operational, Regulatory, and Quality Challenges. *TransNav : International Journal on Marine Navigation and Safety of Sea Transportation,* 12(2), pp. 335-248.

Kongsberg, 2017. *Autonomous Ship Project, Key Facts About Yara Birkeland.* [Online]
Available at: https://www.kongsberg.com/maritime/support/themes/autonomous-ship-project-key-facts-about-yara-birkeland/
[Accessed 14 October 2019].

Kongsberg, 2017. *Yara And Kongsberg Enter Into Partnership To Build World'S First Autonomous And Zero Emissions Ship.* [Online]
Available at: https://www.kongsberg.com/maritime/about-us/news-and-media/news-archive/2017/yara-and-kongsberg-enter-into-partnership-to-build-worlds-first-autonomous-and/?OpenDocument=
[Accessed 14 October 2019].

Kooij, C. & Hekkenberg, R., 2021. The effect of autonomous systems on the crew size of ships – a case study. *Maritime Policy & Management,* 48(6), pp. 860-876.

Kurt, R. E. et al., 2015. *SEAHORSE project : Dealing with maritime workarounds and developing smarter procedures.* s.l., s.n.

Kvale, S., 1983. The Qualitative Research Interview. *Journal of Phenomenological Psychology,* Volume 14, pp. 171-196.

Labib, A. & Read, M., 2013. Not just rearranging the deckchairs on the titanic: learning from failures through risk and reliability analysis. *Safety Science,* 51(1), pp. 397-413.

Lakshmi, A., 2018. *MarineLink - NYK to Stay Ahead 2022 with Digitalization and Green.* [Online]
Available at: https://www.marinelink.com/news/digitalization-ahead435753
[Accessed 14 October 2019].

Lee, J. D. & Sanquist, T. F., 1996. Maritime Automation. *Automation and human performance,* Volume 1, pp. 365-384.

Lee, J. D. & See, K. A., 2004. Trust in Automation: Designing for Appropriate Reliance. *Human Factors: The Journal of the Human Factors and Ergonomics Society,* 46(1), pp. 50-80.

Lee, Y.-G., Bae, J.-C. & Ock, Y.-S., 2020. Study on technical issues related to the introduction of maritime autonomous surface ship. *Journal of Advanced Marine Engineering and Technology,* pp. 250-257.

Li, F., Chen, C.-H., Lee, C.-H. & Khoo, L.-P., 2020. A User Requirement-driven Approach Incorporating TRIZ and QFD for Designing a Smart Vessel Alarm System to Reduce Alarm Fatigue. *The Journal of Navigation,* 73(1), pp. 212-232.

Lileikis, S., 2022. Maritime Transport Employees' Psychological Defense Mechanisms and Self-management. *TransNav - The International Journal on Marine Navigation and Safety of Sea Transportation,* 16(1), pp. 115-120.

Li, S. & Fung, K. S., 2019. Maritime autonomous surface ships (MASS): implementation and legal issues. *Maritime Business Review,* 4(4), pp. 330-339.

Li, X., Oh, P., Zhou, Y. & Yuen, K. F., 2023. Operational risk identification of maritime surface autonomous ship: A network analysis approach. *Transport Policy,* Volume 130, pp. 1-14.

Li, X., Seah, R., Wang, X. & Yuen, K. F., 2022. Investigating the role of sociotechnical factors on seafarers' psychological capital and mental well-being. *Technology in Society,* Volume 71.

Łosiewicz, Z., Nikończuk, P. & Pielka, D., 2019. Application of artificial intelligence in the process of supporting the ship owner's decision in the management of ship machinery crew in the aspect of shipping safety. *Procedia Computer Science,* Volume 159, pp. 2197-2205.

Lou, Y. & Sun, Q., 2021. Over-reliance on database: A case study of web of science. *Human Behaviour and Emerging Technologies,* 3(3), pp. 454-459.

Lušić, Z., Bakota, M., Čorić, M. & Skoko, I., 2019. Seafarer Market – Challenges for the Future. *Transactions on Maritime Science,* 8(1), pp. 62-74.

Lützhöft, M. & Dekker, S. W. A., 2002. On Your Watch: Automation on the Bridge. *Journal of Navigation,* 55(1), pp. 83-96.

Lützhöft, M., Hynnekleiv, Earthy, J. V. & Petersen, E. S., 2019. Human-centred maritime autonomy - An ethnography of the future. *Journal of Physics: Conference Series,* Volume 1357.

MacDonald, R., 2006. Safe manning of ships — Yesterday, today and tomorrow. *WMU Journal of Maritime Affairs,* 5(2), pp. 143-151.

MacKinnon, S. N., Man, Y., Lundh, M. & Porathe, T., 2015. *Command and control of unmanned vessels: Keeping shore based operators in-the-loop..* Milan, 18th International Conference on Ships and Shipping Research.

Maglić, L. & Zec, D., 2019. The impact of bridge alerts on navigating officers. *The Journal of Navigation,* 73(2), pp. 421-432.

Magramo, M. & Gellada, L., 2009. A Noble Profession Called Seafaring: the Making of an Officer. *Transnav - The International Journal on Marine Navigation and Safety of Sea Transportation,* 3(4), pp. 475-480.

Mahtani, A. et al., 2020. *Pedestrian Detection and Classification for Autonomous Train.* Genova, IEEE.

MAIB DMAIB, 2021. *Application and usability of ECDIS,* s.l.: MAIB & DMAIB.

MAIB, 2017. *Grounding of the general cargo vessel Ruyter,* s.l.: Marine Accident Investigation Branch.

MAIB, 2021. *Report on the investigation of the grounding of the general cargo vessel Kaami,* s.l.: Marine Accident Investigation Branch.

Mallam, S. C., Nazir, S. & Renganayagalu, S. K., 2019. Rethinking Maritime Education, Training, and Operations in the Digital Era: Applications for Emerging Immersive Technologies. *Journal of Marine Science and Engineering,* 7(428), pp. 1-9.

Mallam, S. C., Nazir, S. & Sharma, A., 2020. The human element in future Maritime Operations – perceived impact of autonomous shipping. *Ergonomics,* 63(3), pp. 334-345.

Manuel, M. E. & Baumler, R., 2020. The evolution of seafarer education and training in international law. *Maritime Law in Motion,* pp. 471-494.

Marine Accident Investigation Branch - MAIB, 2008. *Report on the investigation of the grounding of CFL Performer Haisborough Sand North Sea 12 May 2008,* Southampton: MAIB.

Marine Accident Investigation Branch - MAIB, 2013. *Report on the investigation of the grounding of Ovit in the Dover Strait on 18 September 2013*, London: MAIB.

Marine Accident Investigation Branch - MAIB, 2015. *Grounding of Lysblink Seaways,* s.l.: MAIB.

Marine Accident Investigation Branch - MAIB, 2017. *Report on the investigation of the collision between the pure car carrier City of Rotterdam and the ro-ro freight ferry Primula Seaways,* Southampton: MAIB.

Marine Accident Investigation Branch - MAIB, 2017. *Report on the investigation of the grounding of Muros,* Southampton: MAIB.

Marine Accident Investigation Branch - MAIB, 2019. *Report on the investigation of the grounding of the general cargo vessel Priscilla on Pentland Skerries, Pentland Firth, Scotland on 18 July 2018,* s.l.: MAIB.

Marine Safety Investigation Unit, 2017. *Safety investigation into the grounding of the Maltese registered container ship in position 22° 02.28' S 168° 38.25' E on 12 July 2017,* s.l.: Transport Malta.

Marine Safety Investigation Unit, 2018. *Safety Investigation Report MV UNIVERSAL DURBAN Grounding in position 02° 14.65' N 109° 05.17' E 13 May 2017,* s.l.: Transport Malta.

Maritime and Coastguard Agency, 2022. *MSN 1856 (M+F) - Amendment 1 - UK Requirements for Master and Deck Officers.* [Online] Available at: https://www.gov.uk/government/publications/msn-1856-mf-amendment-1-uk-

requirements-for-master-and-deck-officers
[Accessed 16 May 2023].

Maritime Coastguard Agency, 2015. *Standards of Training, Certification & Watchkeeping Convention: UK Requirements for Safe Manning and Watchkeeping.* [Online] Available at: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/993822/MSN1868.pdf
[Accessed 01 June 2023].

Maritime Safety Committee - IMO, 2018. *100th Session, Agenda Item 5: Regulatory Scoping Exercise For The Use of Maritime Autonomous Surface Ships (MASS),* s.l.: International Maritime Organisation.

Martime Coastguard Agency, 2016. *The Deadly Dozen -12 Significant People Factors in Maritime Safety ,* Southampton: MCA.

Masalonis, A. J., Duley, J. A. & Parasuraman, R., 1999. Effects of Manual and Autopilot Control on Mental Workload and Vigilance During Simulated General Aviation Flight. *Transportation Human Factors,* 1(2), pp. 187-200.

Maya, B. N. D. et al., 2021. *Creation of an Occurrence Analysis & Learning Centre for Maritime (OALC-M). Results from EU Funded SAFEMODE Project.* Glasgow, Proceedings of the 1st International Conference on the Stability and Safety.

Mcbride, S. E., Rogers, W. A. & Fisk, A. D., 2010. *Do younger and older adults differentially depends on an automated system.* s.l., s.n.

McNeese, N. J., Demir, M., Cooke, N. J. & Myers, C., 2017. Teaming With a Synthetic Teammate: Insights into Human-Autonomy Teaming. *Human Factors: The Journal of the Human Factors and Ergonomics Society,* 60(2), p. 262–273.

Melnyk, O., Bychkovsky, Y. & Voloshyn, A., 2022. Maritime Situational Awareness as a Key Measure for Safe Ship Operation. *Scientific Journal of Silesian University of Technology. Series Transport,* Volume 114, pp. 91-101.

Mišković, D., Bielić, T. & Čulin, J., 2018. Impact of technology of safety as viewed by ship operators. *Transactions on Maritime Science,* 7(1), pp. 51-58.

Mišković, D., Ivče, R., Hess, M. & Koboević, Ž., 2022. The influence of shipboard safety factors on quality of safety supervision: Croatian seafarer's attitudes. *Journal of Marine Science and Engineering,* 10(9), pp. 1-13.

Miyoshi, T. et al., 2022. Rules required for operating maritime autonomous surface ships from the viewpoint of seafarers. *The Journal of Navigation*, 75(2), pp. 384-399.

Mizuma, T., 2018. Measures for Ensuring the Safety and Security of Automated Operation of Public Transportation in Japan. *Computers in Railways XVI,* Volume 181, pp. 387-397.

Mohovic, D., Mohovic, R. & Baric, M., 2016. Deficiencies in Learning COLREGs and New Teaching Methodology for Nautical Engineering Students and Seafarers in Lifelong Learning Programs. *The Journal of Navigation,* 69(4), pp. 765-776.

Molloy, R. & Parasuraman, R., 1996. Monitoring an Automated System for a Single Failure: Vigilance and Task Complexity Effects. *Human Factors: The Journal of the Human Factors and Ergonomics Society,* 38(2).

Moser, A. & Korstjen, I., 2017. Series: Practical guidance to qualitative research. Part 1: Introduction.. *The European Journal of General Practice*, 23(1), pp. 271-273.

Mosier, K. L. et al., 2013. Automation, task, and context features: Impacts on pilots' judgments of human-automation interaction. *Journal of Cognitive Engineering and Decision Making,* 7(4), pp. 377-399.

MSC - IMO, 2018. *100th session, agenda item 5: Regulatory scoping exercise for the use of maritime autonomous surface ships (MASS)*, s.l.: International Maritime Organisation.

MUNIN, 2017. *Research in Maritime Autonomous Systems: Project Results and Technology Potentials,* s.l.: Maritime Unmanned Navigation Through Intelligence in Networks.

Murphy, M., 2008. Matching Workplace Training to Adult Attention Span to Improve Learner Reaction, Learning Score, and Retention. *Journal of Instruction Delivery Systems,* 22(2), pp. 6-13.

Nakashima, T., Moser, B. & Hiekata, K., 2023. Accelerated adoption of maritime autonomous vessels by simulating the interplay of stakeholder decisions and learning. *Technological Forecasting and Social Change,* Volume 194.

Narayanan, S. C., Emad, G. R. & Fei, J., 2023. Theorizing seafarers' participation and learning in an evolving maritime workplace: an activity theory perspective. *WMU Journal of Maritime Affairs,* Volume 2, pp. 165-180.

National Transportation Safety Board, 1995. *Grounding of the panamanian passenger ship Royal Majesty on Rose and Crown shoal near Nantucket, Massachusetts,* Washington DC: National Transportation Safety Board.

Nazir, S., Øvergård, K. I. & Yang, Z., 2015. Towards Effective Training for Process and Maritime Industries. *Procedia Manufacturing,* Volume 3, pp. 1519-1526.

Nguyen, T. et al., 2019. A Review of Situation Awareness Assessment Approaches in Aviation Environments. *IEEE Systems Journal,* 13(3), pp. 3590-3603.

Noble, C., 2002. The relationship between fidelity and learning in aviation training and assessment. *Journal of Air Transportation,* 7(3), pp. 33-54.

NYK Line, 2019. *NYK Conducts World's First Maritime Autonomous Surface Ships Trial.* [Online]
Available at: https://www.nyk.com/english/news/2019/20190930_01.html
[Accessed 14 October 2019].

OECD, 2018. *Ocean shipping and shipbuilding.* [Online]
Available at: https://www.oecd.org/ocean/topics/ocean-shipping/#:~:text=The%20main%20transport%20mode%20for,transport%20arteries%20for%20global%20trade.
[Accessed 24 June 2023].

Oliveira, R. P. d. et al., 2022. Systematic Literature Review on the Fidelity of Maritime Simulator Training. *Education Sciences,* 12(11).

O'Neill, T. A., McNeese, N. J., Barron, A. & Schelble, B., 2022. Human-autonomy teaming: A review and analysis of the empirical literature. *Human Factors,* 64(5), pp. 904-938.

Online Surveys, 2020. *Online Surveys.* [Online]
Available at: https://admin.onlinesurveys.ac.uk/account/newcastle/home/
[Accessed 13 July 2020].

Opdenakker, R., 2006. Advantages and disadvantages of four interview techniques in qualitative research. *Forum: Qualitative Social Research,* 7(4), pp. 1438-5627.

Österman, C., Rose, L. & Osvalder, A.-L., 2010. Exploring maritime ergonomics from a bottom line perspective. *WMU Journal of Maritime Affairs,* Volume 9, pp. 153-168.

Ottesen, A. E., 2014. *Situation Awareness in Remote Operation of Autonomous Ships.* Norway, s.n.

Pak, R. et al., 2012. Decision support aids with anthropomorphic characteristics influence trust and performance in younger and older adults. *Ergonomics,* 55(9), pp. 1059-1072.

Pan, Y., Oksavik, A. & Hildre, H. P., 2020. *Simulator as a Tool for the Future Maritime Education and Research: A Discussion.* s.l., Academic Press.

Parasuraman, R. & Manzey, D. H., 2010. Complacency and Bias in Human Use of Automation: An Attentional Integration. *Human Factors*, 52(3), pp. 381-410.

Patton, M. Q., 1999. Enhancing the quality and credibility of aulitative analysis. *Health Sciences Research,* Volume 34, pp. 1189-1208.

Pauksztat, B., Grech, M. R. & Kitada, M., 2022. The impact of the COVID-19 pandemic on seafarers' mental health and chronic fatigue: Beneficial effects of onboard peer support, external support and Internet access. *Marine Policy,* Volume 137.

Pazouki, K., Forbes, N., Norman, R. A. & Woodward, M. D., 2018. Investigation on the impact of human-automation interaction in maritime operations. *Ocean Engineering,* 153(1), pp. 297-304.

Porathe, T., 2019. *Safety of autonomous shipping: COLREGS and interaction between manned and unmanned ships.* s.l., Proceedings of the European Safety and Reliabilty conference, ESREL.

Prabaswari, A. D., Basumerda, C. & Utomo, B. W., 2019. The Mental Workload Analysis of Staff in Study Program of Private Educational Organization. *Materials Science and Engineering,* 528(IOP Conference Series Materials Science and Engineering).

Pronto, J., 2015. Understanding and Evaluating Survey Research. *Journal of the Advanced Practitioner in Oncology,* 6(2), pp. 168-171.

Punnoose, B., 2018. *Risk Assessment and Management: ISM Code Perspective,* s.l.: ISM.

Rajapakse, A. & Emad, G. R., 2023. Fatigue, an unsolved puzzle that continues contributing to accidents at sea. *Marine Policy*, 155(105745).

Ra, S. et al., 2019. The Rise Of Technology And Impact On Skills. *International Journal of Training Research* , 12(Issue sup1: Special Open Access Supplement Issue: Emerging Labor Markets of the Future – Re-imagining Skills Development and Training), pp. 26-40.

Ratten, V., 2023. The post COVID-19 pandemic era: Changes in teaching and learning methods for management educators. *The International Journal of Management Education,* 21(2).

Riches, B., 1995. ECDIS – Its Impact Today. *The Journal of Navigation,* 48(2), pp. 234-238.

Rieth, M. & Hagemann, V., 2022. Automation as an equal team player for humans? – A view into the field and implications for research and practice. *Applied Ergonomics,* 98(103552).

Ringbom, H., 2019. Regulating Autonomous Ships—Concepts, Challenges and Precedents. *Ocean Development & International Law,* 50(2-3), pp. 141-169.

Rødseth, Ø. J. & Vagia, M., 2020. *A taxonomy for autonomy in industrial autonomous mobile robots including autonomous merchant ships.* Ulsan, The 3rd International Conference on Maritime Autonomous Surface Ship.

Rødseth, Ø. J. & Wennersberg, L. A. L., 2023. *A Criticism of Proposed Levels of Autonomy for MASS.* Singapore, Proceedings of the 33rd European Safety and Reliability Conference (ESREL 2023).

Røds, J. & Gudmestad, O., 2019. Use of Simulator Training to Mitigate Risks in Arctic Shipping Operations. *TransNav - The International Journal on Marine Navigation and Safety of Sea Transportation,* 13(2), pp. 375-379.

Rostek, D. & Baldauf, M., 2024. *Technologies for Situational Awareness in Autonomous Shipping and Their Impact on Maritime Training and Education.* Valencia, INTED2024 Proceedings.

Rothblum, A. et al., 2002. Improving Incident Investigation through Inclusion of Human Factors. *United States Department of Transportation -- Publications & Papers,* Issue 32.

Roth, E. M. et al., 2019. Function Allocation Considerations in the Era of Human Autonomy Teaming. *Journal of Cognitive Engineering and Decision Making,* 13(4), p. 199–220.

Russo, A., Vojković, L., Bojic, F. & Mulić, R., 2022. The Conditional Probability for Human Error Caused by Fatigue, Stress and Anxiety in Seafaring. *Journal of Marine Science and Engineering,* 10(11).

Rylander, R. & Man, Y., 2016. *Autonomous safety on vessels an international overview and trends within the transport sector,* s.l.: Lighthouse - Swedish Maritime Competence Centre.

Saha, R., 2023. Mapping competence requirements for future shore control center operators. *Maritime Policy & Management - The flagship journal of international shipping and port research,* 50(4: Smart port and shipping operations” in Maritime Policy & Management), pp. 415-427.

Sánchez-Beaskoetxea, J., Basterretxea-Iribar, I., Sotés, I. & Maruri Machado, M. d. l. M., 2021. Human error in marine accidents: Is the crew normally to blame?. *Maritime Transport research,* Volume 2.

Saus, E.-R.et al., 2010. Perceived learning outcome: The relationship between experience, realism and situation awareness during simulator training. *International Maritime Health,* 62(4), pp. 258-264.

Save, L. et al., 2021. *Analysis of reporting systems in safety critical domains to develop the SHIELD HF taxonomy. Results from EU funded SAFEMODE Project..* Glasgow, Proceedings of the 1st International Conference on the Stability and Safety.

Schager, B., 2007. When Technology Leads Us Astray: A Broadened View of Human Error. *The Journal of Navigation,* 61(1), pp. 63-70.

Schiaretti, M., Chen, L. & Negenborn, R. R., 2017. Survey on Autonomous Surface Vessels: Part I - A New Detailed Definition of Autonomy Levels. *Computational Logistics,* pp. 219-233.

Schröder-Hinrichs, J.-U.et al., 2013. Maritime human factors and IMO policy. *Maritime Policy & Management,* 40(3), pp. 243-260.

Schuffel, H., Boer, J. P. A. & van Breda, L., 1989. The Ship's Wheelhouse of the Nineties: the Navigation Performance and Mental Workload of the Officer of the Watch. *Journal of Navigation,* 42(1), pp. 60-72.

Setiawan, A. N., Dijaya, Y. P. & Paratama, A. W., 2021. Exploring the Qualifications of Future Seafarers from the Perspective of Stakeholders: its Implications in the Maritime Education and Training. *Jurnal Penelitian Transportasi Laut,* Volume 23, pp. 33-38.

Seya, Y., Nakayasu, H. & Peterson, P., 2008. Visual search of trained and untrained drivers in a driving simulator. *Japanese Psychological Association,* 50(4), pp. 242-252.

Sharek, D., 2011. A usable, online NASA-TLX tool. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting,* 55(1), pp. 1375-1379.

Shi, X., Zhuang, H. & Xu, D., 2021. Structured survey of human factor-related maritime accident research. *Ocean Engineering,* 237(1), pp. 1-12.

Singh, A., Dalaklis, D. & Baumler, R., 2023. Revisiting the HNoMS Helge Ingstad and Sola TS collision: Discussing the contribution of human factors. *Maritime Technology and Research* , 5(3).

Skibniewski , M. & Hendrickson, C., 1990. Automation and Robotics for Road Construction and Maintenance. *Journal of Transportation Engineering,* 116(3), pp. 261-271.

Skitka, L. J., Mosier, K. L. & Burdick, M., 1999. Does Automation Bias Decision-Making?. *International Journal or Human-Computer Studies,* Volume 51, pp. 991-1006.

Slišković, A. & Penezić, Z., 2016. Testing the associations between different aspects of seafarers' employment contract and on-board internet access and their job and life satisfaction and health. *Review of psychology,* Volume 67, pp. 351-361.

Stanković, J. J., Marjanović, I., Papathanasiou, J. & Drezgić, S., 2021. Social, Economic and Environmental Sustainability of Port Regions: MCDM Approach in Composite Index Creation. *Journal of Marine Science and Engineering,* 9(74).

Staruch, B., 2017. The Automation by Expertise by Training Interaction: Why Automation-Related Accidents Continue to Occur in Sociotechnical Systems. *Human Factors,* 59(2), pp. 204-228.

STCW, 2024. *STCW Courses.* [Online] Available at: https://www.stcwdirect.com/stcw-courses/ [Accessed 28 February 2024].

Stene, T., 2018. *Automation of the Rail – Removing the Human Factor?.* Trondheim, SINTEF.

Stępien, B., 2023. Can a ship be its own captain? Safe manning of autonomous and uncrewed vessels. *Marine Policy,* Volume 148, p. 105451.

Strauch, B., 2015. Investigating fatigue in marine accident investigations. *Procedia Manufacturing,* Volume 3, pp. 3115-3122.

Stroeve, S. et al., 2023. SHIELD Human Factors Taxonomy and Database for Learning from Aviation and Maritime Safety Occurrences. *Safety ,* 9(14).

Tam, K., Hopcraft, R., Crichton, T. & Jones, K., 2021. The potential mental health effects of remote control in an autonomous maritime world. *Journal of International Maritime Safety, Environmental Affairs, and Shipping,* 5(2), pp. 40-55.

Tang, L., Bian, C., Fang, L. & Xiong, Y., 2020. *Analysis of ocupational stress and influencing factors of civil aviation pilots.* s.l., ISPCEM.

Tashakkori, A. & Teddlie, C., 2003. The past and future of mixed methods research: From data triangulation to mixed model designs. In: *Handbook of mixed method research in social and behavioral research.* Thousand Oaks Ca: SAGE.

The Mission to Seafarers, 2021. *Seafarers Happiness Index - Q2 2021,* London: The Mission to Seafarers.

Theotokatos, G. et al., 2023. Autonomous shipping — an analysis of the maritime stakeholder perspectives. *WMU Journal of Maritime Affairs,* Volume 22, pp. 5-35.

Thomas, M., Sampson, H. & Zhao, M., 2003. Finding a balance: companies, seafarers and family life. *Maritime Policy & Management,* 30(1), pp. 59-76.

Thombre, S. et al., 2022. Sensors and AI Techniques for Situational Awareness in Autonomous Ships: A Review. *IEEE Transactions on Intelligent Transportation Systems,* 23(1), pp. 64-83.

Transportation Safety Board of Canada, 2016. *Marine Investigation Report - Grounding and subsequent sinking Tug Nathan E. Stewart and tank barge DBL 55,* s.l.: Transportation Safety Board of Canada.

Tsoukalas, V. D. et al., 2014. Questionnaire assessment of training in a marine simulator. *WMU Journal of Maritime Affairs,* 14(1), pp. 293-312.

Turan, O. et al., 2016. Can we learn from aviation: safety enhancements in transportby achieving human orientated resilient shipping environment. *Transportation Research Procedia,* Volume 14, pp. 1669-1678.

Tusher, H. M., Nazir, S., Ghosh, S. & Rusli, R., 2023. Seeking the Best Practices of Assessment in Maritime Simulator Training. *TransNav the International Journal on Marine Navigation and Safety of Sea Transportation,* 17(1), pp. 105-114.

Uitterhoeve, W. & Leunen, G. v., 2021. Lifelong Learning: The Dutch Perspective on the Role of Simulators in Maritime Education and Training. *Scientific Journal of Gdynia Maritime University,* 119(21), pp. 54-63.

Union Internationale des Transports Publics, 2019. *World Report on Metro Automation,* Brussels: UITP.

United States Coast Guard, 2022. *Report of the Investigation into the Ever Forward (O.N. 9850551) Grounding in the Vicinity of Craighill Channel on March 13, 2022,* s.l.: USCG.

Vagale, A. et al., 2022. On the use of maritime training simulators with humans in the loop for understanding and evaluating algorithms for autonomous vessels. *Journal of Physics: Conference Series,* 2311(1), pp. 1-13.

Vidan, P., Bukljaš, M., Pavić, I. & Vukša, S., 2019. *Autonomous Systems & Ships -Training and Education on Maritime Faculties.* Budva, s.n.

Vithanage, R. K. W., Harrison, C. S. & DeSilva, A. K. M., 2019. Importance and Applications of Robotic and Autonomous Systems (RAS) in Railway Maintenance Sector: A Review. *Computers,* 8(56).

Vos, J. d., Hekkenberg, R. G. & Banda, O. A. V., 2021. The Impact of Autonomous Ships on Safety at Sea – A Statistical Analysis. *Reliability Engineering & System Safety,* 210(107558).

Vu, V. D. & Lützhöft, M., 2020. *Improving human-centred design application in the maritime industry-challenges and opportunities.* London, s.n.

Wahl, A. M., 2020. Expanding the concept of simulator fidelity: the use of technology and collaborative activities in training maritime officers. *Cognition, Technology & Work,* Volume 22, pp. 209-222.

Winter, S. R., Rice, S. & Mehta, R., 2014. Aviation consumers' trust in pilots: A cognitive or emotional function. *International journal of aviation, aeronautics, and aerospace,* 1(1).

Wróbel, K., 2021. Searching for the origins of the myth: 80% human error impact on maritime safety. *Reliability Engineering & System Safety,* Volume 216.

Wu, B. et al., 2022. *Experiment Design and Implementation for Human-in-the-Loop Study Towards Maritime Autonomous Surface Ships.* Prague, IEEE.

Xing, W. & Zhu, L., 2023. Exploring legal gaps and barriers to the use of unmanned merchant ships in China. *Marine Policy,* Volume 153.

Yoo, J. & Jo, Y., 2023. Formulating Cybersecurity Requirements for Autonomous Ships Using the SQUARE Methodology. *Sensors,* 23(11).

Yoshida, M., Shimizu, E., Sugomori, M. & Umeda, A., 2020. Regulatory requirements on the competence of remote operator in maritime autonomous surces ship: Situation awareness, ship sense and goal-based gap analysis. *Applied Sciences,* 10(23), p. 8751.

Yu, F. W., Sun, H. Y. & Cui, X. D., 2014. Design of Bridge Navigational Watch Alarm System. *Applied Mechanics and Materials,* Volume 488, pp. 521-524.

Zhang, M., Zhang, D., Yao, H. & Zhang, K., 2020. A Probabilistic Model of Human Error Assessment for Autonomous Cargo Ships Focusing on Human–Autonomy Collaboration. *Safety Science,* Volume 130, p. 104838.

Zhou, X. Y., Liu, Z. J., Wu, Z. L. & Wang, F. W., 2019. Quantitative processing of situation awareness for autonomous ships navigation. *TransNav - The International Journal on Marine Navigation and Safety of Sea Transportation,* 13(1), pp. 25-31.

Ziajka-Poznańska, E. & Montewka, J., 2021. Costs and Benefits of Autonomous Shipping—A Literature Review. *Applied Sciences - Autonomous and Remote-Controlled Ship Operations,* 11(10).

Žuškin, S., Brčić, D., Uroda, M. & Strabić, M., 2023. Evolving ECDIS: Concept Development Through Different Manufacturer Models Comparison. *TransNav: The International Journal on Marine Navigation and Safety of Sea Transportation,* 17(1), p. 227.

Appendix A – Interview Guide

1. **Opening questions**:
    1.1. What age were you when you began your career as a deck officer and what year was it?
    1.2. What was the driving force for you in becoming a navigational officer?
    1.3. For you describe a standard navigational watch and what to expect throughout the duration of the watch.
2. **Autonomous shipping questions**:
    2.1. What are your opinions and views on autonomous technology?
    2.2. What are your greatest concerns on the introduction of autonomous technology within the maritime industry and more specifically merchant ships?
    2.3. The introduction of autonomous vessel operations is looking to initially start with a manned wheelhouse and conduct "supervised" navigation. Going forward past the transition stage what are your views on removing helmsman and navigational officers?
        2.3.1. Do you feel that the ships master should be onboard despite the vessel being under autonomous operations?
    2.4. When do you think that autonomous shipping will become the norm for the maritime industry?
    2.5. To you what does the term "Autonomous Shipping" mean?
    2.6. What do you think the introduction of autonomous shipping will mean for seafarers and the maritime industry?
3. **Revision of legislations**
    3.1. What organisations, do you feel, will be important in the development and implementation of maritime autonomous vessel operations?
    3.2. What regulations and legislation do you think will be heavily impacted upon the introduction of autonomous systems to merchant vessels i.e., STCW, ISO, COLREGs, MARPOL, HASAWA?
    3.3. To allow autonomous vessel operations to be introduced, what medical requirements do you feel need to be revised and do you think that mental health should be considered among these?
4. **Impact of autonomous vessel operations in maritime education**
    4.1. What are your views regarding the change in the education standards of navigational officers?
        4.1.1. What areas of the educational syllabus do you feel should be revised, and why?
        4.1.2. How do you think autonomous vessel operations will impact on certification for qualified officers and future prospective operators?
        4.1.3. How do you think autonomous vessel operations will impact young person recruitment drives for the maritime industry considering the possible reduction in crewing numbers and health implications?
    4.2. At some stage there will be a situation where the educators will be teaching students a form of navigation where they have no prior experience. How do you feel this would affect future generations of seafarers?
    4.3. With technology growing so rapidly how do you think constant updates would impact the navigational officer syllabus?
5. **Maritime Human Factors**

5.1. Do you feel that modern seafarers can be competent in resolving potential machine errors? And how do you view the relationship between the autonomous system and the human operators i.e., navigational officers and helmsman?
5.2. Statistics from Lloyds Register and DNV/GL have shown that the leading cause of maritime incidents can be attributed to human error. So how do you think operators can resolve a potential machine error and reduce the magnitude of the incident?
5.3. Do you think that the length of time at sea could negatively affect an operator’s response to a fault i.e., is the operator more alert during the first few weeks of their contract vs the final few weeks?
5.4. What is your opinion in regular situational awareness training to ensure that an operator is suitably alert during their watch? And how frequently do you think that situational awareness should be trained for navigational officers?

Appendix B – Behavioural Training Transcripts & Material

The following information is a copy of the training video transcription for the behavioural training package received by participants for the Final Study. Within the transcription are video stills of the training package as depicted within Figures B.1 – B.6.

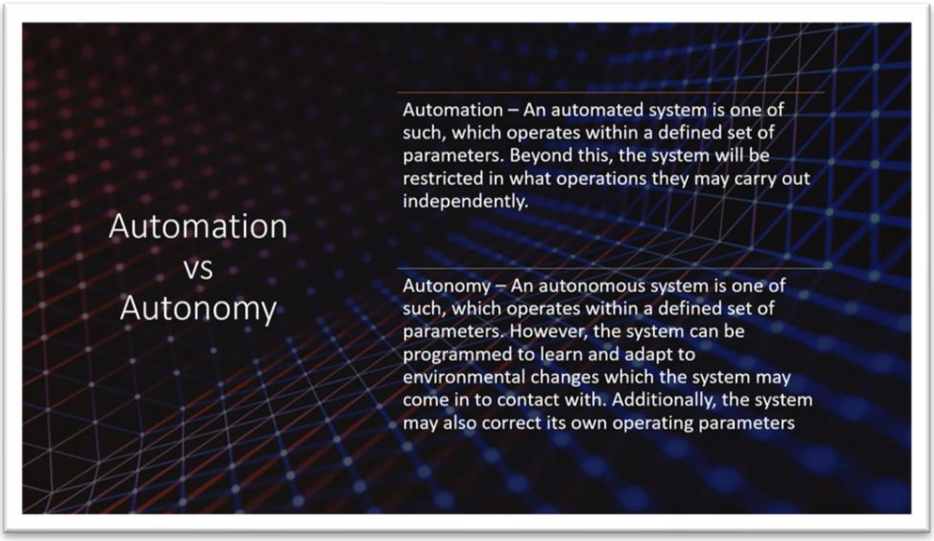
The following video is on maritime automation where we will look at the skills of behaviours that will begin to develop within Seafarers as autonomy becomes more of a mainstay within the maritime industry.

Maritime Automation

Skills & Behaviours

Figure B.1: Introduction Page from Behavioural Training Material

A common misunderstanding with automation is the terminology that is used. Both the terms autonomy and automation have very different meanings. With automation being a system, which operates within a defined set of parameters and beyond that, the system will be restricted in what operations they may carry out independently. Whereas an autonomous system is one that operates within a defined set of parameters however, over time can be programmed to learn and adapt to environmental changes which the system may come into contact with. Additionally, the system may also correct its own operating parameters through machine learning.



Automation vs Autonomy

Automation – An automated system is one of such, which operates within a defined set of parameters. Beyond this, the system will be restricted in what operations they may carry out independently.

Autonomy – An autonomous system is one of such, which operates within a defined set of parameters. However, the system can be programmed to learn and adapt to environmental changes which the system may come in to contact with. Additionally, the system may also correct its own operating parameters

Figure B.2: Definitions Page from Behavioural Training Material

We will now look at a few of the skills which will need to be adapted as autonomy is adopted by the maritime industry the first being situational awareness. As autonomous systems become more of a mainstay in shipping seafarers may also experience a degradation in their own situational awareness. Which can be defined as being aware of what is happening around you in terms of where you are, where you supposed to be and whether anyone or anything around you is a threat to your health and safety as well as the vessel. Allowing the vessel to operate autonomously will ultimately be decided by the seafarer, therefore the more trust the seafarer has in the system could result in more autonomous control. And with system design becoming more sophisticated faults will become more infrequent but potentially more harmful.

Situational Awareness

AS AUTONOMOUS SYSTEMS BECOME MORE OF A MAINSTAY IN SHIPPING, SEAFARERS MAY ALSO EXPERIENCE A DEGRADATION IN THEIR OWN SITUATIONAL AWARENESS

ALLOWING THE VESSEL TO OPERATE AUTONOMOUSLY IS DECIDED BY THE SEAFARER, THEREFORE THE MORE TRUST THE SEAFARER HAS IN THE MACHINE WILL RESULT IN MORE AUTONOMOUS CONTROL

WITH SYSTEM DESIGN BECOMING MORE SOPHISTICATED, FAULTS WILL BECOME MORE INFREQUENT BUT POTENTIALLY MORE HARMFUL

Figure B.3: Situational Awareness Page from Behavioural Training Material

This then leads us to automation bias, which is a tendency to trust decision support systems. With the design of autonomous systems being so advanced there will come the risk of the seafarer trusting the system over their own judgment, which will result in an over reliance towards automation aids and decision support systems. Moreover, it is human tendency to utilise the method with the least cognitive effort while leaning towards automation bias.

Automation Bias

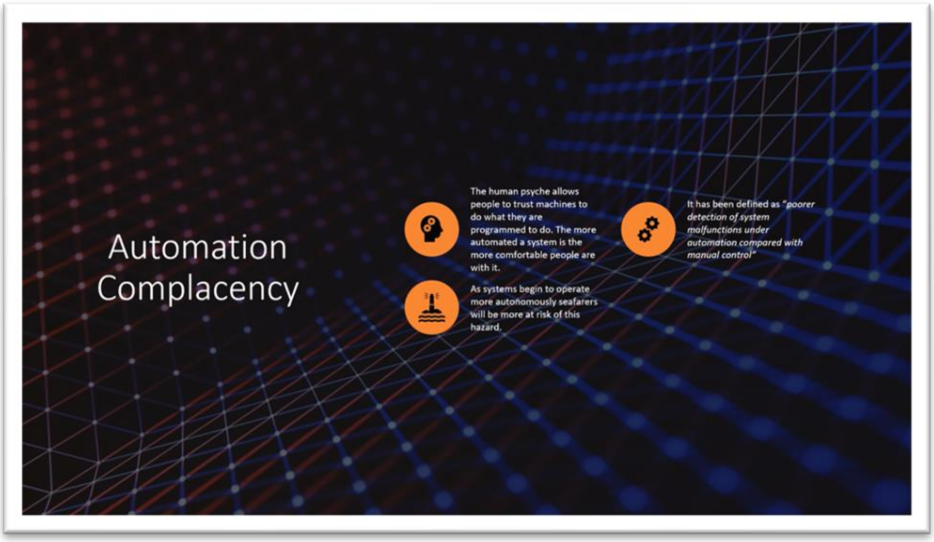
With the design of autonomous system being so advanced, there will come the risk of seafarers trusting the system over their own judgement.

An over-reliance on automated aids and decision support systems develops.

It is human tendency to utilise the method with the least cognitive effort while leaning towards automation bias.

Figure B.4: Automation Bias Page from Behavioural Training Material

And finally, we will look at automation complacency which has been defined as a “poorer detection of system malfunctions under automation compared with manual control, in essence being unable to recognise danger while the vessel control of the automated system. The human psyche allows people to trust machines to do what they are programmed to do. Therefore, the more automated a system is the more comfortable people are with it. Finally, as systems begin to operate more autonomously seafarers will be more at risk of this hazard.



Automation Complacency

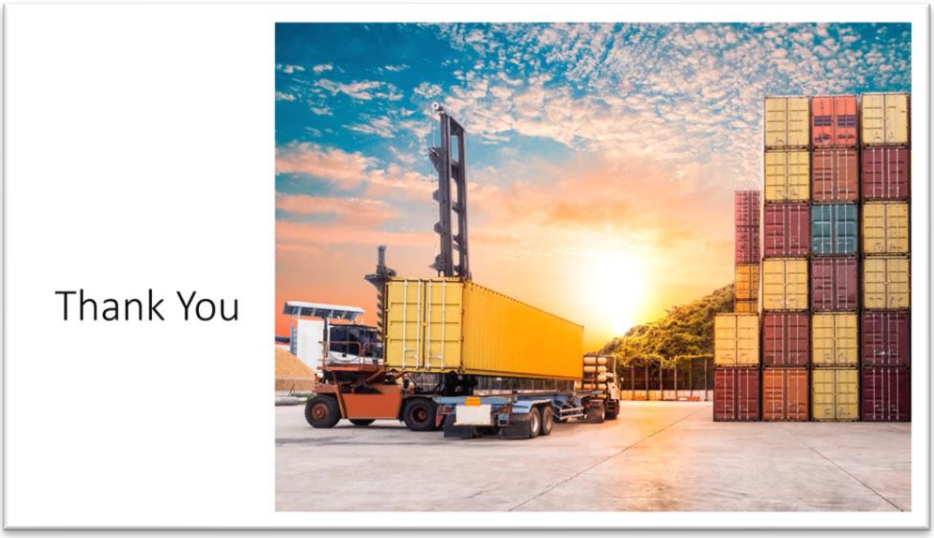
The human psyche allows people to trust machines to do what they are programmed to do. The more automated a system is the more comfortable people are with it.

As systems begin to operate more autonomously seafarers will be more at risk of this hazard.

It has been defined as *“poorer detection of system malfunctions under automation compared with manual control”*

Figure B.5: Automation Complacency Page from Behavioural Training Material

Thank you for paying attention to this information video, if you please head through the door and meet your instructor, they will then assist you with the next part of this study.



Thank You

Figure B.6: Final Page from Behavioural Training Material

Appendix C – Technical Training Transcripts & Material

The following information is a copy of the training video transcription for the technical training package received by participants for the Final Study. Within the transcription are video stills of the training package as depicted within Figures C.1 – C.6.

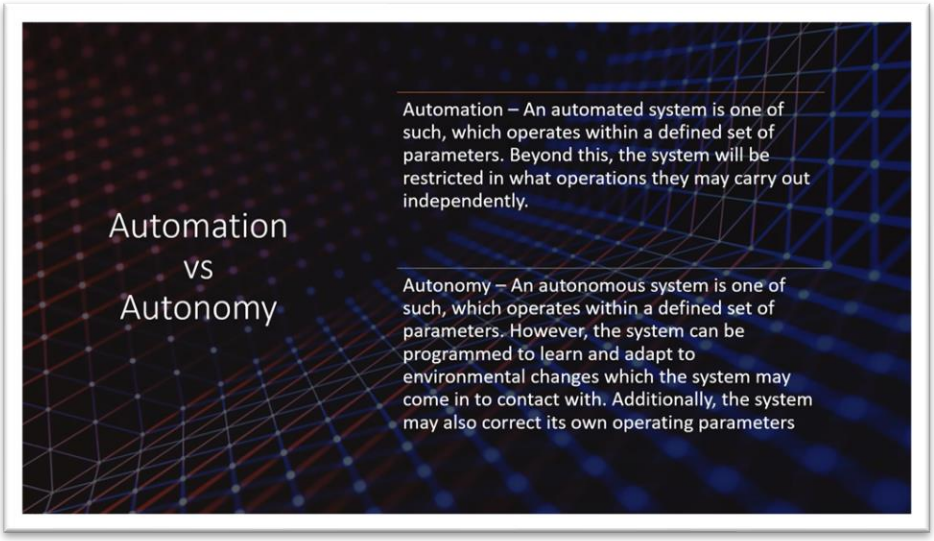
The following video is on maritime automation where we will look at some of the bridge watch navigational systems that will heavily be effected as autonomy becomes more of a mainstay within the maritime industry.

Automation

Bridge Watch Navigational Systems

Figure C.1: Introduction Page from Technical Training Material

A common misunderstanding with automation is the terminology that is used. Both the terms autonomy and automation have very different meanings. With automation being a system, which operates within a defined set of parameters and beyond that, the system will be restricted in what operations they may carry out independently. Whereas an autonomous system is one that operates within a defined set of parameters however, over time can be programmed to learn and adapt to environmental changes which the system may come into contact with. Additionally, the system may also correct its own operating parameters through machine learning.



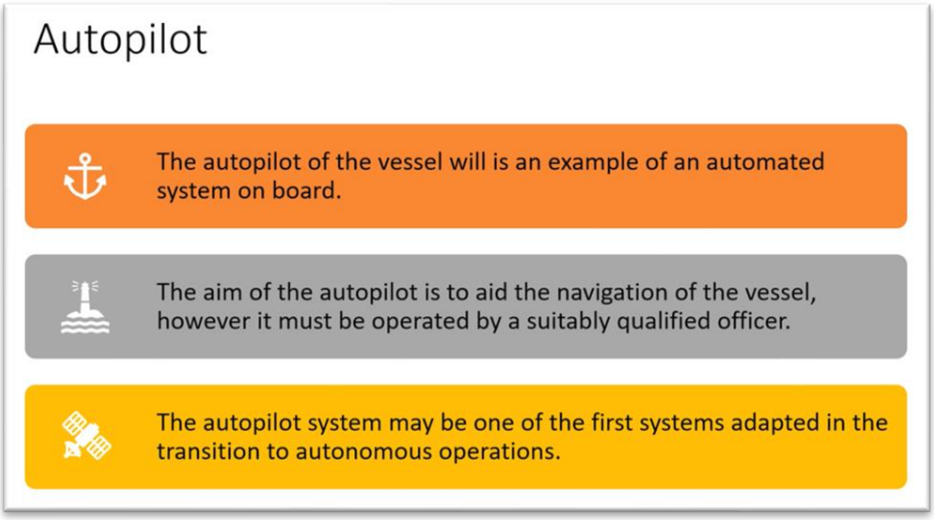
Automation
vs
Autonomy

Automation – An automated system is one of such, which operates within a defined set of parameters. Beyond this, the system will be restricted in what operations they may carry out independently.

Autonomy – An autonomous system is one of such, which operates within a defined set of parameters. However, the system can be programmed to learn and adapt to environmental changes which the system may come in to contact with. Additionally, the system may also correct its own operating parameters

Figure C.2: Definitions Page from Technical Training Material

The first system that we will look at today is the autopilot. The autopilot is an example of an automated system onboard, and the aim of the autopilot is to aid the navigation of the vessel. However, it must be operated by a suitably qualified officer. Additionally, the autopilot system may be one of the first systems adapted in the transition to autonomous operations.



Autopilot

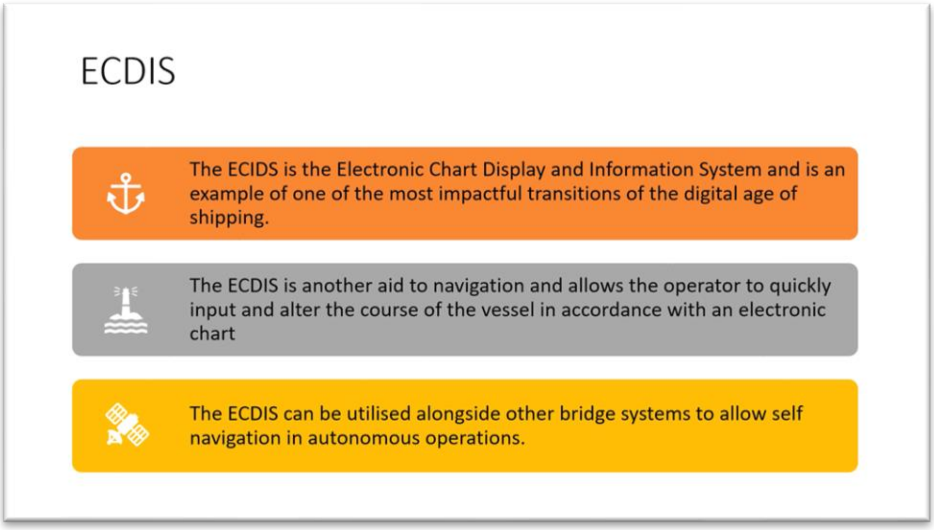
The autopilot of the vessel will is an example of an automated system on board.

The aim of the autopilot is to aid the navigation of the vessel, however it must be operated by a suitably qualified officer.

The autopilot system may be one of the first systems adapted in the transition to autonomous operations.

Figure C.3: Autopilot Page from Technical Training Material

Another example that we will be looking at today is the ECDIS. The ECDIS is the electronic chart display and information system and is an example of one of the most impactful transitions of the digital era of shipping, where the maritime industry changes from paper to electronic charts. The ECDIS is another aid to navigation and allows the operator to quickly input and alter the course of the vessel in accordance with an electronic chart. The ECDIS can be utilised alongside other bridge systems to allow self-navigation in autonomous operations.



ECDIS

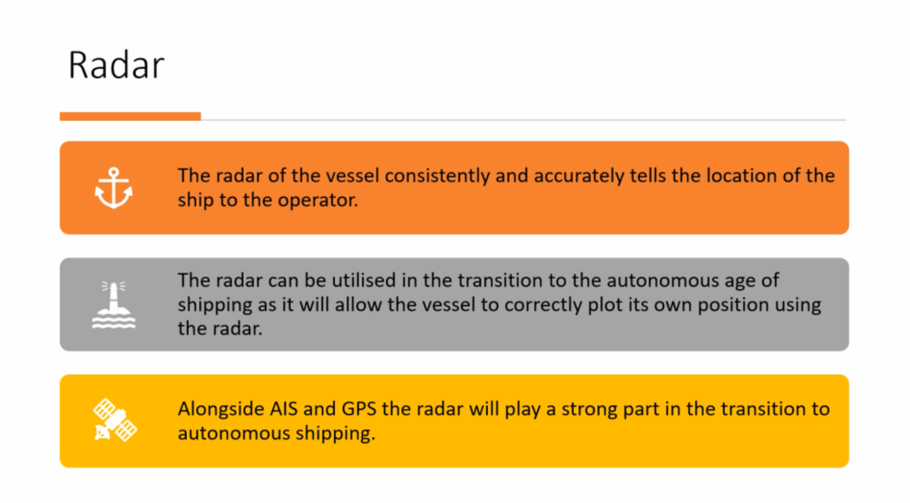
The ECIDS is the Electronic Chart Display and Information System and is an example of one of the most impactful transitions of the digital age of shipping.

The ECDIS is another aid to navigation and allows the operator to quickly input and alter the course of the vessel in accordance with an electronic chart

The ECDIS can be utilised alongside other bridge systems to allow self navigation in autonomous operations.

Figure C.4: ECDIS Page from Technical Training Material

Finally, we will look at the vessels radar. The radar consistently and accurately feedback the location of the vessel to the officer of the watch and can be utilised in the transition to autonomous shipping as it may allow the vessel to correctly plot its own position using the radar for reference.



Radar

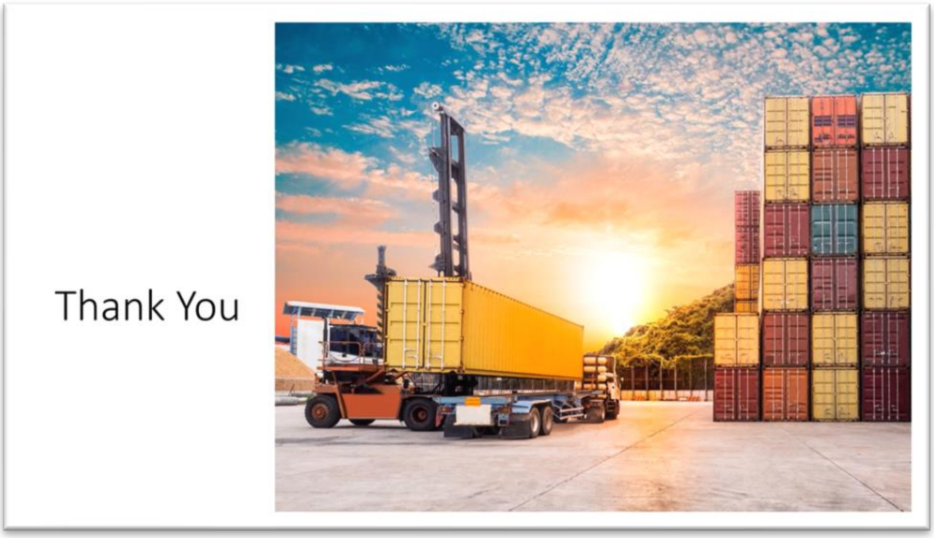
The radar of the vessel consistently and accurately tells the location of the ship to the operator.

The radar can be utilised in the transition to the autonomous age of shipping as it will allow the vessel to correctly plot its own position using the radar.

Alongside AIS and GPS the radar will play a strong part in the transition to autonomous shipping.

Figure C.5: Radar Page from Technical Training Material

Thank you for paying attention to this information video, if you please head through the door and meet your instructor, they will then assist you with the next part of this study.



Thank You

Figure C.6: Final Page from Technical Training Material