HUMAN FACTORS: ELIMINATING INSTRUMENTAL DISTRACTIONS ON A SHIP'S BRIDGE TO IMPROVE WATCH OFFICER'S SITUATIONAL AWARENESS FOCUS

by

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Disclaimer

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination, which has led to the award of a degree.

Signed: A. Khalique Date: 11th May 2024

Declaration

No portion of the work referred to in the thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

Abstract

The International Regulations for Preventing Collisions at Sea (IRPCS) require ships' Officers of the Watch (OOWs) to maintain a proper lookout by sight despite provision of centralised navigational and collision avoidance information via modern multifunction displays (MFDs). However, OOWs spend more time on gathering information from MFDs than on maintaining a visual lookout. Apart from anecdotal evidence, no formal evaluation has ever been carried out to quantify these interruptions. Even though it can be attributed to the lack of a formal definition of the term 'proper lookout' used in the IRPCS but the seafarer fraternity has paid very little attention to the intricacies of maintaining a proper lookout. The author presents a definition for inclusion in the IRPCS, thus paving the way to revolutionise the whole lookout concept.

Further, this research also evidences the impact of MFDs on maintaining a lookout in the context of human eye functionality, leading to recommendations for mitigation of distractions caused by them. This impact was measured by use of Eye Tracking Devices (ETDs) in bridge simulators and on real ships to capture, analyse and compare data on watchkeepers' eye movement. This analysis leads the author to establish a distraction evaluation ratio (DER) for distractions caused by MFDs to maintain a proper lookout as required by IRPCS.

Drawing on research in the aviation and road vehicle industries and making use of the DER, the author introduces the Centre Console Display (CCD) concept, in which only the most relevant collision avoidance and navigational information is displayed to the OOW to declutter information displayed on MFDs, thus reducing distractions thereof. In achieving an overall improvement in the DER, a visual scan pattern associated with maintaining a proper lookout is also introduced to ensure OOWs have some specific guidance when maintaining an effective lookout. After implementing these novel concepts, the ETD data is once again captured in the bridge simulator, analysed and then validated by similar data captured on real ships.

The evidence gathered in this research shows that watchkeepers trained in maintaining a proper lookout are more effective and therefore display notable improvement in reducing DER through refining their behaviours in conjunction with decluttered MFDs that avoid information overload thus overcoming distractions caused by MFDs. The

research outputs lead to a conclusion that the time OOWs spend on maintaining visual lookout can be easily increased, enabling them to comply fully with the true spirit of the IRPCS requirements to maintain a ‘proper lookout’.

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Abbreviations

$\overline{x}$	Sample Mean
$\hat{\mu}_x$	Population Mean
df	Degrees Of Freedom
x	Data Point
x_k	Datapoint in The Sample
μ	Mean
σ	Standard Deviation
f_{obs}	F-Statistic
qk	Cumulative Probability
z	z-score
AI	Artificial Intelligence
AIS	Automatic Identification System
AMSA	Australian Maritime Safety Authority
AOA	American Optometric Association
AOI	Area of Interest
AR	Augmented Reality
ARPA	Automatic Radar Plotting Aid
ATSB	Australian Transport Safety Bureau
BeGaze	Behavioural and Gaze (Software used with ETDs)
BNWAS	Bridge Navigational Watch Alarm System
BV	Bureau Veritas (Classification Society)
CAA	Civil Aviation Authority (UK)
CCD	Centre Console Display
cd	Candela (Used in cd/m^2 – Candela per metre squared)
CHIRP	Confidential Human Factors Incident Reporting

CMG	Course Made Good
CPA	Closest Point of Approach
CTS	Course to Steer
D	Dwell time (applied in context to the text)
Decca	Decca (Hyperbolic) Navigation System
DER	Distraction Evaluation Ratio
DfT	Department for Transport, UK
DFM	Dwell time and Fixations on MFDs
DFW	Dwell time and Fixations on Windows
DNV	Det Norske Veritas (Classification Society)
DIT	Department for International Trade, UK
DoT	Department of Transport (USA)
DSC	Digital Selective Calling
DTG	Distance to Go
EASA	European (Union) Aviation Safety Agency
ECDIS	Electronic Chart Display and Information System
ECFR	Electronic Code of Federal Regulations (USA)
EMSA	European Maritime Safety Authority
ETD	Eye Tracking Device
eV	Electron Volt
F	Fixations (used in context to the text)
FAA	Federal Aviation Authority (USA)
fNIRs	Functional Near-Infrared Spectroscopy
FOV	Field of View
FPS	Frame(s) Per Second
GMDSS	Global Maritime Distress and Safety System

GNSS	Global navigation satellite system
GBS	Goal-Based Standards
GPS	Global Positioning System
GUI	Graphical User Interface
H_0	Null Hypothesis
H_1	Alternative Hypothesis
HCD	Human-Centred Design
HF	High Frequency
HMD	Heartbeat Monitoring Device
Hz	Hertz
IBS	Integrated Bridge System
IBM	International Business Machine (Company)
IFR	Instrument Flight Rules
IHO	International Hydrographic Office
IHIET	International Conference on Human Interaction & Emerging Technologies
IID	Independently and Identically Distributed
IMarEST	Institute of Marine Engineering, Science & Technology
IMO	International Maritime Organization
IRPCS	International Regulations for Preventing Collisions at Sea
ISM	International Safety Management (Code)
IT	Information Technology
lm	Lumen
lx	Lux
LJMU	Liverpool John Moores University
LORAN	Long Range Navigation (System)

LR	Lloyds Register (Classification Society)
m	Metre
M2050	Maritime 2050 – ‘Navigating the future’
MAIB	Marine Accident Investigation Branch
MF	Medium Frequency
MarRI-UK	Maritime Research & Innovation UK
MCA	Maritime and Coastguard Agency
MFD	Multifunction Device
MGN	Marine Guidance Note
MNTB	Merchant Navy Training Board (UK)
ms	Milliseconds (1000th of a second)
N	Number (of Participants)
n.d.	No Date (for a publication)
NAESTO	Navigation Aids, Equipment and Simulator Training (Operational) Course
NTSB	National Transportation Safety Board (USA)
OBS	Open Broadcaster Software in OBS Studio Software
Omega	Omega Navigation System
OOW	Officer of the Watch
PC	Personal Computer
PPI	Plan Position Indicator
RoPax	Roll on Roll off Passenger (ship)
RT	Reaction Time
SA	Situational Awareness
SD	Standard Deviation
SMI	Senso Motoric Instruments

SOLAS	Safety of Life at Sea (International Convention)
SMS	Safety Management System
SPSS	Statistical Package for the Social Sciences (Software name from IBM SPSS)
Stbd	Starboard (side of the vessel)
STCW	Standards of Training, Certification and Watchkeeping for Seafarers (International Convention)
STM	Short Term Memory
T&I	Trade & Investment, UK
TCAD	Traffic Collision Alerting Device
TCPA	Time to Closest Point of Approach (CPA)
THz	Trillion Hertz
TSB	Transport Safety Board (Canada)
TTG	Time to Go
UK	United Kingdom
UKC	Under Keel Clearance
UREC	University Research Ethics Committee (LJMU)
US	United States
USCG	United States Coastguard
USS	United States Ship
VDES	VHF Data Exchange System
VIBGOYR	Voilet, Indigo, Blue, Green, Orange, Yellow, Red (Colours in visible light)
VDU	Visual Display Unit (same meaning as MFD)
VFR	Visual Flight Rules
VHF	Very High Frequency (Radio)
WP	Work Package

WPT	Waypoint
WWS	Window Wiper Scan
XTE	Cross Track Error

Chapter 1: Introduction

1.1 Introductory Remarks

A knowledge of human circadian rhythm warns of a natural weakness at its low points requiring higher attentiveness to avoid errors or omissions, which can lead to accidents. In the same way, an increased understanding of a danger allows development (Abell, 1933; Crittenden, 1999) of rational choices (Fan and Yang, 2023) to help avoid it. The role of the Officer of the Watch (OOW) in maintaining a proper lookout, and thus situational awareness (SA), is not only traditional in the maritime industry but is also mandatory under International Regulations for Preventing Collisions at Sea (IRPCS), 1972 (Norris, 2015).

Maritime safety is continuously facing new challenges due to the introduction of new technologies such as autonomous or remotely operated vessels, as well as new operational environments such as Arctic shipping. The OOW's ability to adapt to uncertain environments and gradually enhance their own ability (Chengbo et al., 2023) is the key to adapting to changing environments as well as technologies. Masters and OOWs continue to navigate ships in an increasingly time and resource-pressured industry. A higher volume of navigation and collision avoidance information is being processed by OOWs, particularly in complex traffic scenarios, which adds an extra layer of complication to the user experience on ships' bridges. Navigational accidents continue to occur despite technological advances allegedly developed to reduce OOW's workload and provide more time to maintain a thorough SA and hence avoid danger.

The three standard modes of transportation, i.e. road vehicles, aviation, and maritime transport are very different from each other but the common factor between these three is the driver, pilot and watchkeeping officer respectively. Any mistakes or error of judgment by any of these could quite easily lead to an accident. Although avoidance of accidents through human error is still being debated and researched to find solutions, use of Artificial Intelligence (AI) in self-driven vehicles and autonomous ships, which a few years ago seemed a gigantic challenge, now appears to be achievable (Kuwata et al., 2014). With advances in technology, an increase in the

number of instruments on the bridge continues, allegedly, to make OOWs' life easier by reducing their workload, providing better SA (Hareide and Ostnes, 2017b) and thus making ships' operations safer than they have historically been.

However, despite technological advancements, it can be claimed that the watchkeeping officers continue to fail to improve their SA, as evidenced by various recent maritime navigational accidents (NTSB, 2020; Voytenko, 2021). A majority of navigational accident reports indicate a contributory cause to be a 'lack of situational awareness' (Wingrove, 2016). Within this, an 'inadequate lookout' (Acejo et al., 2018) seems to find its place in recommendations made by the United Kingdom's (UK's) Maritime Accident Investigation Branch (MAIB), Australian Transport Safety Bureau (ATSB), Transportation Safety Board (TSB) of Canada, United States Coast Guard (USCG) and other similar organisations in the maritime world.

Rule 5 – 'Lookout' of the IRPCS, 1972 requires the OOW and the watchkeepers to maintain an efficient lookout at all times (Norris, 2015), but various factors, including poor design of controls and interfaces (Lützhöft, 2004) and a lack of compliance with Safety Management Systems (Nordby et al., 2018; Gauthier et al., 2019), continue to undermine this function. It has been recognised by Chengbo et al. (2023) that the storing of learning for every collision avoidance situation is notoriously difficult. Norman (2014) believed that poor design of the controls (interfaces), lack of identification (and application) of proper procedures by OOWs, and lack of compliance with Safety Management Systems most often are the culprits. In many cases, a human-centred design combined with factors that do not distract or divert OOWs attention could eliminate most errors.

The maritime industry continues to indicate a lack of effective lookout as a contributor to numerous accidents, with 65% of ship collisions (Wang and Fu, 2022) resulting from improper lookout, and 73% involving improper or poor use of radar. According to the ATSB investigations (AMSA, 2020) into 41 collisions over 26 years identified failure to maintain a proper lookout. European Maritime Safety Authority (EMSA, 2022) indicates that from 2014 to 2021, a total of 563 lives were lost, with 6,155 injuries caused mainly by ship collisions, of which 59.6% of accidents were due to human action and 68.3% of the contributing factors were related to human behaviour. According to the MAIB (2004), 65% of the vessels involved in collisions contravened the IRPCS lookout rule whilst 19% of the watchkeeping officers of the vessels

involved in collisions lacked SA. With the rising popularity of autonomous shipping for real life applications, the focus has shifted towards looking into the safety systems within the maritime industry. Further evidence shows that human error was judged to be responsible for 75% of maritime accidents in 2018 (Allianz Global Corporate & Specialty, 2018) and, even with the development of new technology and risk management training, caused $1.6bn in losses in the same year.

These statistics lead to a more specific question, which is the primary one still un-answered, i.e., 'Are the lookouts actually doing their job as required by IRPCS?' The accident reports suggest otherwise; therefore, the improved technology needs to be assessed from the user's perspective. It is now known that technological advancements have reduced accidents related to technical failure (Bielic et al., 2017), but human factors continue to be the cause of 75–96% of the accidents (Fan and Yang, 2023). On one hand, the maritime sector lags behind the aviation industry in the application of new technologies (Hareide, 2017a) but on the other hand, the regulations to use this technology, and therefore the associated training, lacks a standardised approach for presentation of information to the OOW, thus impacting their ability to maintain a good SA.

1.2 Research Aim and Objectives

Based on the concerns elaborated in the previous section, the research presented in this thesis aims to "*eliminate distractions caused by Multifunction Displays (MFDs) on the ability of watchkeepers to maintain a proper lookout*". This aim is achieved through the following objectives.

1. define the term 'proper lookout' for inclusion in the IRPCS and/or the STCW Code (International Convention and Code on Standards of Training, Certification and Watchkeeping for Seafarers).
2. define an 'ideal' visual scanning pattern for the OOW to maintain an efficient lookout in all conditions of visibility.
3. understand the factors that divert OOWs attention from the primary role of maintaining a proper lookout, thus ensuring a comprehensive SA at all times.
4. recommend improvements in the information displayed for the OOW, considering the research carried out in the aviation industry and keeping in view any distractions caused by instruments or their displays (MFDs).

The research studies the OOWs' performance in a simulated bridge environment to inform a series of recommendations on training and integration of technology in the sector as it transitions towards a more automated, technology driven future. This study, therefore, draws from the following specific questions to meet with its aims and objectives:

(1) ***Why are the watchkeepers not informed and trained on how to maintain a proper lookout?***

This appears to be because of a lack of definition of this term. This question is answered through a comprehensive literature review to understand and define the term 'proper lookout' as applicable to the maritime watchkeeper.

(2) ***In what ways do the instrument panels used on the bridge of a ship affect a watchkeeping officer's ability to maintain an effective lookout?***

The study uses Eye Tracking Devices (ETDs) to compare the watchkeeping officers' efficiency in maintaining a lookout when the equipment displays for

bridge equipment are switched off against their efficiency when displays are switched on. This comparison assists in establishing:

- the distractions caused by instrument displays.
- whether the watchkeeping officers follow any natural visual scan pattern for maintaining an effective lookout. If not, an optimised scanning pattern is recommended.

A number of data collection exercises are conducted. A new approach for design of the bridge instrumentation display, similar to the T-arrangement in the aviation industry, is proposed based on the findings from this research. The improvements and the effectiveness of proposed changes in scan pattern and the information displayed on MFDs is verified through further data collection simulations to gauge whether the proposed changes were successful prior to finalising the results presented in this thesis.

(3) ***How can training in marine simulator be designed to assess and improve a watchkeeping officer's effectiveness in assimilating and acting upon information presented by new technology?***

In order to efficiently use the limited time available for training in simulators, this research looks into making recommendations for improvement of the OOW training on the basis of quantifying the 'anecdotal evidence' that prevails due to very little hard data having been obtained to counter it. At present, it is widely advertised that an OOW's SA is improved by the use of AI augmented technology.

The fact remains, however, that a majority of navigational accident reports indicate a 'lack of SA' a critical cause of human errors (Fan and Yang, 2023) resulting from a 'lack of proper lookout'. Based on the results of data collected in question (1) above, an analysis of research findings is carried out outlining the recommended changes in watchkeeping officers' training to improve their efficiency in maintaining a lookout and thus reduce navigational incidents.

(4) ***Can the information gained during training scenarios be fed back into improving the design and layout of instrumentation?***

The study evaluates the watchkeeper's performance in a simulated bridge environment to inform a series of recommendations on training and the integration of technology as the maritime sector transitions towards a more automated, technology-driven future. The value of a more effective watchkeeping officer could reasonably be described as priceless. Collectively, improved training programmes and better information displayed on MFDs for navigational equipment will have a significant positive impact on the shipping industry. Whilst there is very little additional cost in making changes to the delivery and assessment of watchkeeper training or the modification of the current MFDs, the reduction in navigational accidents and therefore losses and damages can be alleviated significantly. The research and analysis of data gathered will therefore lead to possible changes in the presentation of information to watchkeeping officers, as well as their watchkeeping behaviour. These findings have already been disseminated to the industry and regulators through the publication of articles in maritime magazines and/or journal papers, as listed in Appendix 8: Published Papers & Presentations.

To summarise, the research carried out for this report investigates and presents solutions for improving OOWs SA through:

i. Proposing a definition of the term 'proper lookout' for inclusion in the STCW Code and/or the IRPCS and its application to maritime watchkeeping, particularly for the lookout function on the bridge of a ship.
ii. Optimising display of information on MFDs through Centre Console Display (CCD) concept to limit distractions.
iii. After establishing a Distraction Evaluation Ration (DER), adopting an optimised visual scan pattern that enables a time-sharing technique to apply to looking outside the navigation bridge as well as looking at MFDs to appreciate the distractions caused by instrumentation on the bridge of a ship.

1.3 Novelty of the Study

By 2050, the global demand for freight is expected to have tripled, which will lead to busier waters alongside a growing need to ensure the safety of crew, vessel, cargo and environment. This is predicted by both M2050 (the UK government's policy paper on the future of the maritime sector, commonly referred to as 'Maritime 2050 – Navigating the future') and the Department for International Trade (formerly known as Trade & Investment (T&I) UK).

The M2050 distinguishes the poor global maritime safety standards with high fatal accidents rates even though the UK's standards are relatively good. It also recognises that the human error accounts for the vast majority of maritime accidents. It highlights that the people in the maritime industry play a pivotal role in its success. Consequently, it requires that the 'employees of the future' must remain at the centre of maritime operations through ensuring lifelong training and education supporting them for new opportunities including new technologies. It must continue to take further action based on the findings from accidents and incidents to continue to embed safety culture into safe working practices. This will be supported through use of sophisticated Information (IT) systems wherein training must accommodate greater use of simulation. This will make the UK's 'highly diverse maritime workforce well-looked after, with health, safety and welfare standards being set globally by the UK' through a simple approach i.e. 'prevent the circumstances in which they occur from arising in the first place'. The M2050 summarises its overall aim in one statement 'by 2050 all avoidable accidents will have been eliminated, making the sea a much safer place to work and to enjoy recreationally'.

Aligned to the factors highlighted through M2050 and emphasised in the preceding paragraph, the current study presented in this thesis falls exactly in line with the M2050 aspirations to make UK future ready through innovative recommendations for:

- ✓ improvement of watchkeeper's soft skills by applying better watchkeeping behaviour through a new maritime domain lookout method referred to as Window Wiper Scan (WWS) discussed in Section 4.2.1 and thus an improved SA.
- ✓ better use of simulators utilising ETDs as recommended via this thesis.

- ✓ development of human centred and simplified MFD design as presented through proof of CCD concept in this thesis.

The Department for International Trade (DIT), UK note the following regarding seafarer skills:

- the importance of people and skills to achieving their vision for the future of shipping. The strategies stress the need to ensure that the correct skills are available to operate new technologies and anticipate future needs.
- that the technology will play a crucial role in achieving key ambitions including driverless cranes, autonomous ships and remote operation of services. This transition will not occur overnight and the way in which ship operators and all seafarers interact with technology will become central to its successful integration.

According to the MAIB, "even a cursory consideration of relevant investigations shows that a small number of causal factors are common to nearly all bridge watchkeeping accidents." Two thirds of the 1,647 collisions, groundings, contacts and near collisions reported between 1994 and 2003 were due to 'not keeping a proper lookout' (MAIB, 2004). Further data from MAIB reports indicate 783 similar incidents reported between 2008 and 2018. Whilst the number of incidents has reduced, there is still room for improvement. Despite the MAIB's study and recommendations to the UK's Maritime & Coastguard Agency (MCA) and the industry, recent reports continue to indicate a 'lack of proper lookout' as a contributory factor for ship collisions.

An OOW is responsible for the lives of everyone on board, for millions of pounds of company assets in the form of the ship itself, hundreds of millions of pounds in cargo value, and billions of pounds in terms of liabilities and environmental impact. Therefore, a more effective OOW could reasonably be described as invaluable. It is of particular interest to make time spent on training in a simulator 'quality time'. With simulators already being used to replace an amount of real-world sea service, it is now more important than ever that we address the shortfalls in STCW training standards. Collectively, improved training programmes and better MFDs for navigational equipment will have a significant positive impact on navigational safety.

Through enhanced training and proposals for improvements with regards to relevant maritime codes of practice, this research supports the UK's Maritime 2050 (M2050) – 'Navigating the future' policy (DfT, 2019), through which the UK aims to continue to be recognised as the global leader in maritime safety by undertaking research and gathering data leading to improvements in risk management and safety at sea.

Aligning with the aims of M2050, this research has as its ultimate goal to improve watchkeepers' ability to maintain increased SA and thereby increase safety at sea. The findings from this research will feed into improvements in training methods, operational processes, navigational display design, and codes of practice resulting in a reduction in the number of accidents and an accompanying reduction in financial losses, ship and cargo damage, loss of life and damage to the environment.

The innovative aspect of this research, therefore, is the creation of guidelines, procedures and recommendations for an improved bridge design through modification of currently cluttered (Costa et al., 2018) MFDs. This is something that is not currently available to educators, trainers, operators, or the manufacturers of bridges or simulators.

Whilst there is a clear drive to introduce new technologies, we cannot solely rely on technology as the end goal; people and skills must be firmly placed at the centre of the industry. This research analyses how OOWs apply their skills and knowledge in a simulated environment; an approach that will lead to improvements in teaching and therefore the skills of future watchkeepers, who, due to technological advancements, will be required to perform high risk/high pressure tasks in an ever-changing ship's bridge environment. It also directly supports this aim by gathering intelligence and data as to how officers interact with their environment and bridge controls. Furthermore, the data gathered in this research and solutions proposed in this thesis aim to improve seafarers' attention, cognition and ultimately performance through the creation of an enhanced operational bridge layout, underlining the safety of navigation throughout the process.

There is very little existing work to establish any links between the OOW's role as a lookout and distractions caused by the various displays on the bridge of a ship. It is also surprising that, even though maintaining a 'lookout' is the primary role for all OOWs, there are no recommended techniques regarding how to maintain a visual

lookout on the bridge. This is despite the well-known fact that training and operational design research is instrumental in providing effective outcomes. In order to mitigate potential catastrophic events, which might occur with either human or automation failure, training must support operational requirements dictated by bridge equipment and layout design. The results of this first-of-its kind research will help capture evidence and data that will improve overall awareness and safety at sea, meaning more attentive and effective seafarers with a reduced probability of serious marine accidents and lower likelihood of associated negative environmental impact.

Understanding 'how, what and when' for user interaction on bridge, during normal operations or emergencies, can provide significant findings. This research analyses these human factors, in terms of physical, cognitive, and organisational ergonomics across ship's bridge design, and explores interactions during bridge watchkeeping to ultimately improve maritime safety. The data captures inappropriate and poor design and narrows down the field of design to one area on the bridge to increase the effectiveness of implemented solutions. The research will thus combine the result of eye-motion tracking, to understand if a correlation can be found between these factors.

It is anticipated that, through this research-driven evidence leading to new guidance, trained watchkeepers will be able to minimise errors and omissions that occur during operations. The outputs will help optimise ships' bridge design through development of a multimodal interface that portrays the gist of control with a low cognitive workload, to increase performance and ease decision-making. By creating an experimental prototype, the aim is to measure the level of interaction between the existing bridge layout and the new, developed workplace. This last will lead to a comparative assessment of the interface across all bridge systems, allowing a baseline to be established for the best configurations.

1.4 Thesis Layout

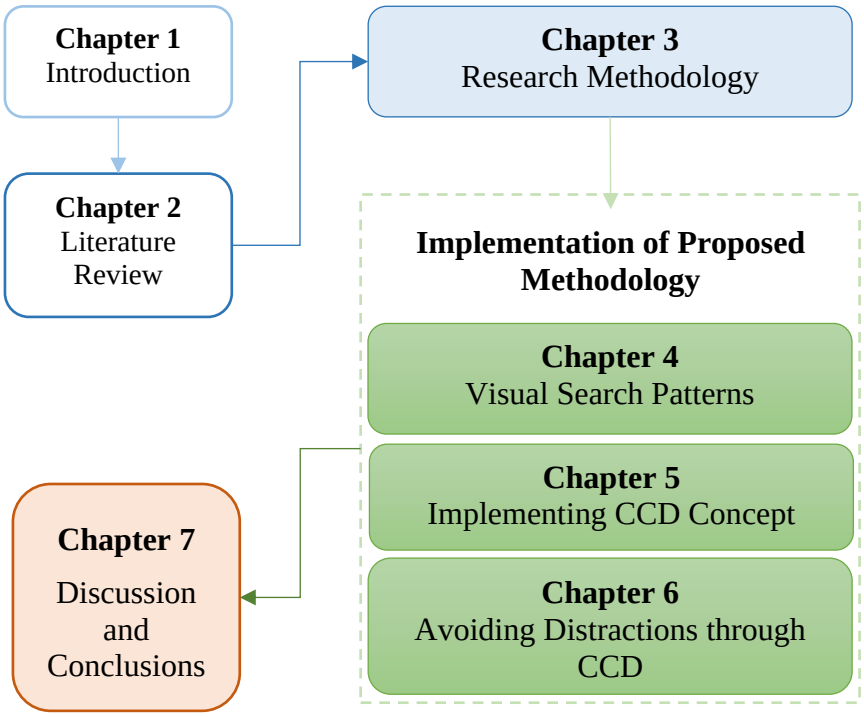

Figure 1 - Dissertation Outline

This thesis is divided into seven chapters (as shown in Figure 1) to maintain distinct topics for discussion.

In **Chapter 1**, an introduction to the topic for this study is given followed by research aim and objectives are stated together with specific research questions that highlight the issues being investigated. A section on novelty of the study is also included, justifying the uniqueness and originality of this research.

Chapter 2 provides a literature review to build upon current research on SA and attention span in relation to visual searching and scan patterns and culminates in research hypothesis for the underlying research. A detailed comparison of maritime watchkeeping is also made with the pilots in the aviation industry and drivers in the road transport industry to see comparable research-based solutions to the similar problems within these three industries. This chapter offers a comprehensive literature review to study existing issues related to SA in the bridge watchkeeping context, use of eye tracking devices to capture watchkeepers' behaviour and thereby understand

the options to offer improvements in watchkeeping practices leading to improved navigational safety.

Chapter 3 outlines the research methodology followed in this study. It provides details of how the ETDs were used in this research to capture data in bridge simulators as well as on real ships. The research hypothesis is outlined, together with details of data capture scenarios to ensure a formalised and consistent approach for the experiment. This chapter concludes with providing a summary of the issues faced during data collection to enable future studies to take those into account when designing new experiments.

Chapter 4 discusses the complications caused by current design of MFDs, including issues with maintaining a lookout during the day and at night, and provides justification for the proposed scan pattern, leading to recommendations for amendments to the STCW code.

Chapter 5 introduces the CCD concept. This novel concept is based on feedback received from experienced seafarers through a questionnaire, which provided users' input on weaknesses in the current bridge design, MFD layout and usability, as well as their input into choosing the most relevant navigational and/or collision avoidance information displayed on the proposed CCDs.

Chapter 6 provides a comprehensive sensitivity analysis of the ETD data captured in this research by defining the statistical model followed on by undertaking a normality and a F-test together with an explanation of the limitations of the model and its validation for use in this study. After data validation, a comprehensive fixations and dwell time between the five experiment scenarios are compared to establish a DER, setting a standard for maritime watchkeeper to overcome distractions caused by MFDs. This chapter therefore concludes with an insight into the time spent on maintaining a visual lookout against the OOWs' time occupied by MFDs. A comparison of this DER is also made with similar data from the aviation industry to identify gaps in the maritime industry's practices.

Chapter 7 provides a summary of research objectives achieved, together with a statement of contribution to knowledge and practice, is given in this chapter to ensure a closed-loop approach for the accomplished research aim and objectives achieved. It also elaborates future work that can supplement the work undertaken thus far. This

chapter concludes with a summary of the whole project to encapsulate the work undertaken and presented in this thesis.

1.5 Concluding Remarks

This first chapter sets the scene for this research by elaborating its objectives through research questions, highlighting the issues caused by information displayed to the watchkeeper via MFDs on modern ship's bridges. It also sums up that the lack of a technique to scan the horizon when maintaining an effective lookout is directly linked to a lack of definition of the term 'proper lookout' in regulations governing watchkeeping principles and practices. It then expands on the novelty of the research, highlighting a lack of similar research in the past allowing continuation of issues raised by MFD distractions in maintaining a proper lookout, that have historically existed for many decades. A brief introduction is given to how the findings from this research will improve navigational watchkeeping safety through improving the use of simulators for training. Finally, a chapter-wise overview of this thesis is provided for ease of reference.

Chapter 2: Literature Review

2.1 Introductory Remarks

MFDs are widely used on ships' bridges to show information ranging from primary vessel information and details of in-water objects to the coastline around the ship. MFDs vary in shape and size but are usually rectangular in shape with a graphical user interface (GUI) showing different objects in various colours, along with 'soft buttons' on the periphery (Biswas, 2018).

An example of such an MFD is ship's radar or Automatic Radar Plotting Aid (ARPA) MFD, which displays the user's own ship in the centre and is referred to as the Plan Position Indicator (PPI). Other objects, i.e., ship's buoys, the coastline, etc., are displayed around the ship on the PPI. When the watchkeepers require, they can track other targets to obtain their motion information by using ARPA.

The target data is analysed using inbuilt computer algorithms to present collision avoidance information such as the target's Closest Point of Approach (CPA), Time of CPA (TCPA), target's course and speed, etc., together with navigational information such as Cross Track Error (XTE), Course to Steer (CTS), etc. All of this data can be displayed in multiple pages on the same MFD, accessible through soft buttons requiring interaction time and effort from the user.

Whilst a lack of human-centred design and consequential issues associated with the MFDs appear to cause some problems, the challenges associated with the watchkeeper as the weak link between presenting and using this information also need to be addressed (Lützhöft and Grech, 2016). At the end of the day, the modern MFDs on the bridge are meant to support the watchkeepers; therefore, they must know all their weaknesses and find ways to work around them in the same way as is the case with our circadian low, where we increase our awareness to mitigate possible adverse consequences.

2.2 Learning from the Aviation Industry

Comparing various modes of transportation, such as road vehicles and aviation, with maritime transport, the latter is still far behind its competitors (Hareide and Ostnes, 2017b). Rasmussen (1999) and Nordby et al. (2018) highlighted the fact that the users of any system should not be treated as add-ons to that system but instead be factored in as integrated parts of the system's functional design to reduce human error. On the contrary, new technologically advanced equipment is frequently just added on the ship's bridge where it best fits, without much research into its impact on human inclusivity, where the watchkeepers must be seen (Lützhöft, 2008) as an integral part of the whole bridge layout. This is not the case for the aviation industry, for example, which uses two sets of rules to choose from, based primarily on visibility (Hareide and Ostnes, 2017b), to assist pilots in choosing an appropriate approach to navigation. These are:

- Visual Flight Rules (VFR), for use in 'clear' visibility conditions.
- Instrument Flight Rules (IFR) generally used when flying in restricted visibility, when the pilot uses instruments in the cockpit together with an IFR flight plan.

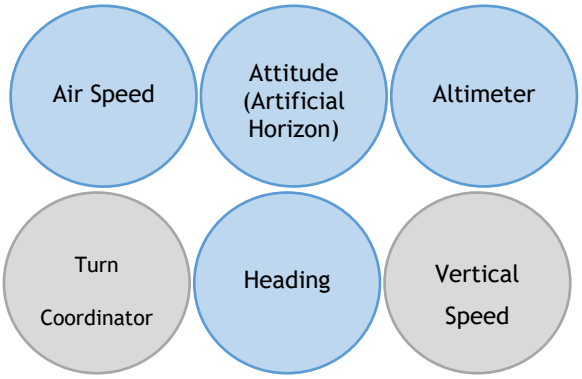

Figure 2 - The Aviation 6 Pack

In order to assist pilots further, the instruments displaying vitally significant information are laid out in a very logical layout known as a 'T-arrangement' (Figure 2) developed through research carried out by Fitts et al. (1949). These instruments include indicators for airspeed (top left); artificial horizon, also known as attitude indicator (top middle); altimeter (top right); and heading indicator at the bottom

middle. Turn coordinator and vertical speed indicator are located at the sides of the heading indicator. This arrangement provides the pilot with primary information at the first 'glimpse' of the panel to enable better situational awareness (Khalique, 2015). In the maritime industry, there does not appear to be any specific research on this aspect, so instruments are traditionally located where they 'best fit' in compliance with broad guidelines provided in International Convention on Safety of Life at Sea (SOLAS), 1972, Chapter V Regulation 15:

"All decisions which … affect bridge design, the design and arrangement of navigational systems and equipment on the bridge and bridge procedures shall be taken with the aim of … facilitating the tasks to be performed by the bridge team and the pilot in making full appraisal of the situation and in navigating the ship safely under all operational conditions".

The maritime industry presents many similarities with the aviation sector (Martinez-Marquez et al., 2021) because both are exposed to similar environments in the dynamic movement of both planes and ships in the air and at sea, respectively. One reason for the fundamental technical advancement of the aviation sector is due to safety factors; as there is a lower chance of survival than in a maritime accident, advancements in aviation have been significant. However, high-profile maritime accidents attributed to human error are being reported more frequently due to increased traffic and congested shipping lanes. Examples include the container vessel Ever Given blocking the Suez Canal in 2021, the oil tanker Sanchi in 2018, the collisions of the US ship (USS) Fitzgerald and the USS John S McCain in 2017 and the sinking of the Costa Concordia in 2015. This is despite the fact that the maritime industry is a highly regulated domain in which, as recommended by the MAIB (2004), "collisions should theoretically be avoided if every vessel abided by the IRPCS".

2.3 Watchkeeper similarities with the Road Vehicle Driver

Modern road vehicles follow the trends in technological advances such as an ever-increasing number of digital displays, allegedly making the driving experience relaxed, and enjoyable as well as assisting drivers in getting to their destination easily through use of the navigation systems. No doubt, the modern road vehicles are safer

and more comfortable, but the modern driver has a higher mental workload due to the need to negotiate continuously with various audio-visual alarms in the vehicle in addition to carrying out with their basic function to drive safely on the road. Some of basic information in vehicles is displayed continuously such as speedometer, engine Revolutions Per Minute (RPM) indicator, fuel, and engine temperature gauges etc., whereas additional equipment such as music player (audio/video) and navigation system, collectively referred to as infotainment systems, are added to improve the driver experience. Supplementary features such as tyre pressure monitoring, lane assist, pedestrian detection system, parking sensors and various drive modes (sport, eco, snow etc.) are not mandatory but can cause a distraction to the driver if operated automatically or through drivers' deliberate interaction. Drivers' performance (Yang et al., 2012) was recorded as worse than being under the influence of 80 mg/100 mL of alcohol while using a mobile phone.

Today's automatic vehicle driver sits in a very comfortable seat to push the accelerator after operating just a button to release the hand brake in contrast to the physical hand brake lever. Afterwards, they only need to push the accelerator pedal to accelerate or brake paddle to brake or stop. The need to constantly adjust pressure on the accelerator does not exist in the 'cruise control' mode, thus the driver has only one job whilst sitting comfortably in the seat i.e. to maintain a lookout for hazards on the road or to slow down or stop for the destination needs. In this analogy, there is a minor resemblance between the driver's function of lookout and the maritime watchkeepers but there are several major differences as well.

The road vehicle drivers' life outside their vehicle is influenced overwhelmingly by technology through regular use of mobile phone, internet in conjunction with electronic and social media. They appear to have become so habitual in its use that sitting in a vehicle to simply focus on the road to look for hazards is not an easy task in the presence of distracting (Le, et al., 2020) infotainment as well as the biggest culprit in the form of mobile phone, albeit being forbidden to use in almost the entire world. According to Dijksterhuis et al. (2011), the driver's mental workload is responsible for the majority of road traffic accidents – a major common factor between the road transport and maritime industries.

Personal experience, anecdotal evidence as well as several research studies confirm that mobile phone, visual displays in vehicles and associated alarms cause distractions

to road vehicle drivers, increasing their mental workload (Dijksterhuis et al., 2011), thus leading to accidents. Despite a much larger number of road vehicle accidents than the maritime navigational accidents, the causal factor for both remains to be the 'human factor' i.e. the driver in a road vehicle (EU-OSHA, 2010) and the watchkeeper in the navigational context.

Driving on road has very different challenges in comparison to ship navigation at sea (Fan, 2020; Vetturi, et al., 2020). The vehicles are driven on marked roads, with speed limits monitored by speed cameras to control the driver behaviour in places where speed control is critical. This however is not the case for ships where they navigate the ship in water through monitoring their position plotted it on a navigational chart in addition to carrying out the lookout function. The drivers however must 'always' maintain their focus on road safety ', and drive within speed limits by avoiding distractions caused by anything that will disturb their focus. This need is reflected in globally applicable road safety rules such as penalties on use of mobile phones whilst driving, or even eating food. No such rules exist for maritime watchkeeper, who are advised to avoid using such additional devices through ship's own SMS but what about the ever increasing number of MFDs displaying enormous amounts of information.

Though many similarities exist between the road vehicle driver and the maritime watchkeeper, a major difference between the two is the reaction time available (Fan, 2020) to the latter being far more than that available to the former. Despite this, navigational accidents caused by lack of maintaining a proper lookout (MAIB, 2004; MCA, 2006) on ship's bridge are far too many to be ignored. Another difference is the non-standardisation of display requirements in the road vehicles in contrast to the displays in ship's bridge. The former does not seem to have much in the way of standards i.e. the road vehicle manufacturer can adapt whatever suits them best whereas the latter has to comply with the International Maritime Organization (IMO) standards, which are questionable as discussed in this report.

Many studies have been undertaken to understand the mental workload on road vehicle drivers (Fan, 2020, Yang et al., 2012, Boyle et al., 2008) but very little similar research is available in the maritime sector (Lim et al., 2018). ETDs have been used in several road vehicle safety studies to understand diver behaviour (Boyle et al., 2008, Rakauskas et al., 2008, Vetturi, et al., 2020, Le, et al., 2020). These studies were conducted to understand drivers' emotions and thus behaviour (Lafont et al., 2018),

there is very little research on this topic in the maritime domain, which makes the research presented in this thesis very unique.

Based on significant differences between the two i.e. the drivers and maritime watchkeepers, as discussed in the preceding paragraphs, a strategic decision during presentation of this research was made to exclude detailed analysis of the data that can compare road vehicle drivers with maritime watchkeeper. However, the following similarities with the current research presented in this thesis and the driver behaviour confirm the lack of research in the maritime domain:

- the distractions deteriorate driver's visual behaviour which can be monitored through their eye movement (Yang et al., 2012) – the use of ETDs in this study.
- the drivers must divide their attention between driving and operating in-vehicle devices (Reimer and Manbir, 2006) to make best use of both – establishment of DER for maritime watchkeeper through this research.

2.4 Information Displays on Ship's Bridges

The technology revolution has resulted in a complex interface of products, systems and workplaces, in particular those of multimodality interfaces such as aircraft cockpits and ship's bridges, to display a large amount and variety of information, which challenge users to recognise and interact with them. Although not necessary, the road vehicles also now have various displays showing a lot of information for the driver.

Advancements in technology have been reported through numerous studies across a variety of sectors, especially the rise in man-machine interactions to perform tasks to a higher quality with greater efficiency; new automation in most safety critical systems is increasing, rather than lowering, cognitive demands. This is no different in a maritime context. The IMO has adopted a vision to address human factors as a critical element for the improvement of maritime safety, explicitly focusing on the avoidance of human error (Gesa, 2015).

Not very long ago, the only instruments on a ship's bridge that required the OOW to frequently look at its screen was Radar and/or ARPA, in addition to less frequent observations of LORAN, Decca, Omega and more recently the Global Positioning

System (GPS). Controls and displays on the bridge were mostly analogue or mechanical, but this changed significantly in the recent past when LORAN, Decca and Omega have all been switched off, allowing the Global Navigation Satellite System (GNSS) now to feed positional information to almost all equipment used for navigating a ship. This modern equipment includes Electronic Chart Display Information System (ECDIS), Radar, ARPA, Automatic Identification System (AIS) and Global Maritime Distress and Safety System (GMDSS). The last includes multiple communication equipment such as Very High Frequency (VHF), Medium Frequency (MF), High Frequency (HF) radios, satellite phone and telex systems with multiple display screens. All these were added to the bridges to serve two purposes, one – to keep abreast of technological developments that assist the watchkeepers in performing their jobs with ease, and two, reduce the number of crew (Sonnenberg, 1988) onboard to control ship's operational costs.

Although these two objectives have apparently been achieved through the use of modern information technology (Jaeyong et al., 2016), there does not seem to be a formalised recognition for the impact of this new technology on watchkeeper's ability to continue to perform their primary function, i.e. lookout. The digitalisation of the controls and displays has led to replacement of analogue or mechanical controls on the bridge with digital screens, mostly MFDs, fitted with many audio/visual alarms in compliance with performance standards set by the International Maritime Organization (IMO).

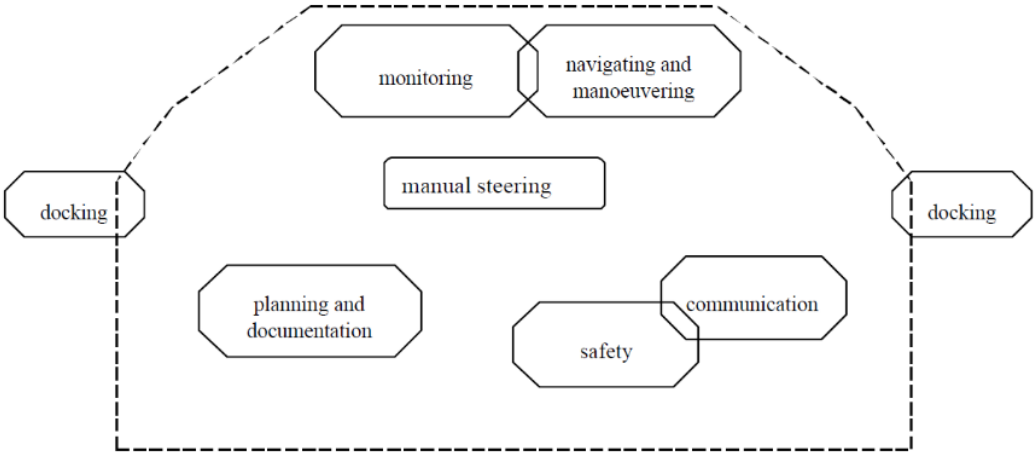

Figure 3 - Example of function areas – showing location of workstations on bridge

(Source: IMO, 2000)

The IMO (2015) supports these requirements through defining Human-Centred Design (HCD) as an approach to system design and development that aims to make interactive systems more usable by focussing on use of the system, applying human factors, ergonomics and usability knowledge and techniques. IMO also requires that "… systems are designed to suit the characteristics of intended users and the tasks they perform, rather than requiring users to adapt to a system".

The guiding principles for bridge design and layout of MFDs within the bridge are well defined by the IMO (2000) which also elaborates on how the workstations for navigating, manoeuvring, monitoring, docking etc. should be laid out on the bridge (see Figure 3). However, none of these guidelines or rules specify the exact location of the controls and/or displays, which therefore does not allow naval architects to design the layout in a specific way as in the aviation industry's T-arrangement. It is therefore only fair to say that, despite IMO (1996, 2004) guidelines, the current ship's bridge design lacks consideration of user experience in workplace/equipment design. Consistent user interface design across the numerous systems that OOWs interact with is rare, even on similar ships.

This is despite well-evidenced research into human-computer interaction that consistency is an essential characteristic to reduce human error and increase user efficiency in using any digital systems (Nordby et al., 2019). There is, therefore, a

clear need for developing new and consistent frameworks for designing modern ships' bridges and associated systems. Based on this fact, both current and future watchkeepers will benefit from optimum solutions for human, user-centred design incorporation into ship's bridge design to reduce the associated human error and improve safety at sea by creating a user-friendly and ergonomically pleasing workplace and systems for multivendor ships' bridges.

A comparison between IMO requirements for Navigation and Manoeuvring Workstations with the classification society rules reveals that many of the IMO requirements are expanded in classification rules (DNV, 2012). However, there does not seem to be much in terms of the 'exact' location of instrument panels, i.e. the MFDs, or where and how the 'vital' information must be displayed in the bridge or within the MFDs. Consequently, it is not possible to draw up a set of generic rules that will determine a detailed procedure for the OOW to adopt for maintaining a lookout until such time that the details of displayed information are precisely defined. It may, however, be the case that each ship's bridge layout has to be studied to establish a 'ship-specific' scanning technique suitable only for that layout.

Whilst the principles established in the aviation industry can be translated for application to the maritime industry, they cannot be directly applied due to significant differences between the layout of a ship's bridge and an aircraft's cockpit. This is despite the similarities between some bridges, where an OOW can be seated in a similar fashion to the pilot or co-pilot in the cockpit of a vessel. An example of such a significant difference is that the ship's bridge is quite large, where the OOW may not be in a seat at all, particularly in congested or high-traffic-density areas.

Currently, the dominant research within the maritime sector has tended to focus on mathematical modelling methods. This often results in applying mathematical concepts to quantify and represent an objective reality, creating a framework to suggest possible regulations or training recommendations to reduce human error. One criticism of this approach is that to implement the training requirements across each task and manage the workload is very time and labour-intensive across each equipment sector and manufacturer. Likewise, poor design in bridge systems has also resulted in the need for increased training and familiarisation, which comes at a cost and does not address the underlying issue (Lützhöft, 2016).

The HCD approach can provide a more intuitive solution that help in reducing training time, simplifies training, and further reduces the overall cost for industry by simplifying complex interfaces, making 'interaction' easier for the user. If the data is communicated in easier format, then it can be processed faster, giving watchkeepers more time and understanding of potential risks, resulting in decisions being made with more clarity, i.e., far better SA at times. Moreover, the HCD principles can be applied to the creation and improvement of virtual and physical interfaces, as well as to the design of effective social phenomena such as service design.

MFDs on a ship's bridge must be in indication of upgraded technology, functionality, and usability. In order to fully benefit from it, the following must be considered:

1. **Technology upgrade:** Incorporation of the latest technological advancements such as touchscreens, higher power computers with new/updated operating systems, and enhanced graphics to improve display quality and responsiveness.
2. **Technology integration:** MFDs require data from multiple sources (e.g. Radar, GPS, AIS, ECDIS etc.). This integration must be seamless (Costa et al., 2018) to avoid data loss, duplication, degradation, and cluttering to avoid causing distractions, enhanced SA and therefore decision making for the watchkeeper (Hareide and Ostnes, 2018). Advanced data fusion algorithms can be implemented to integrate and present information from multiple sources in a coherent and intuitive manner. This includes, for example, overlaying radar images on electronic charts, integrating AIS data with target tracking, and combining sensor inputs for enhanced navigation and collision avoidance.
3. **Customisable MFDs:** This is a new concept presented here for the MFDs display vital navigational information on ship's bridges. The watchkeepers must be allowed to customise each MFD based on their preferences and operational requirements (Jaeyong et al., 2016). They should be able to configure the display layout, select relevant data overlays, and prioritise information according to the current operational context.
4. **Enhanced user experience:** Any new design or change is less likely to be effective without user input (Costa et al., 2018) i.e. learning from experienced users. This approach should then be successful demonstrated by improved user experience manifested through intuitive interfaces, ergonomic design, and user-friendly controls.

5. **Compliance with regulations:** While being a challenge, these should be seen as an opportunity through a two-way dialogue with the professional and governmental bodies to support implementation of changes at par with technological advancements. It can be achieved through changing the current prescriptive IMO standards to 'goal-based standards (GBS) (IMO, 2019). This will help ensure that modernised MFDs comply with relevant maritime regulations and industry standards set by IMO and classification societies.

By addressing these aspects and considerations, the modernisation of MFDs can significantly enhance navigational safety, operational efficiency, and watchkeeper self-confidence (Costa et al., 2018). During navigation, an effective lookout is a basic safety need for the safety of ship from all stakeholders directly involved in this venture. As things currently stand, all MFDs on a ship's bridge are therefore collectively the culprits, drawing OOWs' attention away from traditional watchkeeping tasks, thus causing a diminished SA and a lack of success in reducing navigational accidents (Jaeyong et al., 2016). On this basis, the new issues introduced due to using increased number of MFDs on modern ship's bridges build the foundation for discussions, data collection, literature review and presentation of a solution in this thesis in the form of CCD concept discussed in Chapter 5: Implementing CCD Concept.

2.5 Human and Organisational Errors

Almost every maritime accident report indicates human factor (Costa et al., 2018) as a contributory cause to the accident. This, after having received due recognition by IMO in their revisions of the STCW Code and Convention, has led to inclusion of the non-technical training aspects such as the leadership and management skills in the form of bridge and engine room resource management skills as well as the application of leadership and team working skills (Cordon et al., 2017).

As stated by Ren, et al., (2008), human errors include unacceptable or undesirable performance from an individual but if that individuals' error is not 'trapped' through a system set by the organisation, e.g. the Safety Management System (SMS), then this becomes an organisational error. Both, human and organisational error, from a watchkeeper perspective is simply not maintaining a proper lookout to avoid situation(s) in which the ship is exposed to a risk of collision. From this study's

perspective, the terms 'human factor', 'human error' and 'human and organizational factors' are interchangeable but all of them point to the one same base term i.e. human factor.

The 'Human factor' is a broad term within which several other aspects require focus. In order to limit the breadth of research presented here, it has been focused primarily on the watchkeeper's ability to maintain a proper lookout. Anything that causes the watchkeeper to divert their attention from this primary task is considered a distraction. Distractions, from a watchkeeping perspective, can therefore be events or stimuli that will divert attention, or the intensity of attention, from the primary task (Hamlin, 1896).

In author's view, the distractions can be of two types:

(a) **Voluntary distractions**: These are distractions caused by various tasks undertaken by the watchkeepers. This type of distractions to the watchkeepers include:

- Admin work I – paper-based record keeping or form-filling e.g. completing checklists, logbooks, preparing documentation related to vessel arrival/departure, cargo operations.
- Admin work II – Computer based such as vessel related routine, urgency and distress communications as well as personnel communications (emails or phone calls).
- Mobile phone use (MCA, 2005), particularly during coastal passages.
- Bridge Equipment Alarms – both mandatory, non-mandatory some of which can be irrelevant to the task at hand and therefore may divert watchkeeper's attention. For example, a distress alert received on MF/HF Digital Selective Calling (DSC) received from several hundred miles will require the watchkeeper to investigate and log this call even though no further action will be required.
- Phone Calls I – Internal (From within the ship) such as those from engine room, galley or other crew members.
- Phone Calls II – External (from outside of the ship e.g. shore-based management, charterers, agents etc.)

- Use of computers – personal and shipboard computers are now very common where OOWs indulge them in either ship related work, but more distracting is their use for playing games or private communications.
- Use of personal music devices (e.g. iPods, MP3 players) and even listening to public radios.
- Fatigue is also a known distractor (AMSA, 2020) which can be eliminated through strict compliance with the recommended rest hours.
- Boredom, illness, anxiety or preoccupation are other factors documented by Federal Aviation Authority (FAA, 2012) which can distract the watchkeeper from their primary task.

Ship's Safety Management System (SMS) should incorporate procedures for development and compliance with standing orders that encompass prohibiting the use of distractions caused by all items mentioned in the above list but it is impossible to write a set of procedures that covers every potential scenario. The following general principles should therefore be adhered to at all times.

(i) Clear guidelines from the Master through standing orders against the use of phones (both mobile and ship-based satellite phones), computers (personnel or ship computers for communication or other administrative work). These guidelines should specify that such use be completely and unconditionally prohibited in hours of darkness/restricted visibility, when the vessel is operating in high traffic density areas, traffic separation schemes and during coastal passages.

(ii) All audiovisual alarms on the bridge equipment must be set by the watchkeeper in a way where they know that they must attend the alarm, failing which something will go wrong. However, this is not currently permitted in the equipment design where the alarms continue to sound/show despite the watchkeeper having no need for them. This invariably leads to alarm de-sensitivity or alarm decay where the watchkeepers stop paying attention to the alarms but they can trigger a distraction from the stimulus that will potentially lead to a close quarter situation. The ship's ECDIS is notorious for numerous alarms (Vu et al., 2019), which most of the watchkeepers just choose to ignore because they did not provide them with any new information or accept them without investigation.

(iii) The shore-based personnel who may need to contact ships such as marine and technical superintendents, vessel's voyage managers and others must be clear on the times when the ship is arriving/departing ports, in restricted waters or other situations. Perhaps, the Masters', through updating SMS, can devise a system where a message highlighting the vessel's navigational assiduously heavy workload is sent to all stakeholders such as the one elaborated below.

(iv) The ships may choose to use a traffic signal approach. For example:

- When the navigation operational conditions allow, a green light analogy could be used to allow all communications with the bridge of ship.
- When a vessel is operating in restricted waters or comparatively high traffic density areas, the amber light approach can be applied where only emergency/urgent communications can take place.
- During arrival/departure from ports and harbours, the red traffic light analogy can be used to completely forbid all communications so that the watchkeepers (and the Master) can provide the required focus on safety of navigation.

(b) **Involuntary distractions:** Even though the foregoing recommendations for voluntary distractions will work to some extent but consideration also needs to be given to the factors that are beyond watchkeepers' abilities. It is because the appearance of any new stimulus makes the watchkeeper more susceptible to distraction (Burack, et al., 2012). This stimulus could be a flashing light or sound from an alarm or even watchkeepers' own mind wandering leading to empty-field myopia (FAA, 2012) discussed later in this chapter. In some cases, the equipment such as ARPA or ECDIS may present a hazardous distraction (MAIB, 2021) by adding to the mental workload. This is where the topic of the study in thesis comes in i.e. the technique(s) or methodologies that the watchkeeper must adopt or the modifications that must be made to the MFDs to overcome these involuntary distractions caused by MFDs on the bridge and thus eliminate human factor led accident causation, thus provide effective decision making in accident prevention (Fan, 2020). Distractions can be highly disruptive (Forster, 2013) and therefore must be overcome by the watchkeeper to maintain focus on their primary task.

2.5.1 Situational Awareness

Through an efficient visual search, the watchkeepers' eyes feed information to the brain to become aware of objects in the ship's surroundings. This is referred to as Situational Awareness (SA), which is the cognitive process of knowing activities and situations around a ship (Endsley, 2009) to effectively and comprehensively understand a danger (Abell, 1933; Crittenden, 1999; Fan et al., 2023) so that measures can be taken to avoid it.

Multitasking is intrinsic to navigational watchkeeping, where maintaining an efficient lookout is a subtask, but nonetheless instrumental to developing a fully informed SA. It must, therefore, encompass perception, comprehension and projection of threat's location and movement in relation to the watchkeeper's ship (Endsley, 1995b; Van de Merwe, 2012; Endsley, 2015).

The OOWs' needs can be constructed with Endsley's (1995a) three level SA model shown in Figure 4, i.e.:

- Level 1 SA where the OOW collects the location, heading, and speed information of their own ship with respect to other vessels or objects.
- Level 2 SA where the OOW evaluates the information collected in level 1 SA.
- Level 3 SA where the OOW formulates a solution by applying IRPCS to maintain safety of navigation.

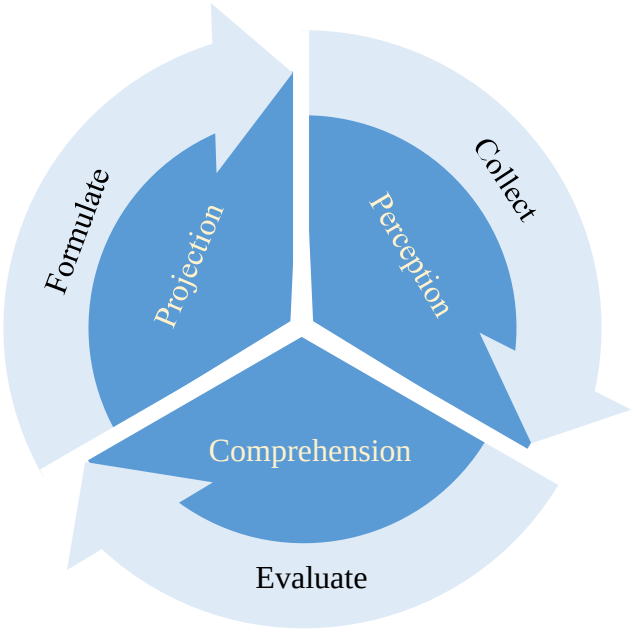

Figure 4: Three-Level SA Model

In essence, when maintaining a bridge watch, the OOW perceives and comprehends the current situation, and runs mental predictive models about the likely outcomes (Hrvoje et al., 2021) with respect to collision avoidance. Any shortfalls in perception or comprehension can easily lead to a lack of or inappropriateness of SA (Chauvin et al., 2013), which is a more serious issue than errors of judgement for poor decisions leading to accidents. Inefficient lookout is directly proportional to lack of attention and vice versa. For example, the aviation industry's 'See-and-Avoid' rule (Hareide and Ostnes, 2017b; FAA, 2019; ECFR, 2021) requires that '… regardless of whether an operation is conducted under VFR or IFR, vigilance shall be maintained so as to see-and-avoid other aircraft'. This rule is supplemented by an enormous amount of research-evidenced techniques for achieving its objectives. Even then, 94% of mid-air collisions between 1991-2000 were attributed to an inadequate compliance with see-and-avoid rules (Morris, 2005). Even in the aviation industry, lack of implementation of the recommended steps is to blame for adverse consequences (Hobbs, 1991). This could be linked to distractions on the bridge or long periods of inactivity (Taylor, 1991) due to lack of traffic around the ship: these are not considered in Endsley's (1995, 2015) three SA levels; i.e., these SA levels come into play only when the OOW

has comprehended the situation and projected the threat. There is, therefore, a need to consider SA's impact on the watchkeeper's decision-making process (Towns, 2007; Hrvoje, 2021). As explained by Williams (2020), "in the context of information processing, the moment when we decide to do something is driven by selecting a particular action that best aligns with the task that must be performed". The author goes further and states, "these actions can be either skill-based, rule-based, or knowledge-based". Whilst OOWs' skills are not questionable, their ability to make decisions based on their SA remains in question, as evidenced by accident reports. Improvement of OOWs' SA measurement is thus included in the scope of this research and discussed in this report.

Surprisingly, the UK's MCA (2006) recognises GMDSS equipment, completion of administrative tasks on the bridge (Moreton, 2000) and routine testing of bridge equipment as 'distractions' to the watchkeeping officers' primary duty of keeping a proper lookout. However, no one appears to propose a solution to overcome them, albeit recognising that these distractions potentially lead to low levels of SA (Maglic et al., 2020). This research looks into this very matter and proposes the CCD concept, i.e., 'bridge of the future', incorporating the 'maritime six pack' in response to the issues discussed here.

2.5.2 Visual Searching

In essence, maintaining a lookout is a 'visual search' exercise. To ensure that their attention is suitably focused to identify any potential hazards, watchkeepers need to establish their own visual search techniques. These should be basic procedures allowing them to maintain an effective lookout across the necessary area, whilst overcoming any potential distractors.

A questionnaire-based survey was conducted as part of this research. A total of 67 responses were received from experienced seafarers, including OOWs, Masters and pilots. The survey participants consisted of 58% masters, 12% chief officers and 30% junior officers (Figure 18), as discussed in Section 5.2. According to Oraith et al. (2021), such a number of participants is acceptable if the data collected are gathered from experienced specialists. This study revealed that only 10.4% of these watchkeepers visually checked the vessel's surroundings to verify other vessels'

location, with only 4.5% indicating that they would verify atmospheric visibility when taking over the watch. These statistics provide evidence that modern watchkeepers do not understand the significance of lookout by sight. They not only need to understand it but must also appreciate the significance of central vision versus peripheral vision fields of the human eye, as elaborated later in this report.

The eye can only fully focus and recognise an object when the object viewed is in its central vision. Objects detected within the eye's field of central vision result in clear, sharply focused messages being sent to the brain. The central vision extends from right in front of the eyes to approximately 2.5° either side. This 5° monocular field of view for each eye provides a total binocular field of view of 10° when both eyes are taken into account. In comparison, peripheral vision extends to approximately 100°-110° on either side of the eye, which is considered extremely useful in identifying objects that may pose a collision threat. When a watchkeeper's gaze switches from one block i.e. Field of View (FOV) area to the other to refocus eyes, peripheral vision helps in detecting objects in relative motion to their own ship. Objects that appear to have no relative motion are unlikely to pose any threat; therefore, even if they are not detected through peripheral vision, they will be picked up when the eyes gain focus in any given block.

In contrast, any visual information that is processed through peripheral vision will be less detailed. Because the eyes can only fully focus on this narrow viewing area, effective scanning is best accomplished with a series of short, regularly spaced eye movements that bring successive sections of the area to be scanned into the central visual field. This is discussed further in Chapter 4: Visual Search Patterns.

2.5.3 Visual Search and Distractions

The watchkeeper's primary task is to perform visual search in addition to maintaining auditory attention to any sounds that may need their response. In addition, they also need to look at the equipment to monitor various elements for safe navigation. Regardless of where the watchkeeper needs to look, the visual search requires the watchkeeper to recognise a particular object amongst other visible objects or features (Treisman and Gelade, 1980). This recognition requires focused attention entwined with, inter alia, SA, attention-related errors and other factors that contribute to the safety of navigation.

Visual search is a natural process one goes through in daily life, in which we actively scan the environment to locate a particular object, also referred to as a visual stimulus, among irrelevant features, referred to by some researchers as 'distractors' (Burack et al., 2012). For example, the search for a desired product on the shelf in a supermarket qualifies as a visual search, where all undesired products are the distractors. The visual search for the desired product is controlled by directing the focus of attention while scanning the products, ignoring undesired products. This is the very principle that watchkeepers need to apply to their visual search when maintaining a lookout, as well as other watchkeeping tasks on the bridge of a ship.

Saccade is a French word that translates as 'a fast jerk' (Bahil, 1980). *Saccades* in the context of this report and the associated research are the repetitive movements of eyes at any given time, which direct the eye's high-acuity fovea to focus on any given location for detailed inspection. Displays larger than the eyes' functional FOV require saccadic eye movements to locate a target or stimulus. The time spent on detecting a target in a larger FOV (Findlay, 2009) is proportional to the number of eye saccades during the search. Thus, the eye motion takes a series of movements through a cycle of seeing 'nothing' to seeing 'something', with the latter culminating in fixations, where the saccades 'pause' to hold fovea in one place, i.e., to focus on a small area to detect a target. If a target is detected, the search is successful; i.e., this detailed inspection reveals a confirmed target or stimulus.

The human active vision system is designed to control the durations of both fixations and saccades. For example, the fixation duration increases when reading difficult words, trying to distinguish between similar targets and particularly when interrupted by distractors of any sort. Here, peripheral vision plays a significant role in detecting targets, particularly those in motion outside of the foveal region of the eye (Li, 2014), keeping in mind that objects that are not in relative motion with respect to one's own ship can be considered as 'no threat' but those with apparent relative motion are a potential threat. Peripheral vision is considered most useful in spotting these potential threats (US DoT, 2016). It therefore facilitates watchkeepers' use of cue acquisition and cue interpretation (Endsley, 1995a), i.e., information collection, evaluation and solution formulation, leading directly to building up their SA. Somewhere between cue acquisition and cue interpretation, the watchkeepers' eyes will shift focus to the threat in question to continue to monitor it so that SA can be fully updated. If,

however, this process was interrupted by a distractor, SA may remain incomplete. It can thus be said that peripheral vision gives the watchkeeper an initial impression before they focus in on an object to confirm its presence.

The eyes are considered a gateway to the brain (Stangor and Walinga, 2014; FAA, 2019) and act as the prime source for updating OOW's SA. However, the background scatter of lights in coastal areas, partitions in the bridge windows, clouds in the sky, all act together in most cases to camouflage a watchkeeper's view. Further, the human eye naturally tends to focus somewhere, even when there is nothing to focus on, such as a featureless sky – a perceptual process known as 'selective attention' (Stangor and Walinga, 2014), i.e., the ability to focus on certain sensory inputs while tuning out others. If no stimuli challenge the vision to attract focus, the eyes naturally revert to a relaxed intermediate focal distance (3 to 10m) (FAA, 2012), a phenomenon known as empty-field myopia.

This highlights two important factors that impact upon the ability to maintain SA as needed for Level 2 of Endsley's (1995b) SA model: (1) the watchkeeper is looking without seeing anything (TCAD, 1998); (2) watchkeepers can miss something important, despite looking outside the window, because they selectively attend to only one aspect of the scene visible to the eye (Simons and Chabris, 1999).

This limitation comes into effect when the watchkeeper is actually looking outside the window, but how about when they are not? Further, there is a tendency for attention to drift to internal thoughts (mind wandering), which can also distract from the primary task. Under non-demanding conditions, the issue of attentional control also creeps in (Rosenbaum, 2010). This could be significant when there is not much traffic around the ship, causing the watchkeepers to be bored. They may turn their attention to MFDs simply as a means to escape boredom; when people are bored, they actively seek sources of distraction as a deliberate strategy. There remains, therefore, a need to evaluate the distractions caused by MFDs on the bridge.

Reaction time (RT) to an auditory or visual stimulus (Salthouse, 2007; Vishteh et al., 2019) is the interval between the presentation of a stimulus, and a voluntary response such as the press of a response key. When our nervous system, i.e., the eyes in the case of a watchkeeper, recognise the stimulus, the information is relayed to the brain (Jain et al.,, 2015), which releases instructions via the spinal cord for hands, fingers or other

body parts to react. Our 'sensory memory' holds the information captured via eyes for 1 to 4 seconds, from where it is transferred into Short Term Memory (STM) (Williams, 2020; Lavie, 2010). The STM can hold this information for 6-12 seconds: it is this duration which defines whether the OOW will deal with the information received, manipulate it mentally and take the required action, i.e., Endsley's (1995a) three levels of SA are fully followed. If, however, a distraction triggers another event, then this information may be lost, leading to inaction by the watchkeeper.

Each navigational task on the bridge of a ship performed by a watchkeeper requires substantial multiple sources of information to be processed (Maglic et al., 2020). When fully focused on the task, depending on an individual's cognitive ability, they can probably identify the source of this information but if overwhelmed by the amount of information presented visually or audibly, their decision-making is almost always likely to be affected (Crowch, 2013), leading to possible human error.

Human error is deemed to be the result of an incorrect decision, improperly performed action, or a lack of action (Rothblum, 2000). If this human error can be trapped, the probability of it leading to accidents can be reduced. Bridge MFDs, however, do not seem to permit this at present. Distractions, from a watchkeeping perspective, can be events or stimuli that will divert attention, or the intensity of attention, from the primary task (Hamlin, 1896). Hofheimer (2020) refers to it as 'fleeting attention span' and explains it as '*lapses in the ability to concentrate on a stimulus or task and sustain the requisite degree of focused attention to persevere with information processing or task attainment'*. Regardless of what nomenclature is used for distractions that shift watchkeepers' attention away from their primary task, the fact that MFDs can cause distractions for the watchkeeper remains true, requiring the fundamental issues to be resolved; hence, it remains a primary focus of this research.

2.6 Attention Span

The basic rules for the safety of navigation remain the same (Hareide and Ostnes, 2017b), despite the introduction of significant automation on ship's bridge. The well-known four stages of passage plan, i.e., appraisal, planning, execution, and monitoring, are still utilised by the modern navigator. The first stage feeds into the second and the second into the third stage, and so on. The task-demand from the OOW increases in

high traffic density or during coastal navigation when monitoring the progress of a vessel that is following a well appraised, planned and executed passage plan. This stage therefore requires increased focus and attention, as a 'slight' loss of attention may lead to a loss of SA.

The human brain's STM is a 'limited capacity system' where two operations requiring it will interfere with each other e.g., a distraction caused by an alarm (MAIB, 2021) when the watchkeeper is trying to focus on the lookout function (Miller, 1956; Grossberg, 1987; Doane and Sohn, 2000; Stangor and Walinga, 2014). Therefore, the OOW is almost always faced with a daunting task of having to focus on one task while deliberately and actively inhibiting or ignoring other tasks which can literally be considered distractions in this context (Lützhöft, 2004). They consequently require a continuous mental effort (Williams, 2020) to shift focus to avoid exceeding their mental capacity to retain and recognise hazards in the STM, process them and take appropriate actions as defined by Endley's (1995a) three levels of SA. Other factors that affect human information processing capability, such as age, health, workplace, experience, stress, and fatigue (FAA, 2019; Williams, 2020) are not factored into this research and hence not discussed, but they do have an impact on SA for the watchkeeper.

The task of maintaining a lookout is an intermittent process (Taylor, 1991), due to external distractions causing lapses of attention, but also from internal stimuli associated with mind-wandering (Reason, 1984; Unsworth et al., 2012; Froster, 2013) possibly associated with fatigue. To err is human: some of it comes as a result of lapses of attention (Unsworth et al., 2012). Significant research has been carried out on what constitutes attention. Posner and Boies (1971) present their first component of attention as the notion of alertness to perform long, boring tasks. The second component is 'selectivity', referred to by Knudsen (2007) as competitive selection through a process he refers as the Bottom-Up Salience Filters. These filters distinguish important stimuli to enhance responses; thus the attention. Here, the nervous system compares information from internal and external stimuli to eliminate distractions and select the most salient stimulus, which is then passed down into the STM. Posner and Boies (1971) refer to this as 'selective attention', i.e., the ability to select information to be processed.

The degree to which one type of information gains full control of STM reflects the relative strengths of the competing representations. Knudsen (2007) takes it further by alluding to Top-Down bias signals, where the significant stimuli reaching the STM cause it to generate signals to improve the quality of processed information. For example, it directs eye movement towards the object from which a stimulus has reached the STM, thus drawing focus towards that object, i.e., directing attention to interrogate and therefore seek further details about that stimulus. This process is referred to as Top-Down sensitivity control.

An OOW's level of vigilance may be referred to as 'human attention span', i.e., the time a person can 'focus' on a particular task prior to being distracted by another sense. Posner and Boies (1971) address this as the third component of attention, referring to it as 'processing capacity'. Singh (2017) further underlines two components of attention:

i. Transient attention, where a watchkeeper responds to stimuli attracting or distracting their attention. This could be events (Taylor, 1991) such as an equipment or machinery alarm, a phone call or a VHF voice communication on the bridge. Here, conscious control of mental events may or may not be separated from automatic activation of the same mental response labelled by Posner and Boies (1971) as supervisory or executive attention. Researchers agree (Singh, 2017) on science's inability to place an exact amount of time on transient attention span.
ii. Selective sustained (or focused) attention, where watchkeepers consciously focus their attention on a given task while ignoring distractions. This cognitive ability can be enhanced through training and practice (Colvin et al., 2005).

The discussion above indicates that the OOW's job is relatively easy, since they are not required to continuously look out for objects. At the same time, this very reason tends to introduce 'intermittence' in the task, forcing their attention away from the primary objective. In other words, they fail to prioritise attention towards maintaining a proper lookout or apply a poor technique (Ren et al., 2008) in undertaking this task. Here, the link needs to be appreciated between looking outside the bridge window and the certain/specific amount of attention required to recognise objects that need processing for further action.

Significant research has been carried out on 'human factors' affecting the watchkeepers on ships, but these studies lack sufficient detail that can lead to specific solutions for overcoming the underlying issues. An example of a suggestion made by many researchers is that the watchkeeper's inattention may be alleviated by increased vigilance, but none of the studies provide detailed guidance on how this can be achieved. In particular, they lack guidance as to how specific information or training can be provided to watchkeepers to (1) raise their awareness, and (2) change their behaviour towards maintaining an efficient lookout, thus improving SA, and reducing accidents. This thesis addresses this very weakness and recommends solutions to mitigate it.

2.7 Visual Scan Patterns

It was established by Smith and Lucacini (1969) that humans are generally weak at maintaining attention in monitoring rarely occurring events or searching for objects in empty space. For OOW, maintaining a proper lookout remains the most important activity, but it is consistently interrupted due to inactivity, other tasks or distractions, as discussed in the previous section. An effective lookout can only be maintained through visual scanning of the ship's surroundings. The OOW needs to apply this skill to systematically use their vision to search in the vessel's surroundings. According to Colvin et al. (2005), this is a human cognitive skill that can improve through training.

In order to improve lookout efficiency, and therefore SA, Taylor (1991) identified some facts that form the basis of an OOW's visual scanning:

1. Ships are large slow-moving masses; therefore, they provide an opportunity to predict their slow movement, as well as significant time to assess the situation and take action to avoid a collision.
2. Once identified, targets do not tend to appear and disappear rapidly, except for indistinct or weaker objects detected by radar alone.
3. If indistinct objects are missed by a lookout, they may not cause a serious problem until they become distinct, provided a proper lookout continues to be maintained.

The time spent on visual scanning varies depending upon whether any object is sighted, not sighted or if the scanning is interrupted due to distractions. Studies carried

out by Taylor (1991) indicated that watchkeepers did not look out of the bridge window for 0.6 to 7 percent of the time, with the lapse durations averaging from 5.4 to 6.3 minutes. These variations assumed the interruptions to be random due to the physical difference in the bridge layouts and the difference in manning levels, etc. The study concluded that approximately 0.28 of each minute (16.8 seconds) was spent on not maintaining the primary task of keeping a lookout. Further, it was established that about 0.5 percent of lapses were likely to last at least 15 minutes, 2.5 percent would last 12.5 minutes or more, etc.

Recognising the lapses in maintaining a lookout, the IMO (2002) introduced Bridge Navigational Watch Alarm System (BNWAS) between 2011 and 2014 on all cargo ships of 150 gt and above, and all passenger ships (IMO, 2002). This equipment detects watchkeeper inactivity; i.e., if the watchkeeper does not press a timer reset button or operate any navigation equipment at pre-set intervals (between 3 – 12 minutes), an alarm will go off to alert the OOW. Repeated failure to activate the reset or use the navigational equipment will alert the other nominated officers or the Master.

Amazingly, accidents have happened where the watchkeepers ignored BNWAS, not turned it on or turned it off completely (MAIB, 2012). While BNWAS has its place on the bridge, i.e., it provides a check if the watchkeeper(s) is awake and, if not, does something about it, the concern here is how to make an 'awake' watchkeeper fully functional with respect to maintaining a proper lookout and therefore SA.

The aviation industry's VFR for 'clear' visibility conditions and Instrument Flight Rules (IFR) for restricted visibility, together with the see-and-avoid rule, are supported by significant research-based evidence (Hareide and Ostnes, 2017b). For example, when operating in VFR mode, pilots are known to spend various amounts of time in actually looking outside of the cockpit (EASA, 2021). This time varies for American pilots from about 20% - 25.3% (Rich et al., 1972) in a simulated environment to 50% according to another study. No such data is available for the maritime industry. This is where the research being undertaken as part of this study is the first of its kind.

2.8 Concluding Remarks

This chapter looked at the common issues and solutions related to maintaining a visual lookout in the maritime, aviation and road transport industries given in literature. It evaluates, various aspects of maintaining a lookout, and current research related to the use of MFDs on ships' bridges. This evaluation includes considering human and organisational factors affecting SA, its application to bridge watchkeeping, cross referencing the techniques used in the aviation industry and principles applied in the road transport safety. It then explains the significance of visual searching in the context of maintaining a lookout on a ship's bridge, focusing on the impact of distractions caused by MFDs. The human attention span is also discussed in the same context, and in relation to the positive impact of the use of visual scan patterns used in the aviation industry.

Chapter 3: Research Methodology

3.1 Introductory Remarks

MFDs, particularly in Integrated Bridge Systems (IBS), facilitate collection and distribution of data displayed on the ship's bridge, allowing watchkeepers to manipulate and control systems from locations away from the actual equipment. Existing research indicates that MFDs need to be compatible with the watchkeeper's needs (Murphy and Mitchell, 1986) but anecdotal evidence suggests that current designs are otherwise, because they do not appear to provide real-time data that falls in line with their mental model to enhance their SA. The eye movement recorded with ETDs can provide a window into the process of the SA mechanism, thus reflecting the user's mental state (Li et al., 2014). At the same time, ETDs can also be used to evaluate MFD locations, layout together with the overall bridge design in addition to monitoring trainees during simulator based watchkeeping training (Hebbar et al., 2022).

ETDs have been used in the aviation industry, road transport, market and medical research (Skvarekova and Skultety, 2019) to study visual scanning behaviour and attention allocation (Lavine et al., 2002; Tomizawa et al., 2012). The ETD data can not only be used to improve a system's usability by identifying likely distractions caused by MFDs but can also assist with a watchkeeper's attention allocation, so the monitoring and search strategy can be adapted for maintaining an efficient lookout. (Poole and Ball, 2005). Based on their research on eye fixations in relation to cognitive tasks, Just and Carpenter (1976) established that the cognitive processing thoughts are at the forefront of the eye's focus. ETDs can provide a valuable insight into a watchkeeper's cognitive processing which cannot otherwise be assessed through simple observation or think aloud practices (Cooke, 2005). Poole and Ball (2005) confirm that ETDs can be used to track a user's attention without interrupting user activity (Li et al., 2014) as is evidenced by their use in aviation, healthcare and marketing.

Although ETDs are now widely used for research relevant to cognitive processing of visual information but there seems to be no research that uses ETDs to evaluate

cognitive processing of information displayed via MFDs on the navigation bridges of ships. This research therefore appears to be the first of its kind that has used ETDs to investigate the impact of MFDs on watchkeeper behaviour while performing bridge watches. This will enable strategies to be formulated to address issues related to the display of information, as well as to provide a mechanism to train watchkeepers on best practices to maintain a visual lookout at all times.

An overview of the proposed research methodology is given in Figure 5 below. It is worth noting that some of the methods given in this methodology are not explained explicitly in this chapter due to their independent nature. Refer to Figure 1 for details of sections to located relevant discussion in this report.

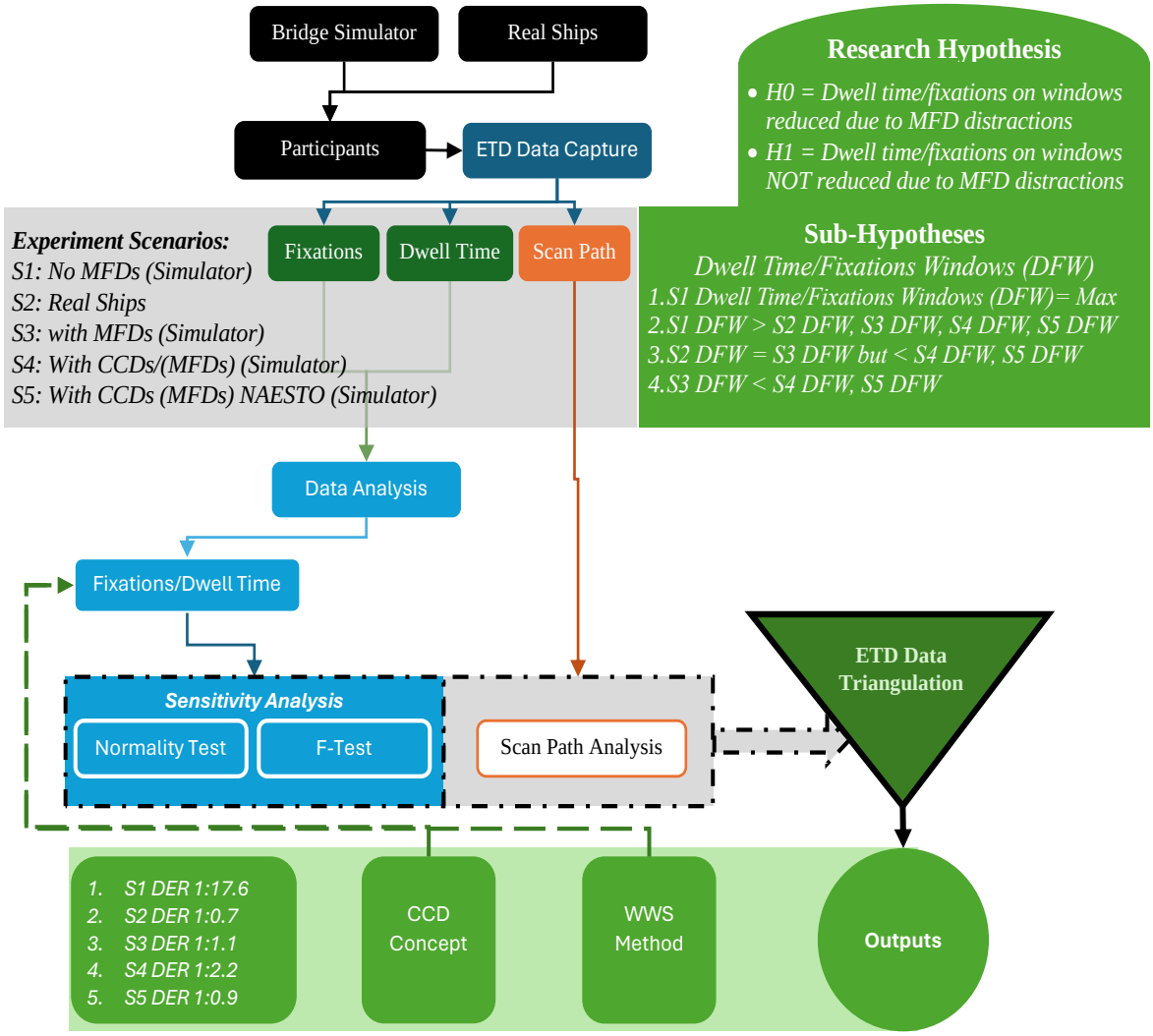

Figure 5 - Research Methodology Overview

3.2 Eye Tracking Device (ETD) Overview

The Senso Motric Instruments (SMI) ETD shown in Figure 6 was used to capture participants' eye movement data during this research. This ETD consists of two parts:

a. Glasses fitted with a high-definition scene camera that records the participant's gaze behaviour in real time, together with a microphone to record audio.
b. Portable recording device connected to the glasses via a cable. This device records audio and video together with eye motion data. The total memory size of this device is limited due to its use of a memory card; hence, all data must be transferred to another data storage location to avoid being overwritten.

The details of ETD and associated software used in this research are given in Appendix 2: Eye Tracking Device (ETD) Specifications.

Figure 6 - Eye Tracking Device (ETD)

Eye movement has been studied (Hyrskykari, 2006) for decades but its use and application in the maritime industry, like all other technologies, is rare. ETDs have now become commonly available to study interaction with a computer screens, particularly to measure human behaviour in relation particularly to maintaining SA. Whilst this study made exclusive use of ETDs, their use in the maritime industry, particularly to study watchkeeper behaviour on real ships is extremely complicated due to the need to standardise its application and seek global regulation, acceptance

and agreements. For this study, one modern ETD supplied by SMI (Imotions, 2022) were used.

The SMI ETDs make use of two cameras and two voice input sensors built in a wearable spectacles frame to record the location of eye focus as well as any sounds during the data capture. The sound recording for this study was not required; hence, no use was made of this functionality. The eye location information was used to measure:

- ✓ The amount of time spent on each Area of Interest (AOI).
- ✓ The time spent between movement of eye between one AOI to another.
- ✓ The path taken by motion of eye from one AOI to another.

The capture of watchkeeper's eye motion data during watchkeeping will provide an insight into mapping their visual attention (Hareide and Ostnes, 2018) on maintaining physical lookout in comparison with the effect of MFDs. An analysis of this data will lead to suggestions for improvement of the MFD design in addition to providing guidance on how to overcome the underlying issues related to 'the inability to maintain proper lookout' highlighted through multiple accident reports. As discussed in Section 2.5.2, visual search is dependent upon the sequence of eye movements confirming that the use of ETD for understanding the watchkeepers' weaknesses in maintaining a proper lookout.

Generally, when environment around own ship is visual scanned, a knowledge of the eyes' fixations and saccades provides a valuable insight into watchkeepers' SA. It is however important to note here that the ETD technology is continuously being developed alongside the software (BeGaze) that is used to analyse the ETD data (Sanfilippo, 2017). Another factor to bear in mind whilst using ETDs and as experienced during this study is the difference in ETD use in simulators in contrast to their use on real ships. The former is a controlled environment where standard scenarios can be repeated within the same environmental parameters (visibility, traffic and sea conditions etc.) whereas on real ships, no two situations can be exactly the same. This is evidenced in data collection S2 on real ships which therefore proves the need to gather more data on real ships prior to confirming the results (Lappi, 2015).

Another factor to consider when using ETDs is their accuracy to gauge reliance on the data quality. Most of the ETDs available in the market, including the SMI ETDs use

in this study required to be calibrated. The ETD manufacturer, SMI allows calibration to be carried out once which can be retained by the device/computer used for data capture for the same experiment. However, to avoid any unknown calibration errors (Miguel et al., 2015) that may creep into data captured, this option was not used by calibrating ETD prior to each data capture exercise.

This study measured only the dwell times and fixations, the accuracy of ETDs given in Appendix 2: Eye Tracking Device (ETD) Specifications, was not a real issue as the AOIs were considerably large with no requirement to make precise measurements for the changes in pupil size etc. Had this been a study for, for example, the exact location of the gaze on an ECDIS or an ARPA MFD, it will be paramount to factor the ETD's point of gaze accuracy (Miguel et al., 2015; BeGaze, 2017; MacInnes, 2018) As a consequence, the impact of environmental factors on the precision and accuracy of ETD performance were not factored in this study.

3.3 Basic Eye-Tracking Measurements

The following basic measurements were used to record eye movements in this research:

1. **Area of Interest (AOI)** – an area of watchkeeper's view defined by the researcher within which measurements can be made.
2. **Dwell Time** – combination of fixations and saccades within an AOI.
3. **Gaze Point** – shows what the eyes are looking at, measured at a sampling rate of 60Hz, i.e., 60 individual gaze points per second. Closely located gaze points indicate a fixation, i.e., the observer looks within a specific area.
4. **Fixation** – time when eyes stop scanning, i.e., hold the vision in one place to obtain information about the area being looked at to process the image. Fixations therefore have spatial (x, y) location and start and end timestamps.
5. **Saccade** – eye movement between fixations from one AOI to another. Rapid eye movement during saccades means poor image quality on the retina.
6. **Scan path** – the path followed by a combination of fixations and saccades, i.e., saccade-fixation-saccade pattern (Poole and Ball, 2005; Gu et al., 2016).
7. **Dwell or Gaze Percentage per AOI –** the proportion of time the eyes dwell on a specific AOI.

8. **Heat Map –** this is the graphical representation of fixations on AOIs resulting from the participant's eye movement. In BeGaze, the Heat map shows fixation hits related to the colour scale between blue (less hits) and red (most hits), with a 3-colour coding selected. The generated heat map is an absolute gaze duration map showing the accumulated time participants spent looking at different areas of the stimulus (BeGaze, 2017; Hareide and Ostnes, 2018) with the diameter of each circle representing the duration of the fixation in each AOI.
9. **Gaze Plot** – shows the location, order, and time spent looking at selected locations on the stimulus and is used to assess the participant's gaze/scan pattern.
10. **Scan Path Strings** – each AOI in BeGaze is represented as a letter-number combination for its location in the given row and column. The columns are labelled A, B, C, etc., from left to right and rows are numbered 1, 2, 3, etc., from top to bottom. For example, a scan path string shown by F5-C5-C4 represents fixations in AOIs F5, C5 and C4 respectively. If any consecutive fixations are duplicated e.g., A1-**F4-F4**- C5-C6 then these can be compressed by removing the duplicate strings to see the scan path and convert it into A1-F4-C5-C6: these are known as 'compressed scan path strings'. Full details of this process are given in Appendix 3: Scan Path Data.

3.4 Research Hypothesis

The research findings in this report focus on three distinct factors:

1. Human Centred Design (HCD) can provide an intuitive solution to reducing training time and therefore the associated costs to the industry. As introduced in Chapter 1: Introduction, a lack of human-centred design and consequential issues associated with the MFDs appear to cause the watchkeeper to be a weak link between presenting and using this information (Lützhöft and Grech, 2016), an issue that needs to be addressed.
2. Turning a complex interface into a simple and easier to interact interface can be easily achieved if it takes into consideration the HCD requirements (Costa et al., 2018). In line with discussion in the literature review and as highlighted by

Rasmussen (1999) and Nordby et al. (2018), system users cannot be treated as add-ons but must be seen as an integral part of its functional design to decrease human error. This is exactly in line with the research presented in this thesis where user input is captured through questionnaire (discussion in Section 5.2) to develop the human centred CCD prototype, thus ensuring human inclusivity i.e. the watchkeeper who is seen as an integral part of the whole bridge layout (Lützhöft, 2008).

3. Clearly communicated information can be processed faster, giving watchkeepers more time and greater understanding of the potential risks. As mentioned previously, the distractions deteriorate driver's visual behaviour (Yang et al., 2012), thus must be eliminated to ensure road safety. In the same manner, the aviation industry's T-arrangement is evidence to confirm this factor regarding clearly communicated information.

These factors can only be tested in simulators, due to the complexities of making changes to real ship's bridge equipment and layout. Simulators have been used for training seafarers for decades, but until they are used effectively to prepare watchkeeping officers for real-life scenarios, their impact on safety improvement is likely to remain minimal. To create a prototype of the 'maritime six pack' based on HCD requirements, the research measures (using the eye motion tracking) the level of interaction between the existing bridge layout and the newly developed workplace. The study is divided into 6 work packages (WPs) as detailed in Appendix 1: Work Package Summary and the Gantt Chart attached as Appendix 10: Gantt Chart.

In WP1 and 2, the simulation exercises are setup for data collection from participants alongside work on WP3 to undertake a literature review. The data was collected in WP4 to assess participant behaviours for lookout horizon scanning using ETDs, both with and without distractions. The literature review and analysis of data captured in WP4 led to WP5, where a prototype of a 'bridge of the future' design was developed alongside recommendations for changes in training, particularly with reference to maintaining a lookout. Finally, in WP6, further data was captured to evaluate the impact of proposed changes.

This research assumed that there are significant differences in participants' ability to maintain focused lookout due to distractions caused by MFDs and the lack of any

defined scan patterns. Based on this assumption, the following five scenarios were utilised in five data capture phases:

1. **Scenario 1 (S1):** Data collection 1 – Here, bridge simulators were used to capture ETD data in simulations without distractions (No MFDs). The number of fixations on visual screens (bridge windows) was hypothesised to be the highest and the collected data was used to determine if a 'natural' scan pattern exists in participants' eye movement when maintaining a lookout (Blascheck and Ertl, 2014; Hareide and Ostnes, 2017a). The number of fixations and dwell time on visual screens was used as a base value to establish DER between visual screens/bridge windows and MFDs, since there were no MFDs to cause distractions (Yang et al., 2012).

   Note: Throughout the remainder of this thesis, the term 'visual screens' or 'windows' is used to refer to the view of the simulated outside world in the bridge simulator or the view through the windows of the bridge of a real ship, as appropriate.

2. **Scenario 2 (S2):** Data collection 2 – This reported ETD data captured on real ships. The number of fixations and dwell time was expected to be similar to S3, with further observation to reveal whether there was an existing 'natural' scan pattern in participants' eye movement when maintaining a lookout. The data collected on real ships provided validation for data collected in simulators, despite a known difference between AOIs used in the simulator bridge and a real ship's bridge.
3. **Scenario 3 (S3):** Data collection 3 – Simulations with distractions (with MFDs). It was expected that the OOWs time spent on looking at visual screens would be far less than that spent in S1 but more than in S4/S5.

Participants were not given any guidance on scan patterns in S1, S2 and S3 data collection.

4. **Scenario 4 (S4):** Data Collection 4: Simulations after implementing CCD. It was anticipated that the fixations and dwell time on visual screens in S4 would be less than S2/S3 but higher than in S5 as participants were given guidance (Koffskey, 2014) on the 'WWS method' in this phase and were

advised to divided their attention between looking at MFDs and visual screens (Colvin et al., 2003; Reimar and Manabir, 2006)

5. **Scenario 5 (S5):** Data Collection 5: Simulations after implementing CCD in a watchkeeping course exercise. This phase was introduced to assess and validate the impact of introducing CCDs and scan pattern guidance on participants in a real training exercise in the simulators.

The hypothesis predicted that S4 would show a higher number of fixations on bridge windows than S3 to maintain a better visual lookout (Table 1). Further, S4 was expected to show evidence of an improved scan pattern as the participants would have been briefed on the WWS pattern. S5 was devised to assess the application of both the windscreen wiper scan technique and a combination of full MFDs and CCD for normal watchkeeping. The S5 results were expected to fall between S1 and S3, showing an improvement in scan patterns as well as more time spent on proper lookout. S2 provided a comparison between the data collected on real ships with the data obtained in simulators.

The research hypothesis can thus be summarised as

"*If MFDs distract the watchkeeper from maintaining a proper lookout, then the dwell times and fixations on bridge windows (DFW) will be lesser than the dwell times and fixations on MFDs (DFM)" i.e.*

$$H_0 = DFW < DFM \text{ due to MFD distractions} \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.1)$$

$$H_1 = DFW \geq DFM \text{ due to null MFD distractions} \ldots\ldots\ldots\ldots\ldots \quad (3.2)$$

In simple terms, the null hypothesis, H_0, proposes that distractions caused by MFDs lead to watchkeepers spending more time looking at MFDs compared to looking out for navigational hazards. This could indicate that the watchkeepers are more distracted by the MFDs, leading to less focus on the mandatory task of maintaining a visual lookout. The alternative hypothesis H_1 suggests that DFW are greater than or equal to the DFM when there are no distractions from MFDs.

It follows from the above research hypothesis that the larger is the distraction caused by MFDs to the watchkeeper in maintaining a proper lookout, the higher will be the dwell times and fixations on MFDs and the lesser will be the dwell times and fixations on bridge windows. In other words, the ratio between the dwell times and fixations on

MFDs and the bridge windows is a measure of the distractions caused by MFDs from maintaining a proper lookout through bridge windows.

The analysis of all data captured in scenarios S1 through S5 is discussed in the next chapters with a summary of the research hypothesis, split into 5 different sub-hypotheses for comparison of dataset in scenario S1 vs S2, S1 vs S3, …, S1 vs S5 and given in Table 1. These are tested using appropriate statistical methods to determine if there is enough evidence to reject the null hypothesis (***H₀***) in favour of the alternative hypothesis (***H₁)***.

Table 1 - Research Hypothesis Summary

Data Capture Phase:
S1: No MFDs
S2: Real Ships
S3: with MFDs
S4: With CCDs/(MFDs)
S5: With CCDs (MFDs) NAESTO

Variables:		**Abbreviations:**	
D	Dwell Time	DFW	Dwell Time/Fixations on Windows
F	Fixations	DFM	Dwell Time/Fixations on MFDs

Dwell Time/Fixations – Windows

Sub-Hypotheses:

Note: The 4 Sub-Hypotheses given here are devised only to compare different data capture scenarios i.e. the base scenario (S1: No MFDs, no distractions) against all other scenarios i.e. S2: Real Ship data to validate simulator data, S3: Simulator with MFDs, S4: Simulator with CCD and WWS method to compare with S1, S2, S3 and S5: application of CCD and WWS in real simulator training exercises. The primary hypothesis given in equation 1 and 2 on the preceding pages remains as the single hypothesis for this study.

1. S1 DFW = Max and S1 DM FM = 0. ∵ No MFDs were visible. S1 used as base value for comparison of distractions with other cases (S2, S3, S4, S5).
2. S1 DFW > S2 DFW, S3 DFW, S4 DFW, S5 DFW i.e. S1 dwell times and fixations on windows are greater than that in S2, S3, S4 and S5. Consequently, S1 DFM < S2 DFW, S3 DFW, S4 DFW, S5 DFW i.e. S1 dwell times and fixations on MFDs are less than S2, S3, S4 and S5.
3. S2 DFW = S3 DFW but < S4 DFW, S5 DFW i.e. S2 dwell times and fixations on windows are equal to S3 but less than S4 and S5. Consequently, S2 DFM = S3 DFM but < S4 DFM, S5 DFM i.e. S2 dwell times and fixations on MFDs will be equal to S3 but less than S4 and S5.
4. S3 DFW < S4 DFW, S5 DFW i.e. S3 dwell times and fixations on windows are less than S4 and S5. Simultaneously, S3 DFM < S4 DFM, S5 DFM i.e. S3 dwell times and fixations on MFDs will be less than S4 and S5.

3.5 Simulation Details

The data for this research was acquired utilising the following apparatus:

1. Full mission ship's bridge simulator.
2. ETD and associated Behavioural and Gaze (BeGaze) Analysis software developed by SensoMotoric Instruments GmbH (SMI). ETDs were used to record participants' eye movement and the software provided a tool to analyse the data captured with ETDs.
3. Experienced seafarers to participate in the experiment. Participants were also provided an induction to the bridge equipment and to the exercise in line with Liverpool John Moores University (LJMU) ethics policy and research procedures. Each participant was given full information about the experiment, as shown in Appendix 4: LJMU Participant Information Sheet and was required to sign an acknowledgement (given in Appendix 5: Research Consent Form to ensure compliance with University policies.

The simulation scenario consisted of a ship occupied by a participant (OOW) with one target appearing from one of the directions in a total of 10 scenarios shown in Figure 7 and unknown to the participant. The ship, referred to as the 'own ship' in the report below, followed a course of 000° at a speed of 18.6 knots for each data collection exercise. If the OOW did not spot the target in time, it would result in a collision with their own ship. The exercise concluded when the OOW spotted the target and pressed the buzzer for the alarm. This was achieved through the following steps after completion of the administrative tasks required to comply with the University procedures:

a. Each participant was fitted with the ETD as shown in Figure 8.

b. After ETD calibration, the simulation ran until the participant sighted the 'target' and pressed the buzzer.

c. ETD was then taken off the participant and data downloaded onto a Personal Computer (PC) for processing in the BeGaze software and further analysis using statistical analysis software, IBM SPSS Statistics (Version 28).

d. A total of 10 exercises were created with targets placed at strategic positions shown by the following in Figure 7:

i. 1R, 2R, 3R, 4R and 5R for target located on the Right/Starboard side of the own ship.

e. 1L, 2L, 3L, 4L and 5L for target located on the Left/Port side of the own ship.

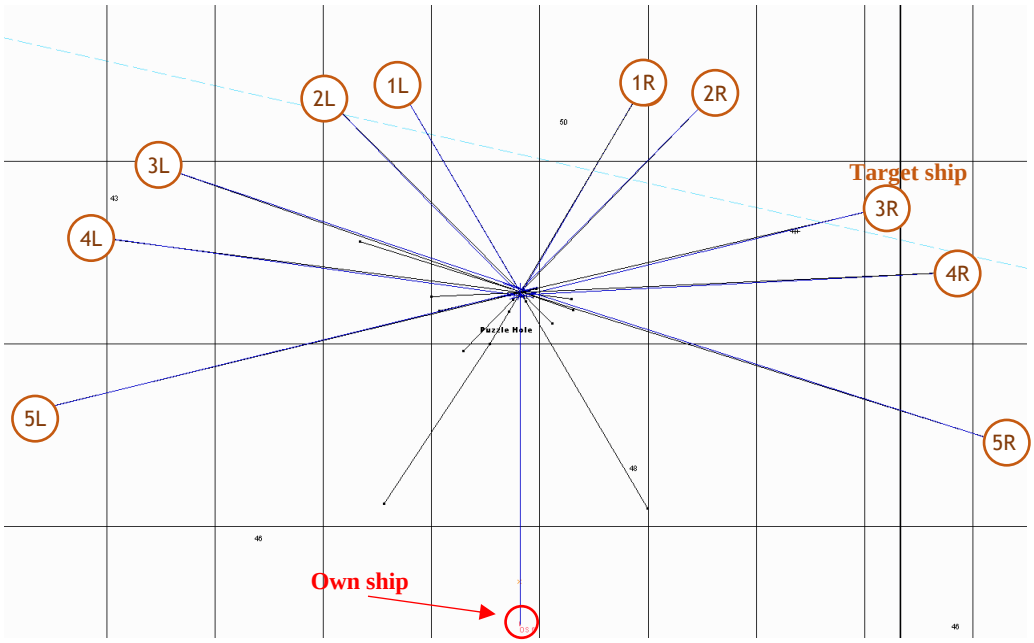

Figure 7 - Data Collection Exercises

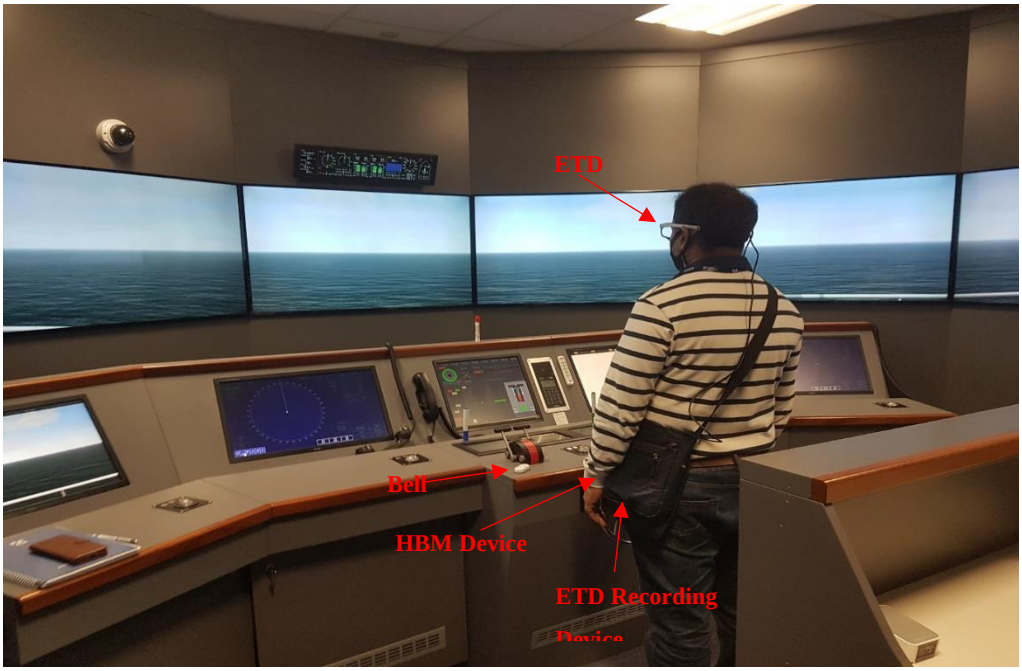

Figure 8 - Bridge Setup for Data Collection

3.6 Experimental Procedure for Data Collection

The simulation exercises were divided into five states as described in this section based on the hypothesis detailed in Section 3.4 above.

1. Simulation participants consisted of a mixture of experienced and novice but qualified watchkeeping officers.
2. For data collection exercises in the simulators, the same AOIs were created and used due to the use of the same bridge layout whereas for data collection on real ships, separate AOIs were used due to the real ship's bridge layout being different than that of the simulator.
3. In BeGaze software:
    i. each stimulus video was mapped for the selected AOIs.
    ii. Event Statistics were opened to retrieve data.
    iii. The AOI Detailed Statistics template under Event Statistics menu was opened to calculate Fixation Frequency, Gaze Duration Mean, Gaze Percentage and Gridded AOIs Scan Path Strings.

iv. For Fixation Frequency (Fixations/Sec), Gaze/Dwell Duration, Mean, Standard Deviation (SD), Minimum, Maximum figures were noted for each AOI.

4. Statistics were recorded in the data collection sheet and used with Microsoft Excel spreadsheet which was then exported to IBM SPSS Statistics for analysis where the data was split into three separate strands for the five data capture phases:
   i. Fixation frequency
   ii. Dwell Duration
   iii. Gridded AOIs Scan path Strings

Further details of the use and analysis of the data captured are given in the next chapters.

3.6.1 S1: Lookout without any equipment

This is the base line exercise to determine:

- Any existing horizon scan pattern.
- DER by comparison with S2 and S3 exercises.

The exercise ran for approximately 20-30 minutes until the observer was able to visually 'spot' the vessel in the S1 data collection exercises:

a. All bridge equipment MFDs, i.e., all screens shown in Figure 9, were switched off so that there was no distraction caused by the equipment MFDs.
b. The simulator bridge has 12 visual display channels to provide a 360^{o} view around the 'own ship'. Vis01 is the display right ahead with rest of the displays number Vis02, Vis03 and so on. Visual displays Vis05 to Vis09 were turned off to provide focused lookout concentrating on the front of the bridge area. For data collection, the available screens were labelled as shown in Figure 10.
c. For the full data collection period, the data collected is shown in Appendix 3: Scan Path Data. This appendix includes heat maps

showing the focus of observers' eyes during their observation period, as well as the scan path for the selected duration.

d. From 5 to 10 minutes into the exercise, when the observer was settled in and had established a pattern for their lookout, a concentrated analysis was carried out using the Key Performance Indicators (KPIs) extracted as shown in Appendix 6: Key Performance Indicators. This data will be combined with the scan patterns shown in Appendix 3: Scan Path Data to establish the scan pattern for each observer.

3.6.2 S3: Lookout with Equipment

The scenario S3 utilised the exercises created in scenario S1, but all the equipment displays (MFDs) in Figure 9 were switched on and set up according to the exercise scenario as required for a proper navigational watch at sea. Target detection on Radars was disabled to ensure the observer maintained a lookout whilst investigating targets on radar if they considered it appropriate. Data collection parameters and the exercise scenarios remained the same as for S1.

3.6.3 S4: Lookout on the 'bridge of the future'

At stage S4, the prototype bridge of the future was developed and installed prior to data collection. The exercises created in S1 were utilised to acquire data on the bridge of the future and compare DER with S1.

Although each simulation scenario was expected to run for approx. 20 – 30 minutes, for analysis purposes, the collected data was split into two 5-minute segments for each participant to allow the participants to settle in the bridge after commencing the simulation. The second 5-minute segment was captured 5 minutes prior to target detection.

3.7 Details of Areas of Interest (AOI)

As required for the ETD and BeGaze software to capture and analyse the watchkeepers' eye movement data, the simulator's visual areas were divided into

various 'view fields' to record and measure eye movements. The simulator data capture was split into two separate parts as given here.

3.7.1 Simulator AOIs

For the following data collection sets, the AOIs used are shown in Figure 9:

1. S1: Data collection 1 – Simulations without distractions, i.e., no bridge MFDs.
2. S3: Data collection 3 – Simulations with distractions, i.e., with all bridge MFDs.

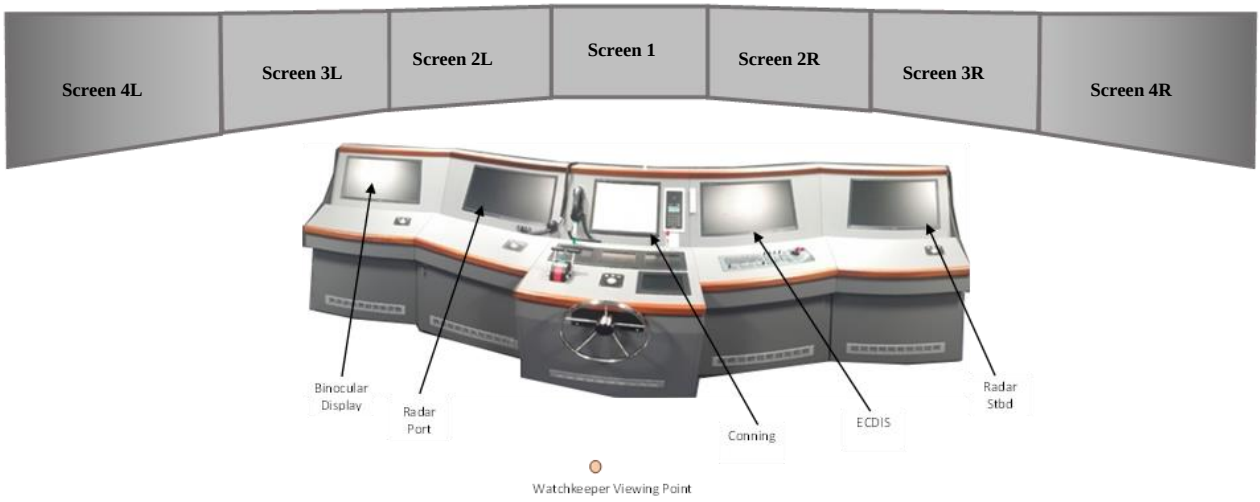

Figure 9 - Simulator Bridge AOIs without CCD

For the following data collection sets, the AOIs used are shown in Figure 10:

- S4: Data Collection 4: Simulations after implementing CCD concept.
- S5: Data collection 5: Simulations after implementing CCD concept during a watchkeeping exercise for an OOW Navigational Aids, Equipment and Simulator Training (NAESTO) course.

The dual display shown in Figure 10 was developed to show information contained in CCD for each MFD. For example, the Dual Display Radar Stbd means the same screen was used to display selected CCD information with a push button provided to switch between full and default information displayed on Radar. This arrangement applied to both Radars, ECDIS and the Conning display.

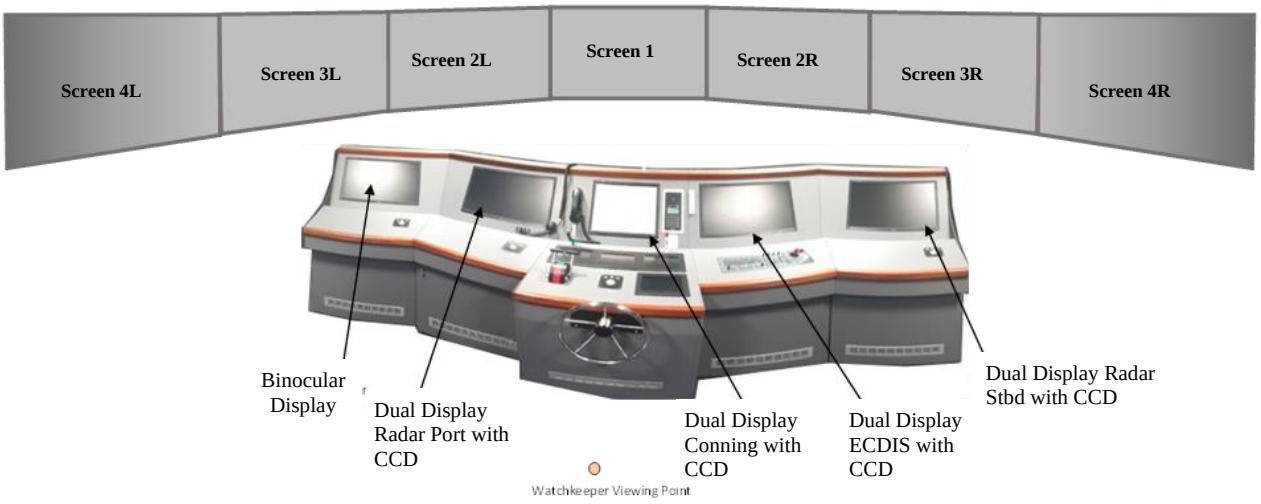

Figure 10 - Simulator Bridge AOIs with CCD

3.7.2 Real Ship AOIs

For the following data collection sets on real ships, the AOIs used are shown in Figure 11:

- S2: Data collection 2: Real ships to compare simulation data with that obtained from real ships.

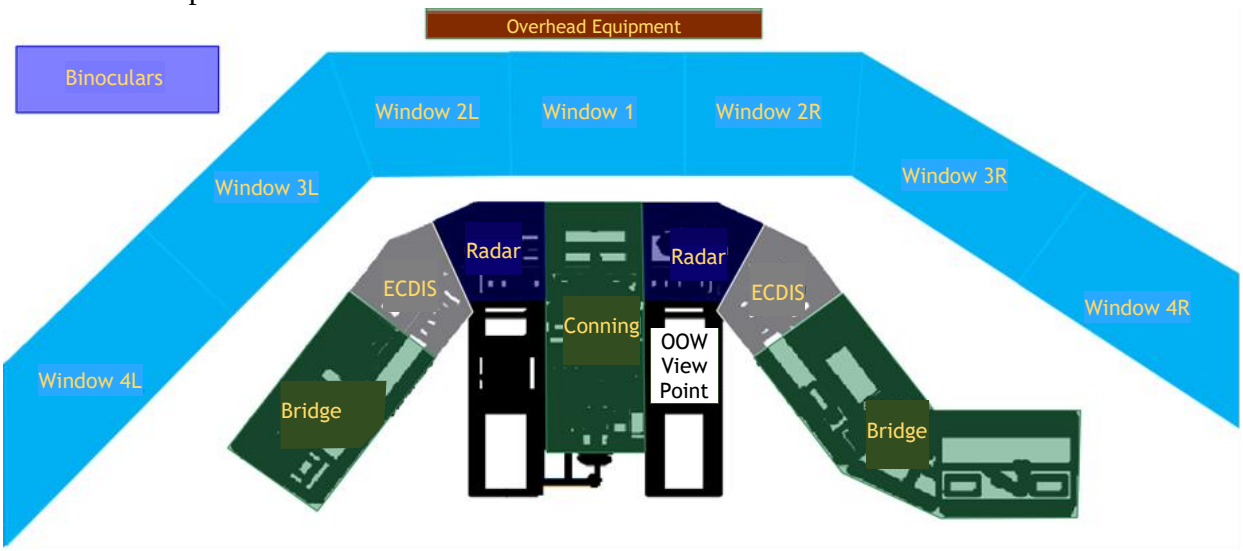

Figure 11 - Real Ship AOIs

3.8 Experiment Sample Size

The number of participants in a study are an important factor that can greatly influence the validity, reliability, and generalisation of the findings. The accomplishment of a

study is valued by the success of implementing its outputs. The required number of participants is based upon multiple factors such as research design, the level of statistical power desired, resources for study, cost and most importantly the qualification, expertise, experience, age, and gender of the participants. In many studies, the availability of the participants becomes a real issue if the research design requires the participants to be of certain age, gender, and qualification or experience. Each study therefore generally varies in the number of participants where a balance can be achieved between practical factors (such as time, resources, and feasibility) and statistical factors (such as the data required to obtain meaningful effects).

In order to assure the afore mentioned criterion can be met, a power analysis provides an easy mechanism to determine the smallest sample size to compare statistically significant effect against the desired level of confidence, particularly in experimental and observational studies. For example, Hooge and Camps (2013) conducted a study using ETDs on visual communication material produced for marketing products. They engaged 48 participants on 39 advertisements (ads). However, their conclusion was that the ads should be measured with ±50 – 100 to obtain better outputs. In their case, both the subject of study i.e. the ads and the participants i.e. those who need to be attracted to the product are easy to find in comparison with the study presented in this report. In current study presented in this report, a target of 20 participants was set in discussion with the director of studies and supervisors, based on literature review of other studies using ETDs in the aviation and road transport safety. However, due to specific requirements for this study, such as the following, extreme difficulties were faced in achieving the desired optimum number of participants:

- Participants were required to be either qualified watchkeeping officers or have sufficient sea-service of at least 12 months to qualify for OOW level certification.
- Gaining access to commercial ships during their sea passages to capture data in S2.
- Accuracy of the captured data, particularly with ETDs as some data was lost during recording with ETDs or in case of real ships, due to bright daylight during the day.

Further, these practical constraints such as such as time, and access to participants when determining an acceptable sample size was factored into making decision to conclude the data capture phases. Covid-19 pandemic severely impacted the availability of experienced seafarers to participate in data capture exercises in ship's bridge simulators. Availability of real ships to capture data presented significant challenges as the ship operators simply did not wish to allow unrelated personnel to be on their ships until the Covid-19 restrictions for fully lifted. Whilst it is appreciated that the number of participants could be higher, the participant numbers are considered acceptable for comparable research (Yaneva et al. 2022).

Due to various reasons, the number of participants varied in different data collection exercises. Data Collections S1 and S3 had 14 and 13 participants respectively. Data collections 4 and 5 had only six participants due to Covid-19 restrictions. On real ships, the time of the day influenced the camera; some data was lost due to high brightness levels but there was still enough data to use for this research. After capturing the data, a sensitivity analysis was carried out as detailed in this report to avoid unnecessary delays which also ensure that the data complied with statistical data analysis standards.

A questionnaire-based survey was also used in this study where a total of 67 responses were received from experienced seafarers, including OOWs, Masters and pilots. The survey participants consisted of 58% masters, 12% chief officers and 30% junior officers. According to Oraith et al. (2021), such a number of participants is acceptable if the data collected are gathered from experienced specialists.

3.9 Issues during Data Collection

The number of participants varied in different data collection exercises. Data Collections S1 and S3 had 14 and 13 participants respectively. Data collections 4 and 5 had only six participants due to Covid-19 restrictions. On real ships, the time of the day influenced the camera; some data was lost due to high brightness levels but there was still enough data to use for this research. A sensitivity analysis was carried out as detailed in ETD Data Analysis, to ensure data complied with statistical data analysis standards.

3.10 Concluding Remarks

This chapter focuses on research methodology used for this study and provides an overview of the ETDs used for data capture during this study. It also introduces historical uses of ETDs and then expands to cover their use for this research. A comprehensive relationship to research aim and objectives stated in Chapter 1: Introduction, to link them with the research hypothesis explaining how the data captured is evaluated in relation to current research in this field.

It also provides details of the scenarios developed for data capture in bridge simulators and on real ships. Finally, it elaborates the issues faced during data capture to provide readers an idea of the limitations of this research.

Chapter 4: Visual Search Patterns

4.1 Introductory Remarks

The STCW 1978 Code is a mandatory system that defines training standards for watchkeepers including those who are just tasked the role as a lookout.

The conduct of bridge watchkeeping and the training for all personnel who are involved in performing watchkeeping duties is therefore internationally aligned to the standards prescribed in the STCW Code. For lookout duties, the Code (IMO, 1978) specifically uses the phrase '*a proper lookout is maintained at all times*…' (STCW Code Table A- II/1, A-II/3,…). It goes a step further in the phrase '*keep a proper lookout by sight and hearing*' for competence required for Ratings forming part of a navigational watch. In explaining the criteria for evaluating this competence, the Code requires that '*sound signals, lights and other objects are promptly detected and their appropriate bearing in degrees or points is reported to the officer of the watch*'. Part 3-1, '*Principles to be observed in keeping a navigational watch*' of the Code, elaborates these two phrases but does not define the term 'proper lookout', leaving a gap that, in the author's view, is the main culprit underlying issues of failure to maintain a proper lookout. One may argue that the methods or procedures for maintaining a proper lookout need to come from the ordinary practices followed for watchkeeping, so there is no real need to define this term.

During the literature review, it was established that some general definitions for 'proper lookout' exist but an appropriate definition for the maritime industry has never been considered. For example, the Webster's dictionary (Merriam-Webster, n.d.) defines a proper lookout as '*the due degree of vigilance expected of the operator of a vehicle/train in avoiding collisions with vehicles or pedestrians*'. Other detailed description of this term and associated factors that this research is focused on, were highlighted by the Australian Maritime Safety Authority (AMSA, 2020) as follows:

> *'AMSA considers the following as ways to keep a proper lookout:*
>
> - *regular visual scans of the entire horizon (360 degrees)*
> - *effective use of the vessel's radar*

- *use of AIS to:*
    - *locate targets in the area, and*
    - *transmit accurate data.*
- *a quiet wheelhouse to allow for:*
    - *VHF radio calls to be heard*
    - *sound signals to be heard, and*
- *all other available means to maintain good situational awareness.*

Watchkeepers need to be aware that any distraction from their duties can have a negative impact on safety. Managing fatigue is one recognised way of minimising distractions, but another factor that has to be considered is the discrepancy between STCW Code competence requirements and actual competencies gained by seafarers upon completion of the required training. For example, Fan and Yang (2023) note that the STCW Code "*addresses limited results-centric or behaviour-based knowledge required by seafarers, which reveals gaps between the rule and the practical performance*." Even though there is no need to re-invent the wheel, the basics have to be revisited to ensure concrete foundations for all training to prevent technology-led complications, muddying modern navigators' application of traditional collision avoidance rules and practices.

Based on the author's experience, including this study, as well as incorporating factors identified in AMSA (2020) above, the term 'proper lookout' is defined in this study as "the application of due vigilance to improve situational awareness by:

a) sight – through systematic visual search scans of the environment around the own vessel.
b) hearing – through a quiet wheelhouse with access to outside sounds.
c) all available means, such as Radar, AIS or other bridge equipment".

This definition of a 'proper lookout' not only encompasses the IRPCS requirements but also provides reference to the visual scanning approach for maintaining the lookout as established through research and presented in this report. The research-based evidence suggests that attention can be trained as discussed in Section 4.2.1 with outputs presented in this report proposing a method to train the lookout's attention.

4.2 Lookout Procedures

In order for OOWs to rank 'visual search' high in their priorities, they must first mentally accept its significance and contribution to maintaining a thorough SA. They then need to be trained in establishing their own 'timesharing technique' to share their focused attention between looking outside of the bridge windows to spot targets and on other tasks on the ship's bridge that require focusing on MFDs, etc. A balance between the two areas needs to be found and maintained. This balance may vary based on factors such as the area of operation, e.g., proximity to coastline or traffic density, etc. Obviously, if higher focus is needed on navigation in coastal areas, additional personnel will be required to assist in maintaining proper lookout. Similarly, where the traffic density and prevailing visibility requires more focus on maintaining visual lookout, then an additional OOW may be required to monitor the ship's progress as per the passage plan. In essence, the manning level on the bridge will depend upon the amount of time required for maintaining the primary lookout. Considering these intricacies of 'maintaining a proper lookout', the watchkeepers must appreciate that:

1. The bridge equipment is mandatory and necessary for safety of navigation, so the watchkeeper must pay attention to it regardless of whether it causes any distractions to the primary watchkeeping task, i.e., maintaining a lookout.
2. The watchkeepers will never knowingly ignore the IRPCS Rule 5 and will therefore make full endeavours to maintain a proper lookout by all available means.
3. There is no single technique (Hareide and Ostnes, 2017a) for maintaining a lookout that will fit all watchkeepers.

This study investigated any existing correlations in watchkeepers' natural behavioural practices they may naturally have or have adopted through training and/or experience. However, no such similarities were found amongst the participants that took part in data collection with ETDs on bridges, with or without equipment. On the assumption that no task can be accomplished through a by-chance approach, maintaining a 'proper lookout' as required by the STCW Code is understood to be no different. Consequently, a scan pattern was adopted and applied and the resulting impact analysed in this research.

4.2.1 Window Wiper Scan (WWS) Method

Electronic devices such as AIS and radar/ARPA, designed to assist the lookout function, are infallible. Even binoculars are only supposed to be used to identify a target after visually sighting it first and not for scanning the horizon. The availability of these devices does not relieve the watchkeeper of their primary duty to maintain an effective lookout by sight and by hearing.

The same regime applies to maintaining proper lookout on large military ships, which have a large number of lookouts (Lutes, 2000). On merchant ships, however, a smaller number of personnel on the bridge are expected to achieve the same results. These ships usually have one watchkeeping officer, with a non-officer rank rating posted on bridge solely to perform a lookout, regardless of the size of the ship.

The effectiveness of maintaining a lookout cannot be a natural process, as the watchkeeper must focus their attention for 1-4 seconds to recognise an object in the sensory memory, followed by transfer into the STM where it will take 4-6 seconds to be formally registered so that the follow-up process can be completed and therefore feed into the SA. This is not withstanding the input that may be obtained from peripheral vision to provide cue acquisition and cue interpretation, as discussed in Section 2.5.3. Without this, the object is unlikely to be mentally considered part of the overall SA.

In order to explain the concept of scan patterns and how the STM works in the context of SA, the participants were asked to experience this through a small eye movement exercise (Lutes, 2000) in which they would move their eyes rapidly from one side to the other, and asking them if they registered any object. Their response was expectedly negative for identification of any object in the given view area. At this point, they were informed about saccadic suppression.

Li et al. (2014) state in their research findings that in normal light conditions as applied in the author's research, the retina needs to see a new image for about 80 ms (milliseconds) before registering it in the cortex and then passing it to the cognitive regions of the brain, i.e., the STM. However, due to a saccade (fast eye motion), the image on the retina is blurred, with the eyes supressing any further processing of the image, thus not registering an object in the cortex and consequently there is no feed into the STM or SA. This phenomenon is referred to by Rosenbaum (2010) as saccadic masking, or

suppression. As previously mentioned in this report, MFDs require more time for their content to be explored due to the quantity of information available via each MFD. This is because the users must focus their attention towards an MFD to locate what they need, avoiding saccadic suppression, a possibility that may lead to tunnel vision or overlooking critical parameters and missing the target (Li et al., 2014).

Participants were also given an explanation of the significance of the central versus the peripheral FOV of the human eye. The former spreads from right in front of the eyes to approx. 2.5° either side, whereas the latter spreads for approx. 100-110° on either side of the eye (Figure 12). The eye focuses, and therefore can recognise, an object fully when it is viewed within the central FOV.

They were then asked to repeat the eye movement exercise by moving the eyes in small steps, focusing on the area of gaze covered by one eye movement, searching in sectors of 10° and focusing on each sector for 4 seconds, thus taking a maximum of 84 seconds (1m 24s) to scan through 210° field of view (as discussed later in this chapter). After each scan, they were advised to rest their eyes for a few seconds and then resume the search. This practice explained the significance of the visual scan pattern concept to the participants.

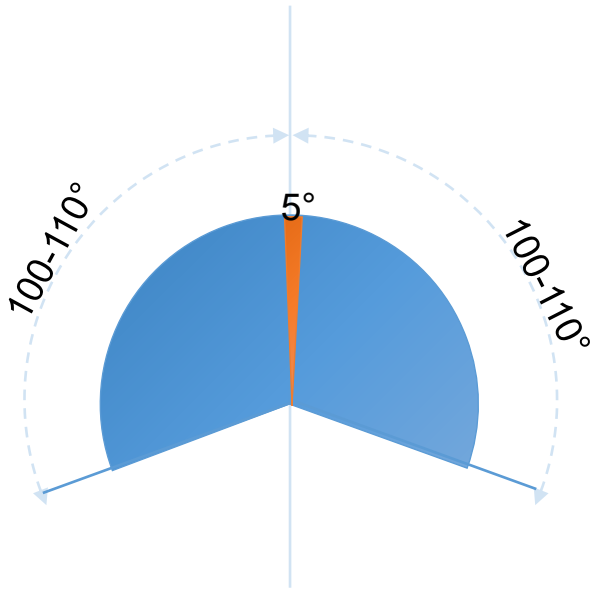

Figure 12 - Human Eye Central & Peripheral Vision Field

To scan effectively, a watchkeeper must know how to make the best use of their eyes' natural capabilities – and train themselves to do this repeatedly. This is not a new idea; it was evidenced as far back as 1989, when video gamers who were trained to use efficient visual scanning patterns showed better performance than those who had received random pattern training or no training at all (Koffskey, 2014). Likewise, airline pilots have long since adopted scanning patterns involving a 'block' system as the most effective way of keeping a lookout.

This system is based on the premise that traffic detection can best be conducted by focussing on a series of fixed points in space as determined through the small eye movement exercise in the previous pages. When the head is in motion, vision is blurred, and the mind (STM) will not register objects. Unless a series of fixations is made, there is little likelihood that an object will be positively identified. To be most effective, a watchkeeper's vision should be shifted and refocused at regular intervals. A scan of the visual horizon should be broken down into approximately 10° 'blocks', to ensure that the field of central vision focusses on each sector in turn before moving on to the next, spending no more than 4 seconds on each sector. The 10° block is not selected randomly but is based on the evidence gathered through a literature review, elaborated fully in Section 4.3.

Scanning the visual field is a key factor in collision avoidance and should be a continuous process adopted by all watchkeepers to fully cover the areas visible from the bridge. In application, the bridge windows are to be divided into blocks, each of which is to be methodically scanned for traffic in a sequential order. This should be performed as follows (Figure 13):

1. Commence the scan in the centre block of the visual field (towards the bow of the vessel).
2. The brain is naturally trained to process vision from left to right (FAA, 2015), so the scan commences towards the left shoulder. Vision is moved to the port side of the vessel, focusing for a period of no more than four seconds on each 10° block.
3. After reaching the last block on the port side, vision should resume its journey back to the centre block, again scanning each 10° block from the port side to the bridge centre, spending no more than four seconds in each block.
4. The same process is repeated on the starboard side of the vessel. Vision is moved from the centre block of the visual field to the starboard side in blocks of 10°, focusing for a period of no more than four seconds on each 10° block and then traversing the vision back to the bridge centre.
5. After having scanned each 10° block of the window, vision should be switched to the instrument panel/MFDs within the bridge. Starting in the middle (in line with the bow), the equipment should be scanned to port employing the same 10° block approach that was utilised for scanning through the bridge windows.
6. From the port side, the vision returns in blocks back to the centre.
7. From the centre (in line with the bow), the equipment MFDs should then be scanned to starboard, employing the block scan approach.
8. To complete the scan cycle, the vision returns in 10° blocks back to the centre.
9. Once an appropriate amount of time has been spent viewing the instrument panels inside the bridge, the external scan process should be resumed by observing through the windows again.

Searching in sectors of 10° and focusing on each sector for no more than 4 seconds means spending a maximum of 84 seconds (1m 24s) to scan back and forth across a 210° field of view in the visual screen areas and 6 MFDs x 4 seconds each, requiring 24 seconds maximum. This time-sharing gives a ratio between visual screen and MFDs of 3.5:1, which falls in the same range as used in the aviation industry (3 ~ 6:1) between visual screens and MFDs.

The eyes may require several seconds to refocus when switching between items on the bridge and outside of the window. Vision should initially be focused on the centre block of the visual field, until the eyes have refocused, before commencing the external scan.

An important factor to consider when viewing these ratios is the time spent on MFDs will vary, depending on the actions an OOW may need to take. The same, however, will apply to external lookout through windows. The watchkeeper should remain constantly alert to all traffic within their field of vision. This means periodically scanning the entire visual field outside the vessel by going out on to the bridge wing to look astern. In addition, watchkeepers should consider blind spots caused by fixed structures within the bridge, such as posts or window struts, and take appropriate action to avoid these masking their view of other vessels.

4.2.2 Lookout at Night

Maintaining a proper lookout at night presents very different and understudied challenges for the maritime watchkeeper, commonly known as ‘dark adaptation’ or adjustment to ‘night vision’. The IMO (2017) requirements in the STCW Code with reference to dark adaptation state, ‘*the relieving officer shall ensure that the members of the relieving watch are fully capable of performing their duties, particularly as regards their adjustment to night vision. Relieving officers shall not take over the watch until their vision is fully adjusted to the light conditions*’.

The STCW Code does not specify how this is to be achieved, nor do the traditional watchkeeping practices make allowances for this due to a lack of knowledge in the maritime industry. Unfortunately, it has been left to the interpretation of legislatures to devise standards and guidance for watchkeepers and bridge equipment display

manufacturers. As a consequence, whilst there is some general guidance about it, seafarers are not taught about the science behind dark adaptation and the consequences of not following a scientific approach to it.

The literature review reveals a major flaw in shipboard systems in this aspect which is the lack of detailed assessment of the impact of lighting and displays, particularly the MFDs on watchkeeper's ability to achieve and maintain dark adaptation. For example, the IMO performance standards for Radar, ARPA and ECDIS, etc., (IMO 1995, 1995b, 1996, 2004, 2006, 2017a, 2017b) require that the '*information is clearly visible to more than one observer in the conditions of light normally experienced on the bridge of the ship by day and by night*'. The classifications societies, such as Lloyds Register (LR), DNV (2012) and Bureau Veritas (BV, 2016) may apply these rules with their own twist, but IMO requirements are the minimum. To control lighting on the bridge of the ship, including that from Visual Display Units (VDUs) or MFDs, IMO (2000) provides various requirements. For example, during the day, the VDU background luminance range is 15-20 cd/m^2 with a display luminance range of 80-160 cd/m^2. But the IMO does not provide a clear min/max luminance at night, which is where the luminance level causes real problems for dark adaptation and, therefore, for maintaining a proper lookout. The IMO only requires the following with respect to the luminance level of MFDs:

- '*a satisfactory level of lighting … to complete such tasks as maintenance, chart and office work satisfactorily, both at sea and in port, daytime and night-time.*
- *Visual alarms on the navigating bridge should not interfere with night vision.*
- *All information should be presented emitting as little light as possible at night.*
- *Displays should be capable of being read day and night'.*

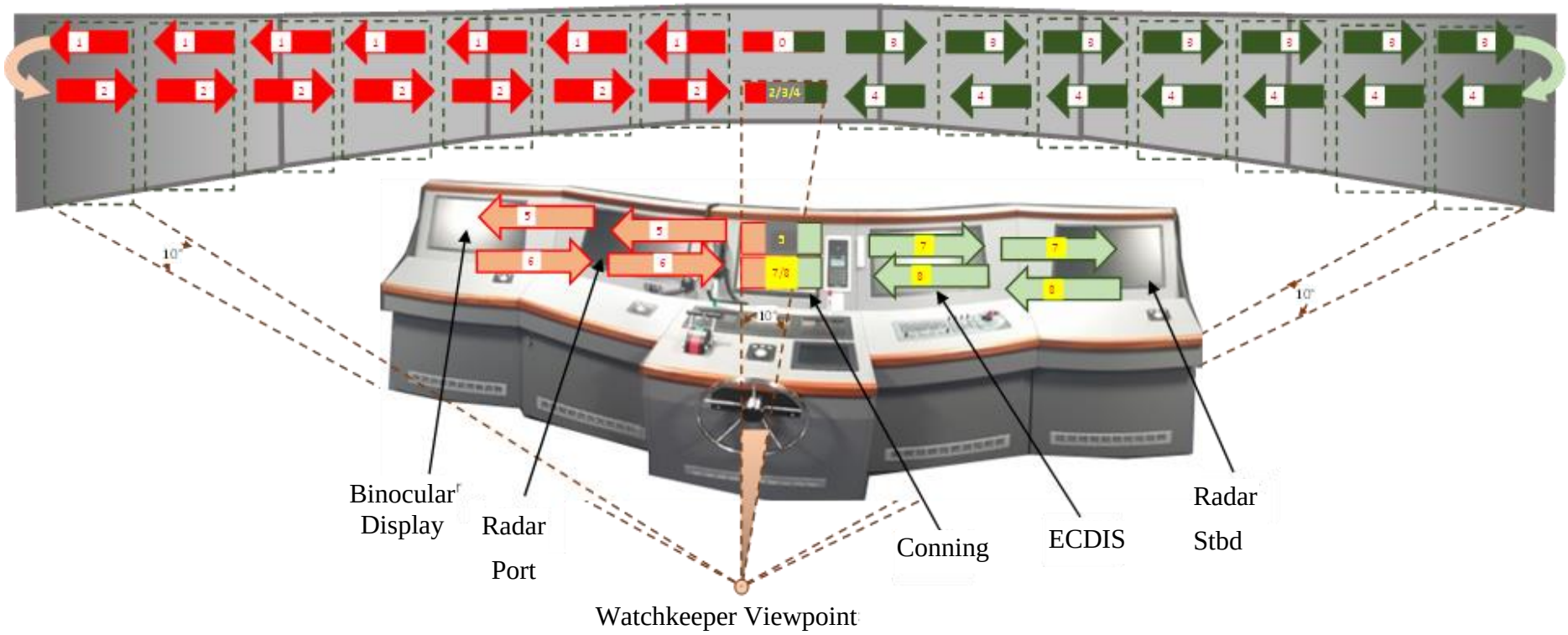

Figure 13 - Window Wiper Scanning (WWS) ***(Source: Khalique and Bury, 2022)***

Definitions:

Lumen (lm) Unit of luminous flux i.e., amount of light emitted from a light source.

Candela (cd) Unit of luminous intensity i.e., number of lumens in emitted light.

Lux (lx) Amount of light hitting a surface i.e., number of lumens on a specific area of a surface.

Luminance Amount of light that passes through, is emitted from, or is reflected from a unit area measured in candela per square metre (cd/m^2)

Illuminance Amount of light falling on a surface measured in units of Lux (Lux = lm/m^2)

1 cd/m^2 = 1 Lux = 1 $Lumen/m^2$

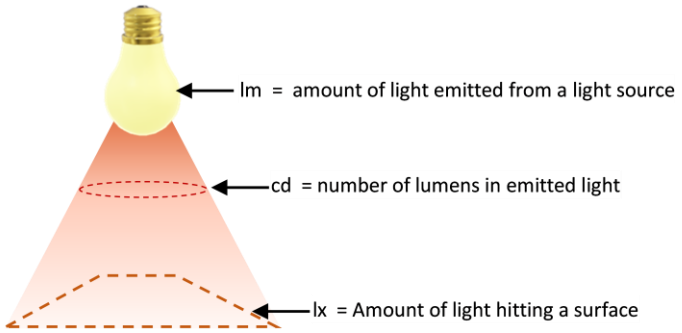

Figure 14 - Illumination Terminology

These requirements however specify that at night, on the bridge, continuously variable red or filtered white light and, on the chart table, filtered white or spotlights are provided for illumination from 0 – 20 lux.

Surprisingly, these requirements show that the watchkeeper is delegated the ability to control variation of these lights, but it is disturbing that they are not educated about the effect of colours and brightness on their vision. Keeping in view that the typical computer screens which may be deployed on a ship's bridge for office work, or may even be the MFDs for bridge equipment, operate with a peak luminance range of 80-500 cd/m2 (Forchhammer et al., 2016), so these are far brighter than the permissible (0-20 lux) for spotlights, so will cause light pollution that will affect dark adaptation.

In order to understand the function of the eyes, two aspects of human vision need to be understood: (1) the structure of the human eye; and (2) the characteristics of the light that, when reflected from objects and received by the eyes, provides vision. These are discussed in the next sections.

4.3 Human Eye Structure

The human eye receives vast amount of information and sends it to the brain for recognition, processing, storage and action. The eyes capture this information via the rays of light reflected from the objects the eyes see. If there is no light to reflect or if the eyes are unable to capture the reflected light, the eyes do not see. When light is reflected from various objects and received by human eye, the collected information must be processed within the eye's photoreceptor cells. The average luminance at which the eyes can see ranges from approx. 0.000001 (10^{-6}) cd/m^2 on dark nights to approx. 100,000,000 (10^8) cd/m^2 during bright sunny day (Boyce, 2003). The most important cells (or nerves) are described here in the context of these brightness levels to elaborate the issues watchkeepers need to overcome when performing a lookout at night. Again, the emphasis is on training watchkeepers' eyes correctly so that they use them for optimum lookout performance.

The basic structure of the eye is shown in Figure 16. The eyes contain two types of photoreceptor cells in the retina; cones and rods (CHIRP, 2017a). Each eye is estimated to have 5-6 million cones and 80-90 million rods. The fovea, a small depression in the central part of the retina, contains mostly cones, and is also referred to as the point of sharpest focus.

Cones recognise colour (certain frequencies of light which are not present in darkness), detail (when bright light is reflected from any object, e.g., sun, moon or artificial light) and distant objects, to provide vision known as '**photopic vision**' available in a luminance range of 10-10^8 cd/m^2 (Nigalye et al., 2022). Cones are activated by release of a photopigment known as Opsin and are further divided into three sub-types based on their colour-sensing ability for red, green, and blue colours, dependent upon three different types of Opsins. A mixture of these colours gives the human eye the ability to distinguish thousands of different colours. Cones are considered to function in brightness level equivalent to that of 50% moonlight at night or above about 3 cd/m^2 luminance (AOA, 2012; Kolb et al., 1995) and reach their peak sensitivity at light of 555 nanometre wavelength (Schubert, 2006).

In the absence of a luminance level of 3 cd/m^2 or more (Boyce, 2003), the second type of cells, i.e., rods provide vision, known as '**scotopic vision**', available in the luminous range of 10^{-3}-10^{-6} cd/m^2 (Boyce, 2003; Nigalye et al., 2022). Rods, mostly located on the outside of the fovea's central part, are designed for the best image perception in low light, but they cannot distinguish colours from lights of different wavelengths; coloured objects can be seen but only in shades of grey. This duplex system consisting of cones and rods allows the eye to provide vision over a wide range of ambient light levels.

In order to see in darkness, the eyes need to shift their focus from using cones to rods, which takes time. When switching from seeing in bright light to darkness, a photopigment known as rhodopsin is produced in the retina that helps rods adjust to low light or darkness (Lamb et al., 2004, AOA, 2012, Williams, 2020). Rhodopsin is produced according to the light intensity, which takes approx. 20-30 minutes to reach its full density in 80% of cases to complete in full darkness of around 10^{-5} cd/m^2. This process is known as 'dark adaptation', and may take longer in some people depending upon their eyesight, age, fitness and level of fatigue, etc. (Jackson et al., 1999). Regardless of these variable factors, research-based evidence suggests that adjustment to night vision cannot be completed in less than 20-30 minutes, even though scotopic vision starts to improve from approximately 5-10 minutes into the process of dark adaptation.

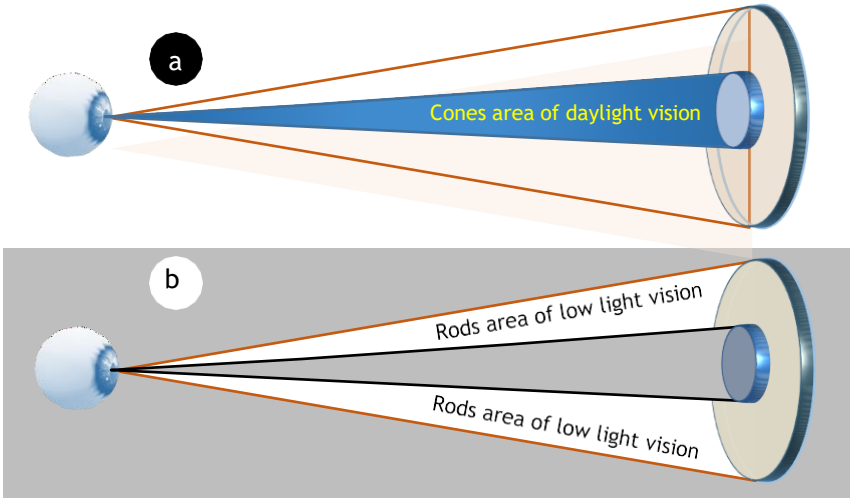

Figure 15 - Day and Night Vision

When eyes are subjected to a bright light for more than one second, the rhodopsin is decomposed, voiding the dark adaptation, but at the same time waiting for light adaptation. It takes 5-7 minutes for cones to adjust fully to the bright light after decomposition of rhodopsin – a phenomenon referred to as 'light adaptation'.

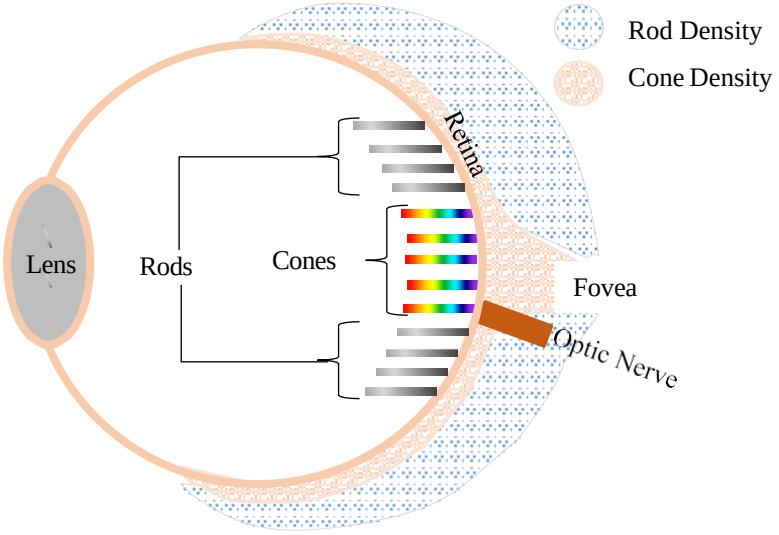

Figure 16 - The Structure of an Eye
(Khalique et al., 2023)

A third function to be considered is the simultaneous functionality of both rods and cones, such as in twilight conditions – a phenomenon known as '**mesopic vision**' where both rods and cones contribute to vision between luminance levels of between 0.003 (10^{-3}) to 3 cd/m^2 (Boyce, 2003). At night, when the brightness is at

its lowest level, but it is not absolute dark, some objects can still be seen due to the contrast between the object, such as the navigational lights of another ship, and the background – a darker sea/ocean over a lighter sky.

In darkness, the cones are 'unavailable' for vision through an area approximately 5 to 10 degrees wide, so the vision must be off-centred to 'spot' an object with rods in the regions shown in Figure 15. This is because the central part of the retina cannot detect an object if looking at it directly due to the night blind spot in the rods area of vision. In the context of binocular vision (seeing with both eyes), the blind spot is not an issue since an object is unlikely to be in the blind spot of both eyes simultaneously, but it may remain undetected in monocular vision e.g., if one eye's field of view is obstructed by a bridge window post. Therefore, a process that must form a part of dark adaptation for watchkeepers is to shift the vision by 4 – 12 degrees to one side so that rods can be fully utilised and blind spot avoided (Nave, 2016). Further, the head should remain in continual motion, as explained in the section 4.2.1 on the window wiper scan, to overcome any issues of missing object detection due to the blind spot.

As explained earlier, photopic vision spans from right in front of the eyes to approx. 2.5° either side, whereas the peripheral vision spreads for approx. 100-110° on either side of the eye (Figure 12), which is the vision outside of the central point of fixation, i.e., foveal vision. The rods provide peripheral vision with their functionality ceiling to luminance levels equivalent to a night with an overcast sky and without moonlight. For a normal eye, the foveal vision provides a 20/20 visual acuity, with peripheral vision acuity in the region of 20/200 (Salmon et al., 2009). Despite a significant reduction in visual acuity, peripheral vision assists in detecting large objects or objects in motion without providing details of the shape and colour of the object.

When dark adaptation is complete, photopic vision is unavailable but peripheral vision is available and extremely useful in the detection of faint light sources, such as the navigational lights of other vessels or dim stars – a function vital for performing optimum lookout, particularly collision threats from other objects. In essence, the lookout or visual search is entirely dependent upon peripheral vision, due to the foveal night blind spot discussed previously. The watchkeeper must therefore look between 5-10° either side of the object, which together with binocular vision provides an overall arc of 100-110° on either side of the eye. This can only be achieved if the

watchkeeper does not search for objects in the foveal region but scans the areas adjacent to it. This is where the author's proposed WWS pattern becomes more useful, as the head and eyes are moved in 10-degree blocks, allowing the peripheral vision to scan each block to detect both stationary and moving objects.

4.4 The Visible Spectrum of Light

The foregoing discussion shows how cones and rods function within the eye. However, the main element that makes it possible to see things is light. The literal meaning of the word 'photo' is 'light'; i.e., without light, there is no photo and no vision. In order to see objects using the eyes, visible light stimulates the photoreceptors (cones and rods). Visible light includes violet, indigo, blue, green, orange, yellow and red (VIBGOYR) colours with wavelengths between 400 to 720 nanometres (Helmenstine, 2020) (see Table 2). Shorter wavelengths correspond to higher frequency and energy in the visible spectrum; for example, red has the shortest frequency (400-484THz), lowest energy (1.91eV) and a wavelength of 620-720 nanometres, whereas violet has the highest frequency (668-789THz), the highest energy (3.10eV) and a wavelength of 400-440 nanometres. Ultraviolet wavelengths (<400 nanometres) fall below the visible spectrum, whereas infrared wavelengths (>720 nanometres) fall above this spectrum and are considered invisible to the human eye. However, some of us may continue to see some colours in both the ultraviolet and infrared wavelengths, though prolonged exposure to these may damage the eye.

With respect to the visible light spectrum and the photoreceptor cells (rods and cones), three distinct areas need to be considered from a watchkeeper's perspective, particularly when maintaining a proper lookout at night:

1. **Dark adaptation:** As watchkeepers walk at night into the wheelhouse, their eyes don't see anything, i.e., total darkness. This is the time at which dark adaptation commences, which depends upon successful release of rhodopsin which reaches its peak sensitivity when exposed to wavelengths of around 500 nanometres (Kazilek and Coope, 2010) which corresponds to blue-green light wavelengths. Rods have a higher sensitivity to blue light of wavelengths 460-500 nanometres or less, no sensitivity to red light of wavelengths greater than 620 nanometres.

Table 2 - Visible Light Spectrum

(Adapted from Rabia, 2018; Polishchuk and Tykhanova, 2022)

Colour	Wavelength*** (nanometre)	Frequency* (THz)	Energy** (eV)	Used by Rods or Cones
Violet	400 - 440	668 - 789	3.10	Violet border i.e., the lowest wavelength/frequency limit of visible light.
Indigo	440 - 460	600 - 700	2.48	
Blue	460 - 500	606 - 668	2.75	500nm rhodopsin released at peak sensitivity
Green	500 - 570	526 - 606	2.25	
Yellow	570 - 590	508 - 526	2.14	Most sensitive wavelength for cones 555nm (yellow-green)
Orange	590 - 620	484 - 508	2.06	
Red	620 - 720	400 - 484	1.91	Red border i.e., the highest wavelength/frequency limit of visible light.

* THz – Trillion Hertz

** eV - electron-volt

*** There are no agreed limits for the visible spectrum. The values used here are found in most of the reference materials.

In order to facilitate a quicker adaptation to darkness (CHIRP, 2017a), the watchkeepers are recommended to spend some time, for example, in a chart room illuminated by red light. This is because lights in the red wavelengths offer biological benefits in terms of not triggering the decomposition of rhodopsin. This, however, only works with dim monochromatic (single frequency or wavelength) red light and not a white fluorescent light bulb covered with red liner, coating or filter. As rods are not sensitive to red light

wavelengths, rhodopsin continues to be released to commence dark adaptation and remains at the same saturation level as long as the eyes are exposed to the same level of red light. This is why the use of red light (or red goggles) is recommended for many control spaces, e.g., in ships' bridges, submarines, aircraft and so on, where the operators can continue to be 'darkness adapted' while performing tasks. In the case of ships' bridges, then the same approach can be adopted to provide better night vision.

2. **Light adaptation:** When a person moves from darkness into light, even if that means focusing temporarily for a brief period on an MFD, e.g., ECDIS display, using multiple colours, the eyes achieve light adaptation, which means rhodopsin will decompose (Nigalye et al., 2022). If this focus remains on the MFD for approx. 5-7 minutes, the cones will adjust fully to the MFD colours, thus requiring a further 20-30 minutes for the regeneration of rhodopsin to dark adaptation.

Whilst the foregoing is a basic account of the extreme situations for dark and light adaptation, there is, however an intermediate function that assists in transition between dark and light adaptation. This is pupil dilation, i.e., the increase in pupil diameter (to 8 mm) with decreasing brightness and the reverse process of decreased diameter (to 2 mm) with reducing brightness by up to about four times its normal diameter (Boyce, 2003; Burns and Arshavsky, 2005). Although the change in rod and cone sensitivity happens gradually over several minutes, the pupil dilation is much quicker. Nevertheless, despite the known changes in pupil diameter, the effect is minimal and hence not considered in this report from a watchkeeper's perspective.

Table 3 - Luminance Level on Real Ships

	RoPax*	***Tanker***
	Luminance (cd/m^2)	Luminance (cd/m^2)
ECDIS	5.8	-
Radar 1 Output	0.72	1.37
Radar 2 Output	0.21	1.15
Engine Controls	2.4	0.14

** RoPax - Roll on Roll off Passenger Ship*

Based on the foregoing discussions, it is vital that watchkeepers are conscious of the level of luminance in the bridge at all times to see its impact on dark and/or light adaptation.

The International Hydrographic Office (IHO, 2014) requires that, *'For the ECDIS this means setting up the display for bright sunlight, when all but the starkest contrast will disappear, and for night when so little luminance is tolerated that area colours are reduced to shades of dark grey (maximum luminance of an area colour is 1.3 cd/m^2 compared with 80 cd/m^2 for bright sun)'.* A study carried out by Wynn et al. (2012), luminance levels (Table 3) from various MFDs on the bridges of a RoPax and an oil tanker were recorded at night during normal passages. For RoPax, it was clearly evident that the ECDIS luminance was higher than the minimum allowed but not set by the watchkeeper. On this basis, it is only fair to assume that the watchkeeper was either not aware of this option in ECDIS, and by extension for other MFDs, or they did not apply this due to a lack of awareness of the impact on their dark adaptation.

Further, the maximum luminance of an area colour of 1.3 cd/m^2 allowed by IHO falls in the mesopic vision range, i.e., 0.003 (10^{-3}) – 3cd/m^2, meaning that despite the watchkeepers adjusting the ECDIS luminance to the minimum design level, it will still be above the Scotopic vision luminance (< 0.003(10^{-3}) cd/m^2); thus, they will never have the conditions to switch to full dark adaptation. This is further complicated by the fact that the combined luminance from various MFDs, engine and communication controls and other light pollution caused by accommodation lights, etc., will increase the prevailing

luminance on the bridge (wheelhouse), so the possibility of never achieving full dark adaptation remains quite high.

3. **Back scatter of multiple light colours:** The IRPCS 'Rule 6 – Safe Speed' requires vessels to take into account '*at night the presence of background light such as from shore lights or from back scatter of her own lights'* because it may take longer to distinguish between different colours of light exhibited on shore that may confuse the watchkeeper, requiring more time to understand their position with respect to those lights.

   When the vision shifts from photopic (cone-based) vision to scotopic (rod-based) vision, the blue and green lights appear relatively brighter (when placed in close proximity and looked at simultaneously with 15-20° off-centred vision) as compared to yellow or red lights. This phenomenon is known as Purkinje shift (Dodt, 1967). However, red light appears brighter when the eyes are fixating centrally.

   Relating the Purkinje shift to the IRPCS Rule 6 requirement, the watchkeepers must be able to see the link between some lights, particularly the shore lights of different colours appearing and disappearing with the shift from central to peripheral vision. Thus, they must keep this in mind when looking out at night.

   To summarise the techniques for maintaining a proper lookout at night, the following must be considered by all watchkeepers:

   1. This simplified description of the structure of cones and rods shows that the eyes are used differently at night than during the daylight.
   2. Treating the eyes as a precise instrument which needs adjustment to the change in illumination allows for avoidance of missing potential threats from being visually spotted.
   3. It takes approx. 20-30 minutes to achieve dark adaptation, but once adapted, it takes only one second to lose it, even if it is just a result of looking at an MFD for a brief period of time. This will require the dark adaptation process to commence from the beginning, i.e., requiring 20-30 minutes for full dark adaptation again.

4. It takes approx. 5-7 minutes to achieve light adaptation. This period should not be overlooked, particularly when inspecting details on ECDIS.
5. The luminance levels for the bridge, as well as for each MFD, must be risk-assessed to ensure they remain within the photopic, scotopic or mesopic vision limits, or alternative measures such as posting a dedicated lookout who does not require to switch between dark and light adaptation during their watch.
6. When maintaining a lookout at night, the basic proposed procedure for WWS can still apply and provide better mechanism to use peripheral vision.

All watchkeepers are recommended to practice the guidance provided here to find their own optimum for dark/light adaptation and use of WWS.

4.5 Analysis of Scan Path Data Collected

The scan path plots were created for all participants using 'Gridded AOIs' function in BeGaze to export 'Scan path strings' into Microsoft Excel and then creating/analysing the scan path for each phase to compare the differences in participants' behaviour for maintaining a lookout.

By capturing participants' eye movement, the sequence in which they looked at the AOIs was identified, leading to an understanding of a pattern in the movement of their gaze during the experiment period (Blascheck and Ertl, 2014). Tracking the eye movement alone may not be sufficient to understand watchkeeper behaviour towards maintaining effective lookout, because of the complexity of modern bridges due to a large number of MFDs and the possible distractions that may be caused by them to maintaining continuity in the watchkeeper's task at hand, i.e., maintaining a lookout. A combination of multiple methods was therefore required to gain a thorough insight into watchkeepers' behaviour (Saraiya et al., 2005; North, 2006; Gotz and Zhou, 2009; Gomez et al., 2014; Guo et al., 2016). Therefore, triangulation of data (Blascheck and Ertl, 2014) from gaze path, duration of fixations and saccades was assessed together with the questionnaire (Appendix 7: Questionnaire) to fully understand the impact (Figure 17) to ensure a holistic approach through 'explaining more fully the richness

and complexity of human behaviour by studying it from more than one standpoint' (Cohen et al., 2000). In a simple format, the data is collected, abstracted, synchronised and analysed, with the analyst providing an input as the temporal information becomes clearer.

A quantitative and qualitative data analysis approach as used by Sullivan et al. (2011) was adopted to analyse the data, but instead of differentiating between the expertise of the participants, the availability and impact of equipment (MFD) was studied. In order to establish visual scan patterns, the raw eye tracking data needed to be simplified for visual analysis (Goldberg and Helfman, 2009; Peysakhovich and Hurter, 2018). This is because heat maps show the area of a participant's focus (Hareide and Ostnes, 2018), whereas gaze plots show fixation points as circles, with their diameter increasing according to the number of fixations in each location. The order of fixations is obtained when the scan path is played back, necessitating aggregation of the data gathered in various formats.

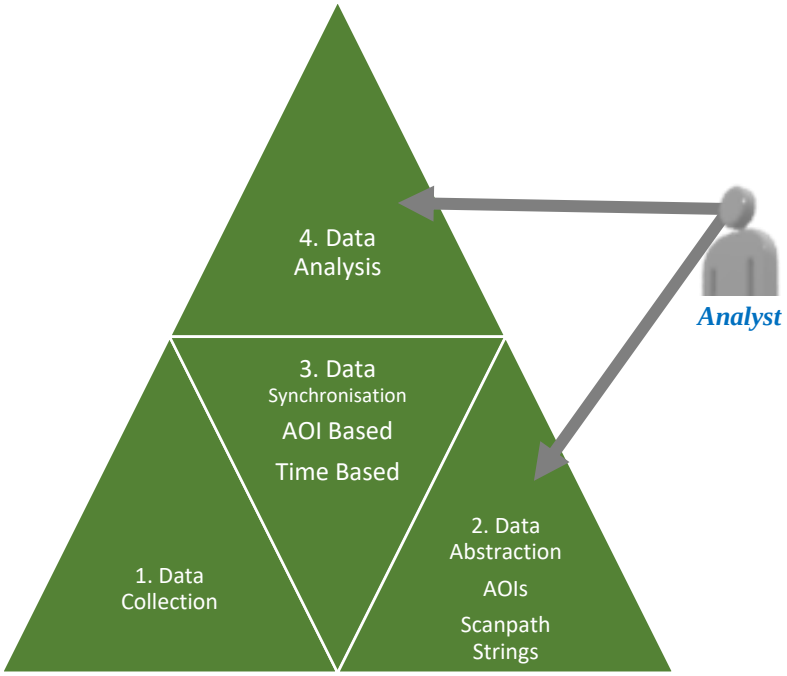

Figure 17 - ETD Data Triangulation

In essence, neither the heat maps nor gaze plots provide an easy-to-understand output due to large, cluttered areas after about 10-15 fixations. Therefore, once the data was analysed through triangulation, infographics were used to create line charts together with visual analysis of the scan path (see Appendix 3: Scan Path Data). As a consequence of this, quantitative analysis consisted of application of a visual aggregation technique (Peysakhovich and Hurter, 2018) to make it possible to reduce visual clutter and provide a mathematical basis for scan path comparison.

The visual aggregation technique was applied as follows for qualitative analysis of the captured data:

- Scan Path Strings from BeGaze output were converted to compressed scan path strings to cluster fixations, also known as dwell-based representation (Holmqvist et al., 2011)
- Compressed scan path strings were then coded into SPSS to assign X and Y axis to each component of the AIO, e.g., A1, B2, C3, D4, … H8 from A to H and 1 to 8 AOI blocks was coded to 11, 22, 33, 44, … 88 and so on.
- To avoid cluttering of the line chart, the scan path for each participant was observed for only the first and final 3 minutes but the first 10 fixations were plotted (shown in Appendix 3: Scan Path Data).
- A line chart was then drawn for each participant in each experiment phase.
- The line chart was observed together with **qualitative analysis** through visual observation of the live BeGaze scan path in the same time period to deduce comments tabulated in Appendix 3: Scan Path Data for each data collection phased S1 through to S3.

Based on the above, scan paths for participants in all experiment phases were compared using a similarity map approach (Le Meur and Baccino, 2013) based on the ‘Euclidean geometry fact’ that two objects are similar if they have the same shape, or one is the mirror image of the other, which may be determined by enlargement, rotation, reflection or reduction of the first shape. The objective for this research was to establish:

- If any common features existed in the scan patterns applied by experienced seafarers.
- If there was an existing a scan pattern, were there any distractions caused by MFDs and their impact?
- A comparison of scan pattern data with heat maps to validate both.

From initial research, it was established that the watchkeepers did not apply any consistent scan pattern to scan the horizon during their time on the bridge (S1: No Equipment) on real ships (S2) and the MFDs caused distractions during lookout periods (S3: with MFDs). The participants in the fourth (S4: Simulation with CCD) and fifth (S5: Simulation with CCD on NAESTO) phases were provided guidance to follow the given WWS pattern. The assessment, therefore, is restricted to assessing only the areas given in the next paragraphs removing the need to deduce results for fixation clustering, saccade bundling, and generation of flow direction maps, as suggested by many researchers (Santella and DeCarlo, 2004; Duchowski et al., 2010; Goldberg and Helfman, 2010; Lhuillier et al., 2017; et al., 2014; Peysakhovich, 2018).

The combination of qualitative and quantitative data analysis provided the following results:

1. S1, S3 scan paths show that participants' gaze moved haphazardly, jumping from one AOI to another without following any sequence. 60% (9/15) participants spent majority of their time on two AOIs (visual screens).

2. S2 scan paths on real ships validate the scan pattern data captured in the simulator due to a similarity in participants' scan paths, which remained random both in simulators (S3) and on real ships (S2). However, an equal amount of time was spent on visual screens and MFDs by participants in S2 and in S3.

3. S4 shows four out of five participants followed the author's guidance on scan pattern. This is evidenced in both the heat map and scan path extracts shown in Appendix 3: Scan Path Data. In S5, results were less favourable than in S4, despite having provided the briefing. Nevertheless, S5 results were an improvement on S3, which was expected because the participants in S5 were on a different simulation scenario due to being part of their NAESTO course.

4.6 Concluding Remarks

Chapter 4 commences with establishing STCW requirements for maintaining lookout while performing watchkeeping duties on a ship's bridge. It establishes that neither the STCW Code nor any other guidelines for watchkeepers define the term 'proper lookout'. The author then defines this term, which forms the basis of the guidance provided to research participants prior to data collection in the later stages of this project to see improvement in their lookout behaviour. This guidance is developed further into the WWS method of maintaining a lookout. For the sake of completeness, the chapter further looks into the structure of the human eye to investigate and provide solutions for maintaining a proper lookout at night and the impact of illumination on bridge on achieving and maintaining dark adaptation. Finally, the outputs of scan path data collected during the study are analysed and discussed.

Chapter 5: Implementing CCD Concept

5.1 Introductory Remarks

The concept of e-Navigation, i.e., '*the harmonized collection, integration, exchange, presentation and analysis of information by electronic means*' is aimed at enhancing safety of navigation (IMO, 2015, 2018). The complications presented by the international nature of ship building, design and operations makes it very difficult to apply the e-Navigation concept in the exact prescriptive same manner due to, for example, grandfather clauses that allow ships of the 'old' design to continue to operate for a significant time period. The irony of the current 'state of the nation' with respect to both 'bridge design' and the 'human factor' is the lack of user input into modern bridge design to understand how and where information overload (Jaeyong et al., 2016) occurs, as well as what exactly the user needs for problem solving in collision avoidance situations. This chapter explains how the author of this thesis implanted the CCD concept for evaluation of the proposed changes to the MFD design onboard ships.

5.2 Participant Questionnaire Analysis

In order to overcome the issues arising from a lack of user input into the bridge equipment layout, particularly presentation of information on MFDs, a questionnaire-based survey involving 67 experienced seafarers was conducted as part of this research. Based on contributions from the survey participants, the author proposes the use of a CCD or 'Maritime Six Pack' similar to the 'aviation six pack' through a CCD for each equipment display, showing only the vital information required for collision avoidance or navigation.

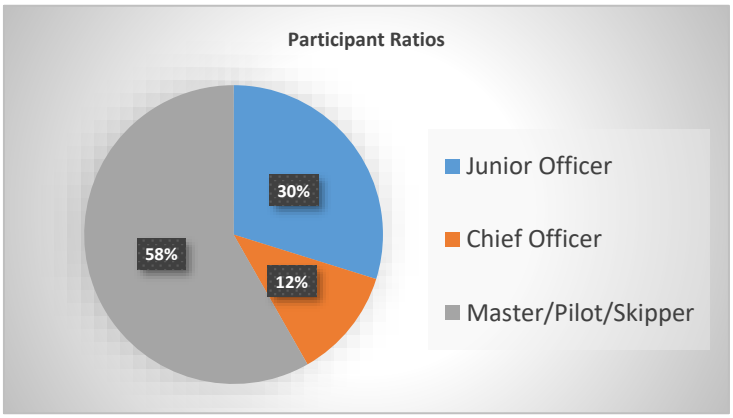

Figure 18 - Participant Ratio

This CCD concept was implemented in bridge simulators in response to the feedback received from the survey participants, who comprised 58% masters, 12% chief officers and 30% junior officers (Figure 18). The analysis shows shockingly low scores of 10.4% of the participants 'visually' checking the vessel surroundings to verify other vessels' location in relation to their own ship. Only 4.5% of the participants indicated that they would physically verify prevailing visibility when taking over their watch. These facts confirm the author's observation during simulator training that today's watchkeepers are forgetting their primary task, i.e., maintaining a lookout by sight, and now appear to be more focused on the use of equipment (Radar/ARPA/ECDIS) to update their SA.

A staggering 58.2% of participants claimed that the multiple interfaces of the bridge equipment made them question their decision-making, with 52.2% claiming that it distracted them from completing their primary task. Additionally, the feedback confirmed the following:

- Duplication of information due to being unable to distinguish between urgent and non-urgent information requires them to go through the various menus on each piece of equipment to find the relevant information. This time, according to them, could be better utilised for performing other tasks. Further, information overload can result in watchkeepers either becoming overwhelmed or over reliant on bridge equipment (Jaeyong et al., 2016; Costa et al., 2018). This appears to have resulted in diminished use of

physical watchkeeping tools, such as visual lookout supported by binoculars.

- There is 'a lot of equipment to monitor', with too much technology and too many alarms. Some participants commented that due to a large number and frequency of alarms, they simply reset them, ignoring what triggered them. This is a critical fact that must not be overlooked by decision makers in the design, development and approval of bridge equipment. This is further evidenced by some 70.1% of participants stating that decision making in close-quarter situations is harder when bridge equipment is showing multiple warnings and alarms. It is worth noting that this response was received from 55.7% of masters, 14.2% of chief officers and 30.1% of junior officers. 65.7% of participants confirmed their agreement with the opinion that the alarms and warnings provided by bridge equipment can lead to human error. This is particularly concerning because the master, who may need to make decisions when called by an OOW, will have very little time to assess the situation and take action to avoid a close-quarter situation or a collision.
- Over reliance on e-Navigation (IMO, 2018) seriously affects decision making. Clusters of cluttered and irrelevant layers of information could be a risk factor on its own (Costa et al., 2018).
- With multiple MFDs, the need to look out of the bridge windows is completely forgotten because the watchkeeper needs to check and verify the information, e.g., the CPA calculated by ARPA and second ARPA compared with that computed by AIS. If a target is tracked in all these systems, the alarms will have to be attended to in all three of them. This takes away valuable time from the primary task of maintaining a lookout.
- Additional time is required for new watchkeepers to become familiar with all alarms.
- Setting up and amending alarm parameters on all equipment to be monitored, while they may not be required at all.
- The bridge equipment is designed and installed for the convenience of technician and installer and not to improve the efficiency of navigation. This statement was made despite the fact that 80.6% of the participants agree that

the current level of bridge equipment utilising modern technology aids decision making for collision avoidance, and a further 88.1% agreeing that the technology on the bridge is provided to facilitate the watchkeepers' job.

- Technological advancements mean new equipment and therefore more MFDs.
- The OOW may ignore what they cannot see on MFDs.
- If the bridge has an integrated system, the most relevant information can be placed on one or two displays.
- Current bridge environment rarely indicates prioritisation or hierarchy of alarms and alerts.

Some participants commented in support of the current provision of information displays on the bridge in their current format. For example, it was commented that:

1. Multiple information resources, e.g., ARPA and AIS allow for full evaluation followed by corroboration of opinion in the decision-making process, allowing the information presented to be cross checked.
2. ARPA overlay on ECDIS facilitates combining collision avoidance with navigation, i.e., all information available in one place.

Some participants stated that the watchkeeping officer must always be in control. For example:

- when deemed necessary, they should be able to 'mute all alarms' for a brief period of time to focus on prioritised task(s).
- Instead of providing a generic interface, the user should be given the option to choose an interface on the basis of circumstances.

Based on the user feedback summarised above, it is evident that watchkeepers would favour the CCD concept presented here and discussed in the next sections of this chapter.

5.3 Radar/ARPA CCD

A total of 86.6% participants considered Radar/ARPA to be the most important equipment for collision avoidance, with 10.4% opting for ECDIS and 3% for VHF. Amongst these, 92% of Masters were in favour of Radar/ARPA as the most important

equipment for collision avoidance, with the remaining 8% favouring ECDIS. Surprisingly, all of the chief officers favoured Radar/ARPA, whereas 40% of the respondents amongst junior officers favoured ECDIS.

These results provided two areas to investigate further: (1) does Radar/ARPA readily provide the required information when it is needed? (2) does it burden the user's cognitive ability to such an extent that they are distracted from other tasks while informing their SA from this display? These areas were analysed through ETD data collected and indicate that MFDs significantly reduce the amount of time watchkeepers spend on maintaining a physical lookout.

Confirmed by the survey, 61.2% of the responses showed CPA to be the most important information for collision avoidance, with 25% asking for target identification, 6% participants expressed an interest in knowing TCPA, 1.5% wanted to know target course and range and 4.5% went for target bearing as their first choice for the most important collision avoidance information. Finding that 61% of the Masters wanted to see the CPA as their first priority was not surprising at all, with 4.5% of them going for target bearing and only one opting for target course. This result is validated by the response of 94% of the participants confirming the use of ARPA/Radar/CPA to gain SA when taking over a watch.

There appears to be consistency in the responses on the most important information for collision avoidance, with 77.6% in favour of the Radar/ARPA for course and speed through water. However, 17.2% of participants favoured Course and Speed Over Ground for collision avoidance. This now confirms, from a user perspective, that Radar/ARPA is considered to be the most important equipment for collision avoidance with target CPA and identification as the most important information for each target to be displayed.

These options are useful only when targets are acquired in ARPA. What about those targets that are not acquired, so would not show any target information? This is where the radar display showing disposition of traffic around the own ship, together with the target vectors, remains vital in establishing target movement on first sight. This, however, does not need to be permanently switched on to prod the watchkeeper to comply with IRPCS Rule 7 (b) Rule 7 Risk of collision, i.e., '*Proper use shall be made of radar equipment if fitted and operational, including long-range scanning to obtain*

early warning of risk of collision and radar plotting or equivalent systematic observation of detected objects'.

The IMO Performance Standards for Radar/ARPA provide some concise statements regarding their use, but they appear to have been lost, perhaps with the introduction of MFDs. For example, ARPA (IMO, 1995a) should reduce the workload of observers by enabling them to automatically obtain information so that they can perform equally well with multiple targets as by manually plotting a single target. Further, ARPA training (IMO, 1981) should ensure that the watchkeepers '*have knowledge of the possible risks of over reliance on ARPA*' and be aware that '*ARPA is only a navigational aid and that its limitations, including those of its sensors, make over-reliance on ARPA dangerous, in particular for keeping a look-out*'. Sadly, these performance standards appear to be being ignored by watchkeepers as the questionnaire analysis shows a low-ranked response in favour of maintaining a visual lookout. ARPA, in essence, is 'advisory' in its role; therefore, the information presented must be verified, where possible, by other means such as AIS or, even better, visually.

On the basis of this research, one proposed solution is to reduce the primary ARPA display to acquire all targets within, for example, a 12-mile range (to be selected based on traffic density) and provide CPA for the most critically threatening targets, defined by the OOW, along with target identification, as well as a Plan Position Indicator (PPI) of the targets around the own ship. When this is displayed, the additional information (display mode, on-screen controls for gain, clutter, brightness, own course and speed, vector mode, etc.) which will impact upon a watchkeeper's cognitive ability to search through a large quantity of information, can be temporarily hidden. This will have an additional benefit of diluting the light pollution discussed in Chapter 4: Visual Search Patterns. It should, however, be possible to turn on this information, e.g., by a touch of the display or click of a button in the case of a radar/ARPA CCD concept being presented here.

Another tool on the bridge that can potentially be used for collision avoidance is the AIS, which utilises GNSS for the vessel's speed and course over ground calculation. Not very surprisingly, none of the survey respondents chose AIS as their first choice for collision avoidance, which aligns with the fact that some Masters may choose to turn the AIS off, and some smaller vessels may not even be fitted with AIS. Nevertheless,

AIS is a vital tool that feeds information to ARPA to verify the most critical targets within the user-selected range. This can be achieved by modifying outputs from the existing AIS setup or introducing a new ship-based VHF location transmitter/receiver that is not permitted to be switched off as an AIS cam be. The VHF Data Exchange System (VDES) (Zhang et al., 2018), a system with such a capability, is already in advanced discussions at IMO and will become available in the near future.

When participants were asked about the location where the most important information for collision avoidance should be displayed, there was an almost equal split between those who wanted it to be shown on a separate console (CCD) (38.8%) and those who wanted it to be shown on the equipment itself (41.8%). 10.4% of participants favoured display of this information on ECDIS, whereas Augmented Reality (AR), i.e., overlaying the most important information on, for example, the bridge window attracted only 9% of the participants. Amongst those who favoured CCD, 69.2% of the respondents were Masters.

It can therefore be deduced that the majority of the participants (58.2%) were in favour of displaying vital collision avoidance information at a location other than the equipment itself. This, however, does not mean that the equipment itself will still continue to display all the information required to be displayed under IMO requirements, but outputs can be provided to display information on CCD. For example, displaying the ship's own course and speed on the ARPA display at all times is of very little significance. Such information can, therefore, be called upon only when required by the user.

Most participants appeared extremely satisfied that they can readily interpret the information shown on the current format of the ARPA display in critical navigational situations (92.5%) and that the display is suitable (91%). The AIS display was not favoured by 58.2% of the participants, expressing their dissatisfaction with its suitability to show the vital information required in critical navigational situations, but 55.2% confirmed the information is readily available.

The survey results confirm a lack of detail in the IMO performance standards with respect to information displayed on MFDs, allowing the manufacturers to choose different options. For example, the minimum size of the ARPA display (IMO, 1980) is 340mm, but the manufacturers have the option to make it larger, which they do but

keep the radar/ARPA display area limited to 340 mm and use the additional display to show optional information. Whilst this may be a good use of the technology, it does not ease the impact on the watchkeeper's cognitive ability through information overload and the ability to maintain good visual lookout, and add to more 'light pollution' on the bridge (see Section 4.2.2).

As discussed earlier, the RT to an auditory or visual stimulus and a voluntary response only happens when this information is held in the STM for 6-12 seconds. Retention of this information in STM defines whether the OOW will ultimately feed it into the required action or not. If, however, a distraction triggers another event, such as the OOW's focus shifting to other information, then information requiring action may be lost. It can thus be concluded that if the OOW is overwhelmed by the amount of information presented visually (or audibly), the decision-making is almost always likely to be affected due to fleeting attention span or lapses in the watchkeeper's ability to concentrate on a stimulus.

With current technology, it is not beyond basic electronic input/output re-configuration to select the required output from individual equipment or display and show it on CCD. A radar/ARPA CCD was developed as part of this research by using live video outputs from a simulator to an additional PC connected to a radar/ARPA display. This PC used Open Broadcaster Software (OBS) Studio software where the live video (Figure 19 top) was edited to display selected information as shown in Figure 19 (bottom).

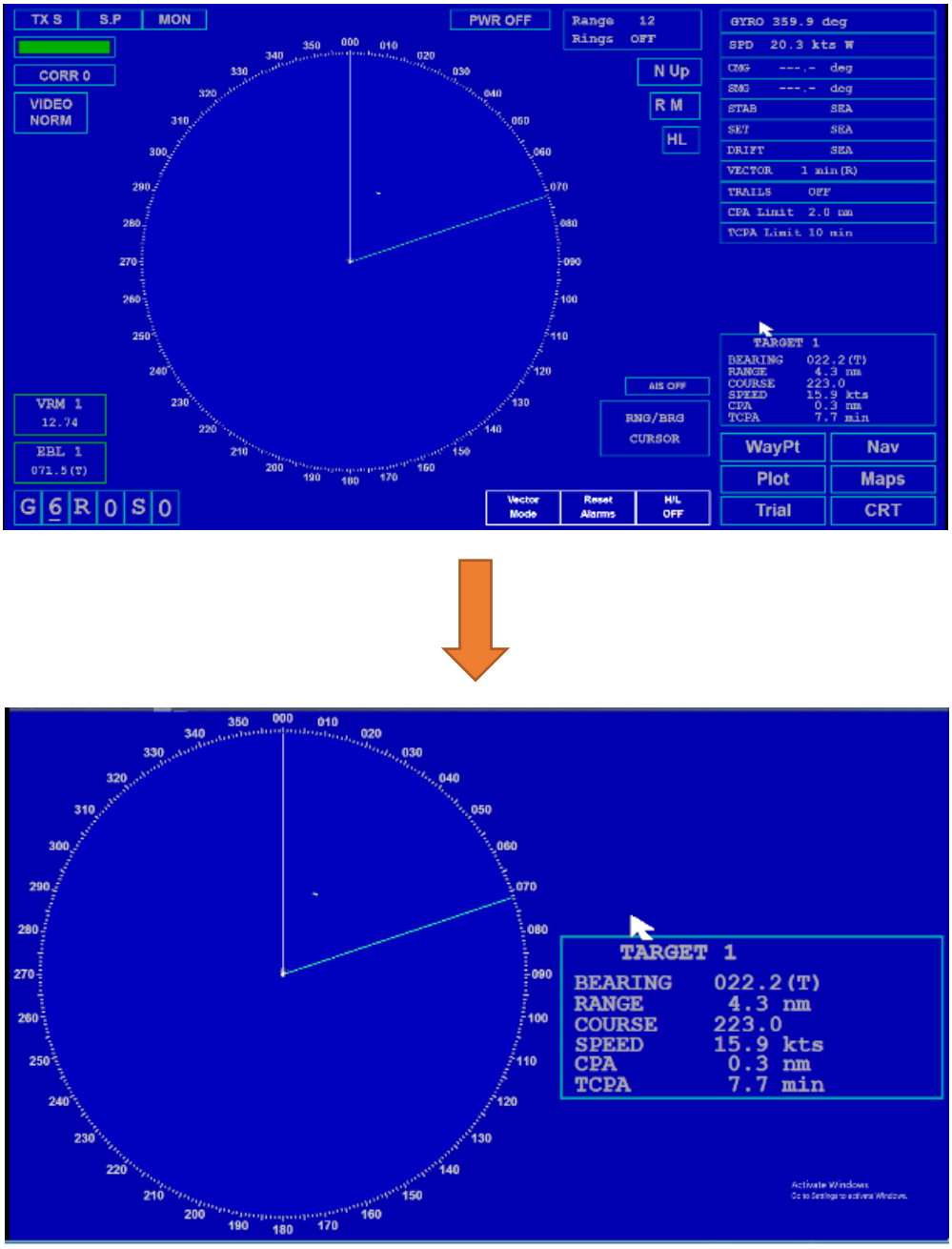

Figure 19 - Radar/ARPA Full Display (top), CCD Prototype (bottom)

5.4 ECDIS CCD

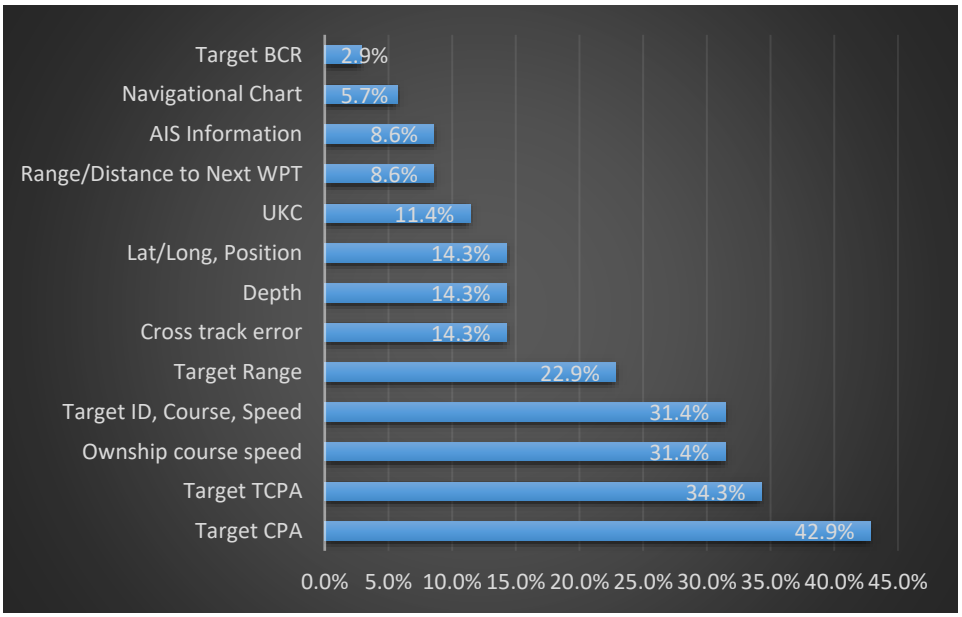

Figure 20 - Information to Display on CCD

When survey participants were asked about the usefulness of audio-visual equipment, particularly the information displayed on ECDIS and the display size, their responses were very varied. For example, 55.2% participants agreed that the size of the ECDIS display was suitable to show the vital information required in critical navigational situations, but 44.8% participants did not agree. 73.1% participants confirmed that they can readily interpret the information displayed on ECDIS display in current format even in critical navigational situations. Surprisingly, when asked if it would be better to show the most important information from ECDIS on the CCD, 52.2% responded yes whereas 47.8% were not in favour of this new concept. Those who were in favour of the CCD wanted the following information to be displayed on it (Figure 20):

- Own ship course speed - 31.4%.
- Cross track error - 14.3%.
- Under Keel Clearance (UKC) - 11.4%.
- Depth - 14.3%.
- Range/Distance to Next Waypoint (WPT) - 8.6%.
- Position (Lat/Long) – no one mentioned the GNSS position quality - 14.3%.

- Navigational Chart - 5.7%.

In contrast to 86.6% of participants choosing Radar/ARPA as the most important equipment for collision avoidance, only 10.4% opted for ECDIS as the first choice, but 47.8% selected ECDIS as their second choice. Amongst these, the Masters formed the highest proportion (59.4%) choosing ECDIS as a second option to Radar/ARPA (62.1%). This highlights a significant weakness amongst senior officers that 'ECDIS does not provide any collision avoidance information on its own but shows results of information obtained from Radar/ARPA or AIS'. Surprisingly, the AIS found its second place with 57.1% Masters whereas no junior/chief officer chose it as their first option for collision avoidance. It also seems that this distribution of choice of equipment varies with experience e.g., 9.5% junior officers, 23.8% Chief Officers and 57.1% Masters selected AIS as their second choice whereas it flows in almost reverse order for ECDIS where 18.8% junior officers, 9.4% chief officers and 59.4% Masters went for ECDIS as their second choice after Radar/ARPA.

Based on the survey results, it is evident that the information displayed on ECDIS also requires an overhaul. The current IMO (1995) Standards allow a significant volume of information displayed at all times with an option to remove certain information. However, the watchkeepers tend not to select from this information to suit their watchkeeping requirements as they appear not to appreciate the distractions that may be caused by non- essential information, or indeed the additional light pollution at night. No doubt, this information may be required at some point in time but is it all required at all times? 'The more the better' does not always work. Can this information be reduced, albeit temporarily, to facilitate improved SA?

If a comparison is made between the traditional paper charts used in conjunction with the existing bridge equipment, the chart shows the planned route along with positions plotted by the watchkeeper and a map of the area at a much larger 'size' than the current minimum display size (270 x 270mm) allowed by IMO (1995b) standards. Whilst ECDIS provides significant benefits during passage planning and execution stages, much of the information does not need to be displayed at all times. For example, the ECDIS CCD can show reduced information to display the map within a range chosen by the user, thus providing a larger, zoomed-in visual display (Figure 21). Again, in the same way as for ARPA CCD, the main display as required under IMO standards

can be turned on periodically, through a click of a button. Subsequently, the most significant information, e.g., Course to Steer (CTS), Course Made Good (CMG), Cross Track Error (XTE), Distance/Time to Go (DTG/TTG) to next WPT, chosen by the watchkeeper, can then be transmitted to the CCD.

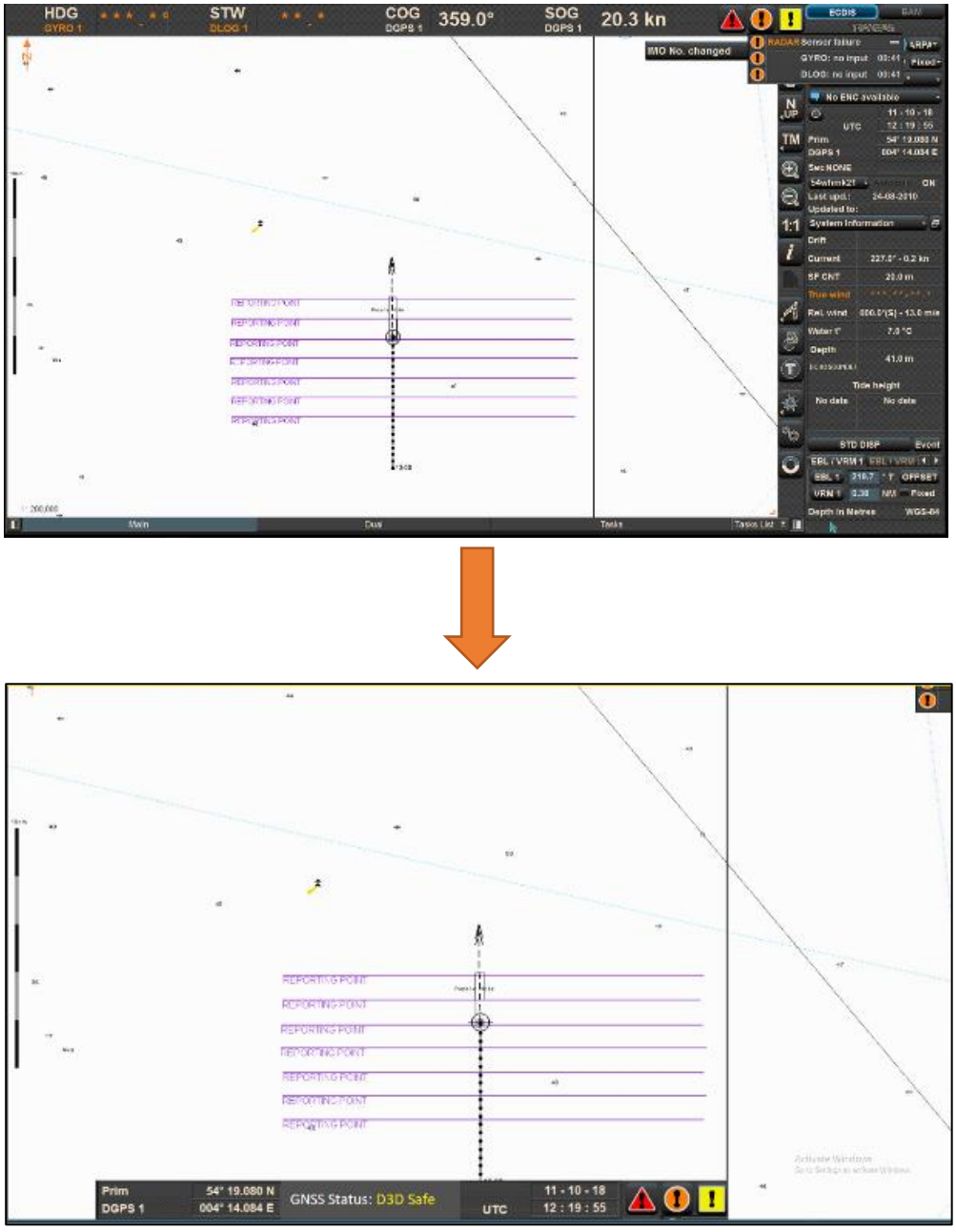

Figure 21 - ECDIS full view (top), CCD Prototype (bottom)

5.5 Conning Display CCD

Continuing with the hypothesis that multiple MFDs showing the same information cause distractions; that is, the same information on multiple displays and locations and in different styles has an impact on OOWs' cognitive ability. For example, the ship's course being steered is displayed on the steering console, conning display, multiple repeaters (justifiable in bridge wings), radar/ARPA, ECDIS and many more. Some of these displays, such as Radar/ARPA and ECDIS, may have repeater displays. This was also simplified for the conning display CCD in the simulator bridge, as shown in Figure 22.

The CCD prototypes for ECDIS, Radar/ARPA and Conning were implemented in the simulator bridges for acquiring data in data collection S4 and S5. Analysis of this data is discussed in Section 6.2.

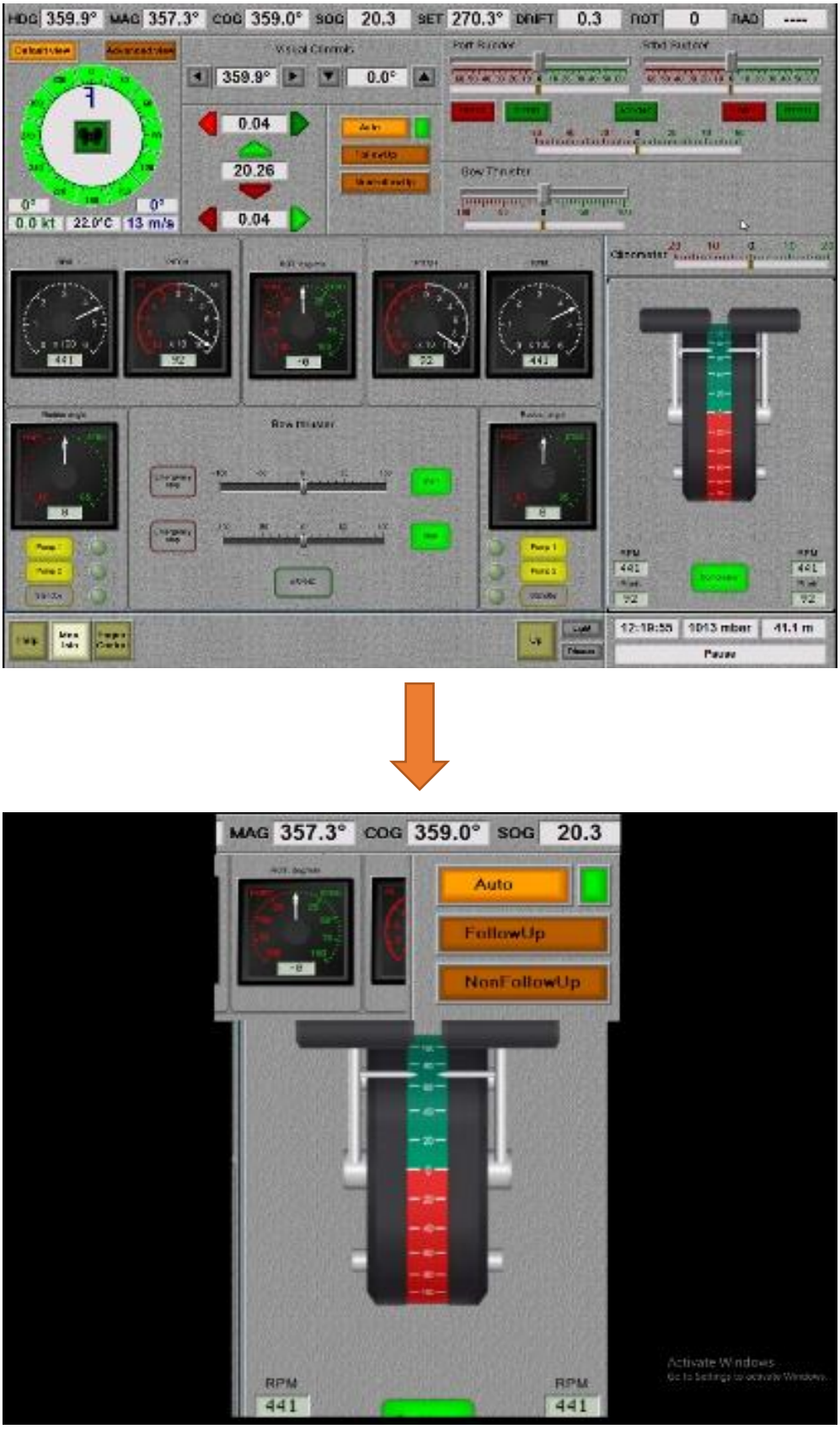

Figure 22 - Conning full display (top), CCD Prototype (bottom)

5.6 Concluding Remarks

This chapter provides analysis of the data captured through questionnaire (Appendix 7: Questionnaire) that was distributed to gauge user requirements for the information they would prefer to see on the MFDs for navigation and collision avoidance. It explains how the CCD prototype for all MFDs showing only the most important information to the watchkeepers was developed prior to data capture scenarios S4 and S5.

Chapter 6: Avoiding Distractions through CCD

6.1 Introductory Remarks

Eye movement controls fixations within AOIs, so is directly linked (Li et al., 2014) to participants' perceptual, cognitive and behavioural activities that underpin watchkeepers' need to seek relevant information. Fixations provide an insight into their attention allocation (Yu et al., 2014), whereas participants' attention shifting to different AOIs indicates multi-tasking, such as operating bridge equipment – or, in other words, being distracted from the primary task of maintaining a lookout.

At the same time, the distribution of a watchkeeper's fixation on important and relevant AOIs can be an indication of their expertise level (Koen et al., 2012), as well as their level of SA. On the other hand, higher attention to less significant AOIs indicates tunnel vision or poor appreciation of SA (Orasanu 2005, Shinar 2008). This comparison highlights the need to test these behaviours during watchkeeper training to mitigate adverse consequences. It is a concept that falls in line with Endsley's (1995a) three-level SA model (as discussed in Chapter 1: Introduction), where the watchkeeper collects and evaluates information, then formulates a solution to the situation presented; i.e., the OOW perceives and comprehends the current situation and runs mental predictive models about the likely outcomes (Hrvoje et al., 2021).

6.2 ETD Data Analysis

The ETD data was analysed in two distinct ways:

1. A sensitivity analysis of the captured data was carried out to ensure it complied with statistical data analysis standards. A full report on this analysis is given in in the next Section
2. Sensitivity Analysis.
3. Analysis of mean fixations and dwell times in various AOIs used during data capture with ETDs. This is given here in the section that follows.

6.2.1 Sensitivity Analysis

Eye tracking data is typically analysed quantitatively (Blascheck et al., 2017), applying statistical methods. As discussed in Section 4.5, the sequence in which the participants looked at the AOIs led to an understanding of patterns in the movement of their gaze during the experiment period (Blascheck and Ertl, 2014). A combination of multiple methods was applied using triangulation of data (Blascheck and Ertl, 2014) from gaze path, duration of fixations and saccades to gain a thorough insight into watchkeeper's behaviour (Saraiya et al., 2005; North, 2006; Gotz and Zhou, 2009; Gomez et al., 2014; Guo et al., 2016).

It is important, however, to compare and contrast other approaches to analysing eye tracking data to justify the approach adopted here for data analysis, where the data is collected, abstracted, synchronised and analysed, with the analyst providing an input as the temporal information becomes clearer.

Eye tracking data can be analysed (Blascheck et al., 2017) through one of the following eye tracking visualization techniques:

- Temporal – focusing on time, thus using the timeline as one axis. This is the case for data analysis in this report, where dwell time is plotted against each AOI in a line chart to compare dwell time on each AOI between various scenarios (see Figure 39)
- Spatial – makes use of the x, y and possibly z-coordinates of the data. This study also investigated the relationship between AOIs, i.e., comparison of the higher or lower impact of different AOIs (MFDs) on watchkeepers' attention to maintaining a visual lookout. This analysis provided for identification of the highest 'focused' AOI to isolate it as a 'distractor', thus requiring action to mitigate its adverse impact on visual watchkeeping.
- Spatiotemporal – This approach uses a combination of both temporal and spatial eye tracking visualisation techniques, in which temporal and spatial aspects are considered jointly to reach a conclusion. As elaborated above, neither a temporal nor a spatial approach on its own will suffice for the needs for this research, a spatiotemporal technique was considered the most suitable, and hence applied to gain the required results.

A number of other techniques considered suitable for this research include:

- Heat Map – amongst other options for analysing the eye tracking data, a heat map is an output provided by BeGaze which gives a very quick overview of the main area of the watchkeeper's attention. However, heat maps do not provide any details, as each AOI quickly becomes cluttered.
- Scan path visualizations – both scan paths and heat maps cause significant visual clutter within a short time, thus requiring alternative approaches to be sought.

For the reasons mentioned above, visual inspection of the scan paths was carried out for the first and final 3 minutes of the captured data, as detailed in Appendix 3: Scan Path Data.

The captured data has been statistically analysed in the following four steps:

1. Establish statistical model.
2. Normality test: This step was applied to the captured data to ensure it complies with statistical normality.
3. F-test: For equality of variances by assessing whether the two populations have the same variances or standard deviations.
4. T-test: This test was used to assess the significance of difference between the means of two groups but is typically applied when the research participant sample size is small, and the population standard deviation is unknown. In this study, however, the sample size is small, but the standard deviation is known, hence the T-test results are given in Appendix 9: Statistical Analysis Data.

An explanation of these steps is given in the next sub sections together with how results are compiled. It must be noted that the statistical analysis was carried out for the captured data rather than directly for the research hypothesis testing. The outputs from the captured data were however used to reach conclusions as required for this study.

6.2.2 Statistical Model

In this section, the statistical model outlining the approach used for analysing the eye tracking dataset is presented. A number of assumptions are incorporated for generation of sample data for eye tracking (Jhangiani et al., 2020) together with a characterisation of the population under study.

The statistical model consists of five datasets as below with the significance level for each set to 0.05 (5%):

1. S1: Phase 1: No Equipment (MFD) – Used as variable X with n number of participants.

   Based on the primary research question, i.e., 'understand the factors that divert OOWs' attention from the primary role of maintaining a proper lookout, thus ensuring situational awareness at all times', the first data set (S1) was used as the base line for comparison of other datasets (S2 to S5). This allowed for a measurement of distractions caused by various AOIs on the watchkeepers' ability to maintain a proper lookout.

2. S2: Phase 2: Real Ships – Used as variable Y_a with m_a number of participants.

3. S3: Phase 3: With Equipment (MFD) – Used as variable Y_b with m_b number of participants.

4. S4: Phase 4: With CCD – Used as variable Y_c with m_c number of participants.

5. S5: Phase 5: NAESTO Course – Used as variable Y_d with m_d number of participants.

In these datasets, the eye tracking matrices are based on identical eye tracking areas:

- X is an AOI for participants with no equipment (MFD) from dataset S1
- Y_a is the same AOI for participants on real ships in dataset S2
- Y_b is the same AOI for participants with equipment (MFD) in dataset S3, and so on.

- x_1 to x_n are the dwell times (%) for dataset S1 and y_{a1} to y_{am}, y_{b1} to y_{bm}, y_{c1} to y_{cm} and y_{d1} to y_{dm} are the dwell times (%) for S2, S3, S4 and S5 respectively.

As the comparison was made between dataset S1 and all other datasets (S1, S2, S3, S4), the variable and observation nomenclature is standardised from y to ya, yb, yc, yd and m to ma, mb, mc and md respectively, as shown in Table 4.

Table 4 - Statistical Model Data Presentation

Dataset 1 (S1)		**Dataset 2 (S2)**		**Dataset 3 (S3)**		**Dataset 4 (S4)**		**Dataset 5 (S5)**	
n Observations		m_a Observations		m_b Observations		m_c Observations		m_d Observations	
Variable	Observation	Variable	Observation	Variable	Observation	Variable	Observation	Variable	Observation
X_1	x_1	Y_{a1}	y_{a1}	Y_{b1}	y_{b1}	Y_{c1}	y_{c1}	Y_{d1}	y_{d1}
X_2	x_2	Y_{a2}	y_{a2}	Y_{b2}	y_{b2}	Y_{c2}	y_{c2}	Y_{d2}	y_{d2}
…	…	…	…	…	…	…	…	…	…
X_n	x_n	Y_{am}	y_{am}	Y_{bm}	y_{bm}	Y_{cm}	y_{cm}	Y_{dm}	y_{dm}

The data analysis involved computing means and standard deviations for each dataset for all AOIs to characterise the central tendency and variability of the data, using Microsoft Excel. These are given in Appendix 9: Statistical Analysis Data, the following assumptions were made for data analysis:

1. All variables and observations are independent and normally distributed random variables but normality in each group is tested separately as it is essential for testing for equal standard deviations (Hareide and Ostnes, 2017a). This assumption of normality within each group was examined as detailed in this section. Finally, it is tested whether the means are equal between the comparison groups, i.e., S1 to S2, S1 to S3, S1 to S4 and S1 to S5, for evaluating the outcome of the test for equality of standard deviations.
2. Normality is examined for each dataset to ensure data within each group is independently and identically distributed (IID) as detailed here.
3. $X \sim N(\mu x, \sigma x)$ for $1 \leq k \leq n$ ……6.1
   i.e. the variable X follows a normal distribution with mean μx and standard deviation σx.
4. $Yk \sim (\mu y, \sigma y)$ for $1 \leq k \leq m_{a...d}$ ……6.2
   i.e. variable Yk follows a normal distribution with mean μy and standard deviation σy for datasets S2, S3, S4, S5).
5. The following formulae were used in Microsoft Excel:
   a. Mean: μ_k = Average (data range)
   b. Standard Deviation: σ_k = STDEV.P(data range)

Within each dataset, the following parameters are estimated using the averages (means) and empirical standard deviations.

Mean S1:

$\hat{\mu}_x = \overline{x} = \frac{1}{n}[(x_1 + x_2 + \cdots + x_n)]$ or

$\hat{\mu}_x = \overline{x} = \frac{1}{n}\sum_{k=1}^{n} x_k$ ……6.3

i.e. the Sample Mean ($\overline{x}$) is equal to the sum of all x values divided by the total number of observations (n) for dataset S1.

Mean S2…S5:

$\hat{\mu}_y = \overline{y} = \frac{1}{m}\sum_{k=1}^{m} y_k$ ……..……6.4

Where:

- $\overline{x}$ and $\overline{y}$ are the sample means, which are the average values of set of observations $x_1, x_2, \ldots, x_n$ for dataset S1 and $y_1, y_2, \ldots, y_n$ for datasets S2 to S5 respectively.
- $\hat{\mu}_x$ and $\hat{\mu}_y$ are population means for dataset S1and S2 to S5 respectively and have been assumed to represent the population.
- n represents the number of observations in the sample
- x_k and $y_k$show the datapoints in the sample, e.g. x_1 is the first observation, x_2 is the second observation and x_n is the nth observation.
- $\sum_{k=1}^{n} x_k$ means adding all the x values from x_1 to x_n (same method for y values) which is then applied with $\frac{1}{n}$ i.e. divided by total number of n observations to calculate the mean.

Standard Deviation S1:

$\hat{\sigma}_x = \sqrt{\frac{1}{n-1}\left(\sum_{k=1}^{n}(x_k - \hat{\mu}_x)^2\right)}$ ……...……6.5

Where $\hat{\mu} = \frac{1}{n}[(x_1 + x_2 + \cdots + x_n)]$ and represents that the sample standard deviation ($\hat{\sigma}_x$) for dataset S1 is equal to the square root of the sum of the squared deviations of each data point from the sample mean, divided by $n-1$.

Standard Deviation S2 … S5:

$\hat{\sigma}_y = \sqrt{\frac{1}{m-1}\left(\sum_{k=1}^{m}(y_k - \hat{\mu}_y)^2\right)}$ ……...6.6

Where $\hat{\sigma} = \frac{1}{n}[(y_1 + y_2 + \cdots + y_n)]$ and represents that the sample standard deviation ($\hat{\sigma}_y$) for datasets S2 to S5 is equal to the square root of the sum of the squared deviations of each data point from the sample mean, divided by $n-1$.

6.2.3 Normality Test

For this research and the associated data analysis, it has been assumed that X1, X2, X3 … Xn are random variables for each scenario (S1, S2, S3 … S5) of observations Y_{a1}, Y_{a2}, Y_{a3} … Y_{an}. Therefore, the hypothesis for normality needs to be tested, i.e., whether the 'null hypothesis' is true. This is done by checking if there is a relationship between the two dataset variables, e.g., S1 vs S2 or S1 vs S5 through testing H0 (normal probability distribution) against H1 (not normal distribution). If a relationship exists between H0 and H1, then an alternative hypothesis must be developed, which was not required for this study as the data complied with normality requirements.

The test for null hypothesis was carried out through a normality plot for each combination of datasets, i.e., S1-S2, S1-S3, S1-S4 and S1-S5. Based on the above, the calculations were carried out and normality plot generated (Figure 23 – Figure 28) using Microsoft Excel as below:

1. Calculated z-scores for each dwell time percentage in AOIs using the formula:

$$z = \frac{x - \mu}{\sigma}$$

   where:

   x = data point (e.g. cell B2 in Microsoft Excel)

   μ = mean of dataset

   σ = standard deviation of the dataset

   z = z-score

   The z-score calculation allowed an understanding of the measure of standard deviations for a particular data point above or below the mean of a dataset to see how far away it is from the mean.

2. The cumulative probability (qk) corresponding to the z-scores was then calculated using the formula below in Microsoft Excel:

   qk = NORM.S.DIST (Z_score,TRUE).

   qk provided an indication of the probability that a randomly selected observation from a standard normal distribution is less than or equal to the z-score.

3. Since Microsoft Excel does not directly generate normality plots, a scatter plot was created by using the z-score values on one axis and the original 'Dwell time [%]' data on the other axis to visualize the relationship.

4. Correlation between cumulative probabilities (q values) for the k^{th} observation (qk) and the original time data (o values) was then calculated using the CORREL function in excel with the following formula:

   CORREL (q_k_column, original_data_column).

   The correlation coefficient between two datasets quantifies the strength and direction of the linear relationship between the two variables. It ranges from -1 to 1, where:

   - 1 indicates a perfect positive linear relationship.
   - 0 indicates no linear relationship.
   - -1 indicates a perfect negative linear relationship.

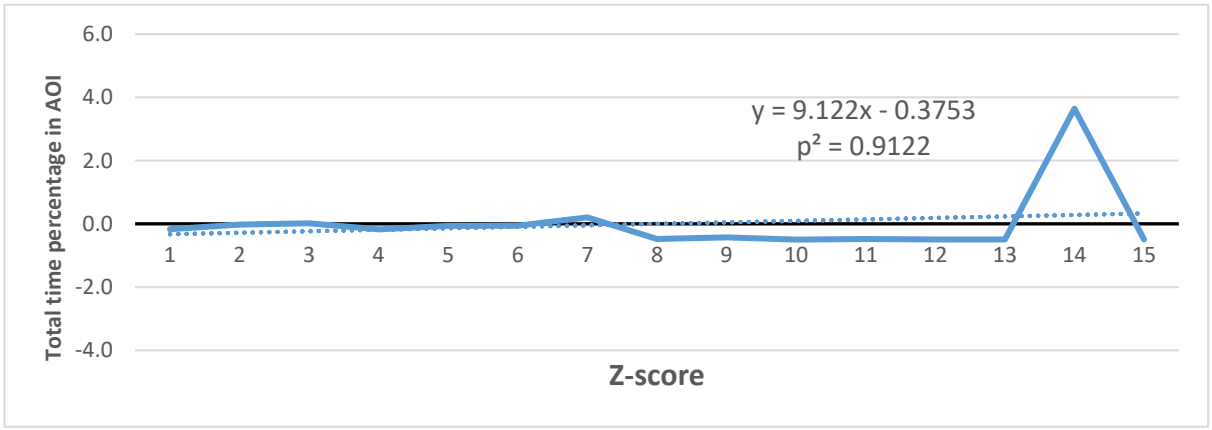

Figure 23 - S1: No Equipment Normality Plot

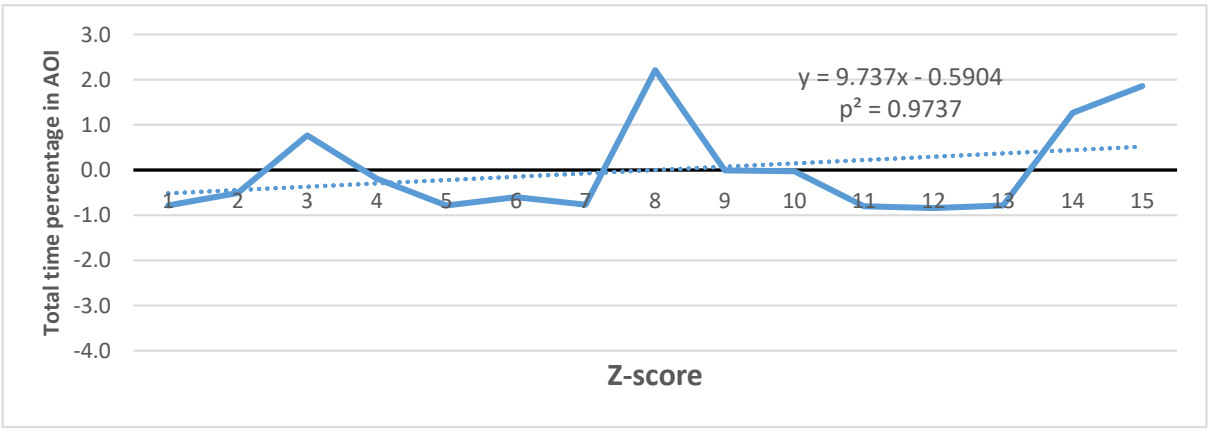

Figure 24 - S2: Real Ships Normality Plot

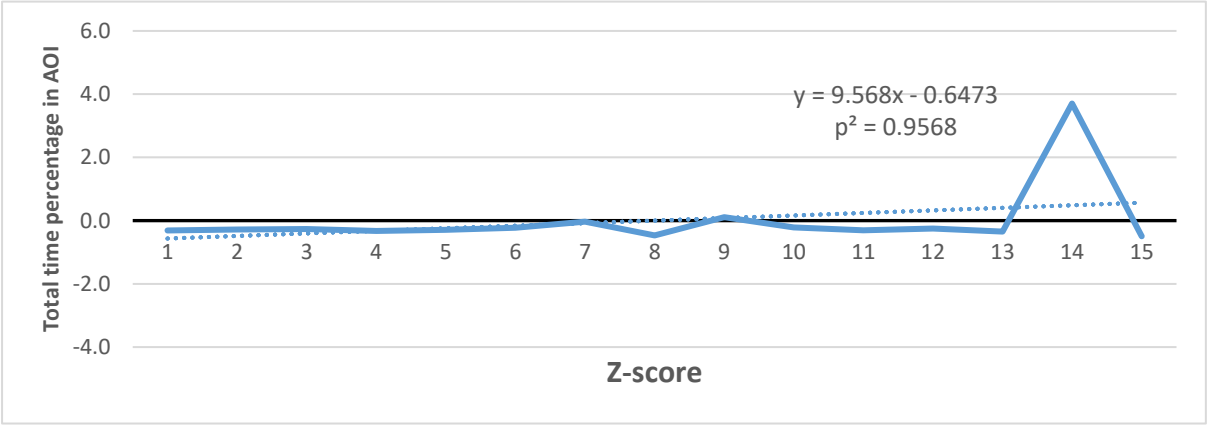

Figure 25 - S3: With Equipment Normality Plot

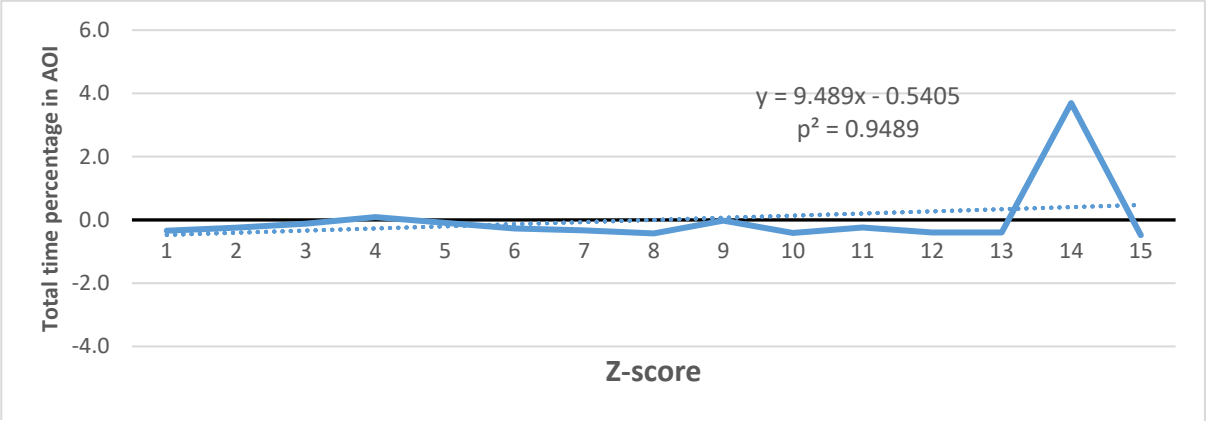

Figure 26 - S4: CCD Normality Plot

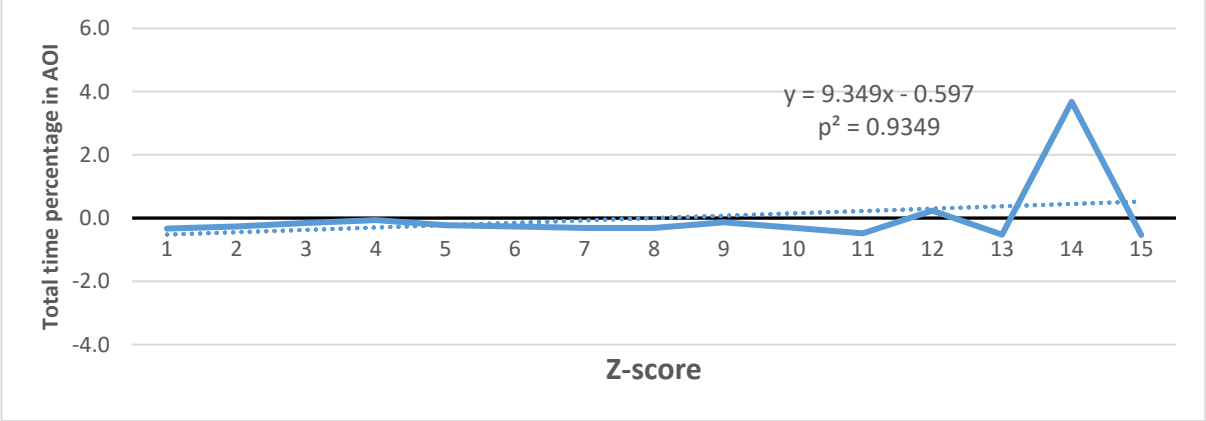

Figure 27 - S5: NAESTO with CCD Normality Plot

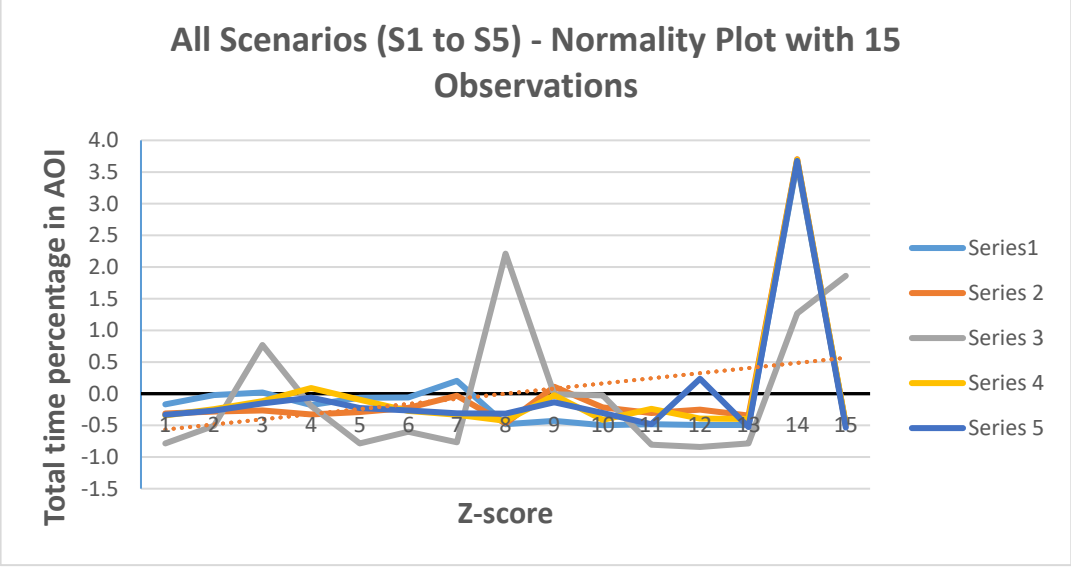

Figure 28 - All Scenarios Normality Plot

6.2.4 F-Test

The F-test of equality of variances is a test to assess the null hypothesis (H_0) for two populations to have the same variances or standard deviations. For the datasets (S1, S2, S3, … S5) being analysed in this study, the ratio of two sample deviations were tested one sample at a time, i.e., S1-S2, S1- S3, S1-S4 and S1-S5. i.e. the population standard deviations (σ) of two independent samples or populations, x and y were compared. The null hypothesis (for F-test) states that there is no significant difference in the population standard deviations between the two groups.

$$H_0: \sigma x = \sigma y \; against \; H_1: \sigma x \neq \sigma y \quad \ldots\ldots\ldots\ldots 6.7$$

H_0 states that the population standard deviations (σ) of the two groups are equal whereas H_1 states that the population standard deviations (σ) of the two groups are not equal.

This hypothesis test was conducted to assess whether there is enough evidence to reject the null hypothesis (H_0) in favour of the alternative hypothesis (H_1). The test results (given in Appendix 9: Appendix 9: Statistical Analysis Data) show a p-value > 0.05, so the null hypothesis (H_0) is not rejected i.e. there is no significant difference in the population standard deviations between any two groups i.e. S1 vs S3, S1 vs S4 and S1 vs S5. However, the F-Test one-tail p-value for S1 vs S2 is 0.000001386 i.e. <0.05, this is an indication against the null hypothesis in favour of the alternative hypothesis.

The Microsoft Excel built-in 'Data analysis toolpak' was used to perform the F-test. This enables a check for the equality of deviations between any two given data sets (S1-S2, S1- S3, S1-S4 and S1-S5). The procedure conducting F-test using Microsoft Excel included the use of the formula below to calculate the F-statistic:

$$f_{obs} = \frac{\widehat{\sigma_1}^2}{\widehat{\sigma_2}^2}$$

i.e. the observed/calculated F-Statistic (f_{obs}) value is calculated as the ratio of the squared sample variances of the two groups ($\widehat{\sigma_1}^2 \; and \; \widehat{\sigma_2}^2$).

The result of the findings of the F-test are summarized in the equation:

$$\text{p-value} = \begin{cases} 2 \, . \, P \, (F \leq f_{obs}), if \; f_{obs} < 1 \\ 2 \, . \, P \, (F \geq f_{obs}), if \; f_{obs} > 1 \end{cases}$$

The p-value is calculated based on the observed F-Statistic (f_{obs}). If it is less than 1, the p-value is twice the probability of an observing an F-statistic less than or equal to f_{obs}. If f_{obs} is greater than 1, the p-value is twice the probability of observing an F-statistic greater than or equal to f_{obs}.

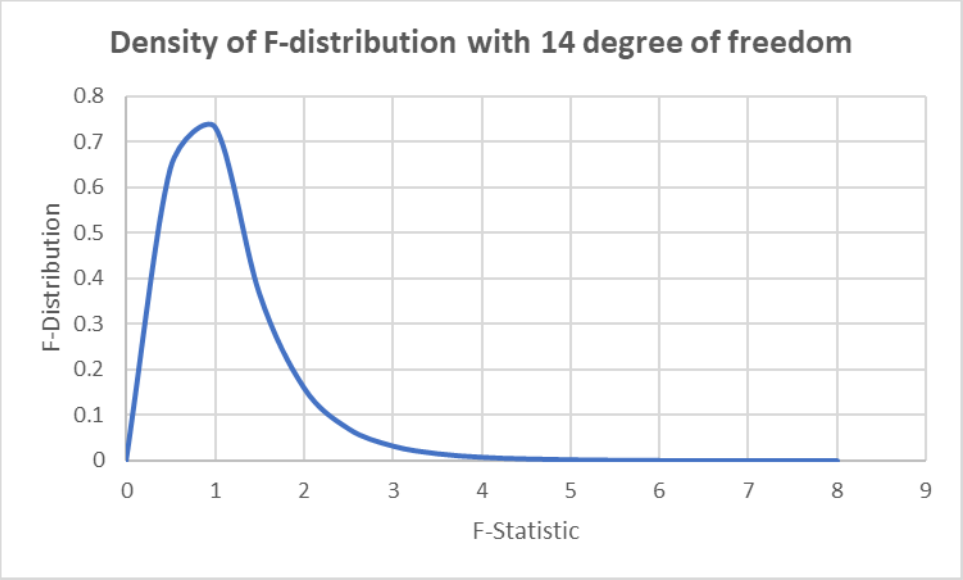

Figure 29 - Density of F-distribution with 14 Degrees of Freedom

Fisher's distribution or F-distribution was also plotted (**Error! Reference source not found.**) to analyse variances using two degrees of freedom – df1 (S1) and df2 (S2, S3, S4, S5) with p-value = 0.05. All F-distribution values were > 0.05, therefore it was used to accept the null hypothesis H0.

6.2.5 Limitations of the Model

Statistical modelling is a mathematically deduced, statistically arranged technique to approximate certainty/truth. The model is generated from the underlying data captured during this research, which helps in forecasting further results. The statistical model outlining the eye tracking data captured during the study described here encapsulates a set of assumptions regarding the capture of eye tracking data and the population in use.

For various reasons, including the Covid-19 pandemic as well as the availability of experienced seafarers within simulators and availability of real ships to capture data presented some challenges. Whilst it is appreciated that the number of participants could be higher, the participant numbers are considered acceptable for comparable research (Yaneva et al. 2022).

This study has used a significance level (p values) of 5% (0.05), which was based on the American Statistical Association (ASA) statement (Benjamin et al., 2018) that '*the widespread use of statistical significance (generally interpreted as p≤0.05) as a license for making a claim of a scientific finding (or implied truth) leads to considerable distortion of the scientific process'*. The objective for research underlying this report was to assess if the evidence against the null hypothesis is sufficient to compare against an acceptable standard i.e. p≤0.05, which was the case and hence outputs were deemed to be acceptable.

6.2.6 Model Validation

The reliability of a statistical model is attributed to the consistency of the outputs so that the same experiment can be repeated under similar conditions to produce comparable results (Kane and Mislevy, 2017), making it possible to forecast further outcomes. In order to achieve this, however, the variables must be controllable. If this cannot be done, as is the case of capturing data in S2 on real ships, the reliability is questionable. This is evidenced by outputs obtained for Mean, Variance, P(T<=t) one-tail, P(T<=t) two-tail and P(F<=f) one-tail values for the real-ship dataset S2. Nevertheless, this data is 'valid' on its own, but as the variables, i.e., the AOIs for Real

Ship (S2) are not exactly the same as for the datasets S1, S3, S4 and S5, the outputs appear skewed.

6.3 Fixation Comparison

The raw averages of mean fixations for the five data collection exercises given in Table 9 and Figure 34. The analysis from these outputs is given in the sections below.

6.3.1 Mean Fixations for S1 (No MFDs) vs S3 (with MFDs)

The graph in Figure 30 shows a comparison of the mean number of fixations between the simulation without any MFDs (S1) and the simulation with all MFDs switched on and available (S3), as required during normal training and watchkeeping. The results indicate that when MFDs were made available, the total fixation duration on visual screens reduced from 613.3 to 294.2 in the selected 5 minute interval; i.e., reduced by 48% (100 x 294.2/613.3).

The findings were as per the hypothesis given in Section 3.4 and shown on the next page in Table 5.

S1D = 0. i.e., in S1, there were zero distractions caused by MFDs as they were all blanked out.

Table 5 - Mean Fixations for S1 (No MFDs) vs S3 (with MFDs)

Fixations – Windows	**Fixations – MFDs**	**Actual Mean Fixations (ms)**	
S1 FW = Max	S1 FM = 0	S1 FW = 613.3	S1 FM = 34.86
S1 FW > S2 FW, S3 FW, S4 FW, S5 FW	S1 FM < S2 FM, S3 FM, S4 FM, S5 FM	S2 FW = 164.5	S2 FM = 243.6
		S3 FW = 294.2	S3 FM = 260.4
		S4 FW = 344	S4 FM = 156.6
		S5 FW = 401	S5 FM = 349.8

Comments:

The results under 'Actual Mean Fixations' obtained from data capture show that the sub-hypothesis for S1 vs S1, S2, S3, S4, S5 was correct.

Abbreviations:

FW/DW Fixations Windows/Dwell Time Windows FM/DM Fixations MFD/Dwell Time MFD

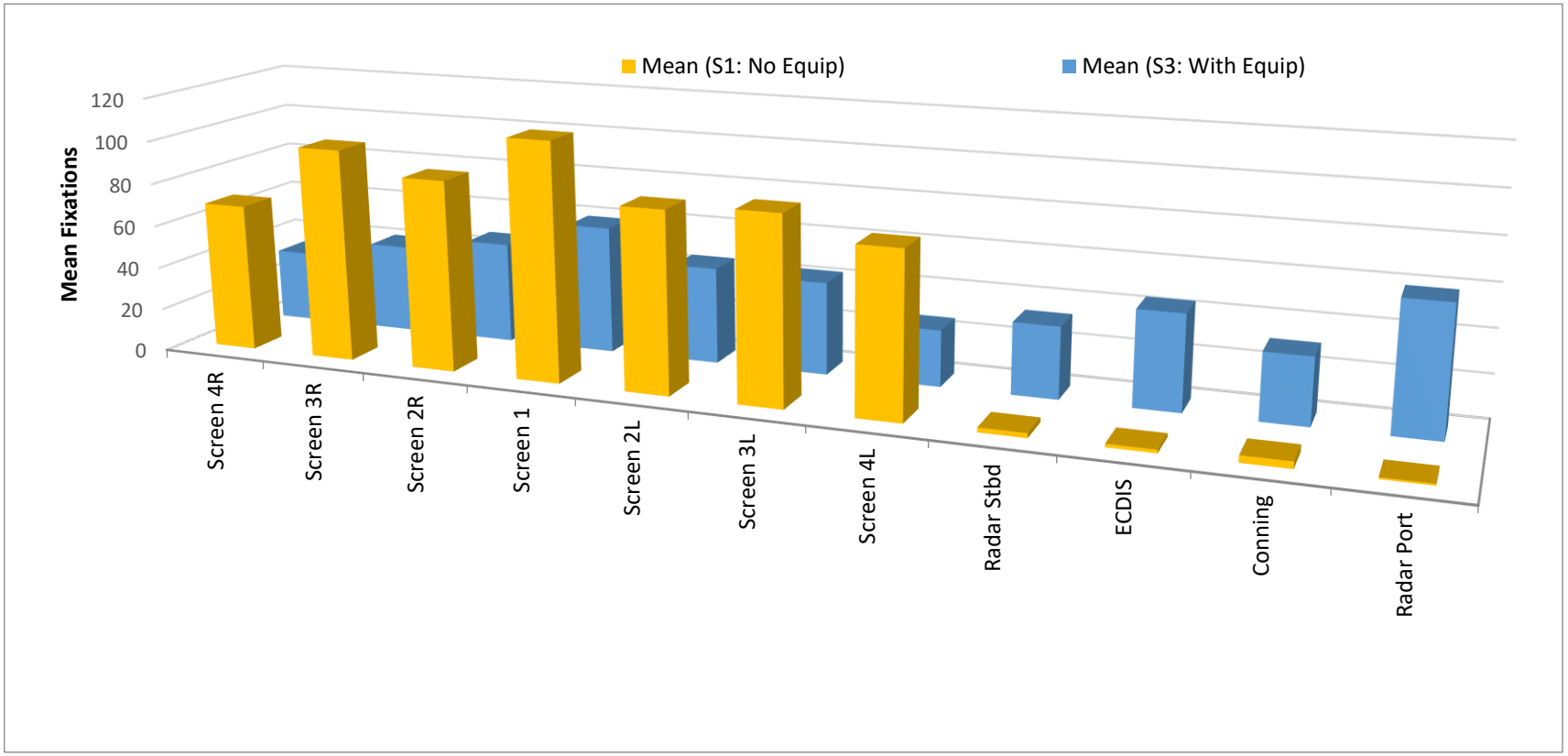

Figure 30 - Mean Number of Fixations for S1: No MFDs Vs S3: with MFDs

6.3.2 Mean Fixations for S3 (With MFDs) vs S4 (CCD)

Here, a comparison is made between the number of fixations during the simulation with all MFDs available (S3) and when MFDs were modified by CCDs (S4). The number of fixations on visual screens in S4 was higher with CCDs (344) in comparison with S3 MFDs (294.2), as shown in Figure 31. This indicates that the level of distractions caused by MFDs and CCDs was reduced and more time was spent on visual screens.

This is not withstanding the fact that participants were switching to full MFD on ECDIS, Radars and Conning display for long-range scanning and then reverting to CCD. This data therefore shows an improvement through the use of CCDs.

The findings were as per the hypothesis given in Section 3.4 and shown on the next page in Table 6.

S1D = 0. That is, in S1, there were zero distractions caused by MFDs as they were all blanked out.

Table 6 - Mean Fixations for S3 (With MFDs) vs S4 (CCD)

Fixations – Windows	**Fixations – MFDs**	**Actual Mean Fixations (ms)**	
S1 FW = Max	S1 FM = 0	S1 FW = 613.3	S1 FM = 34.86
S3 FW < S4 FW	S3 FM > S4 FM	S2 FW = 164.5	S2 FM = 243.6
		S3 FW = 294.2	S3 FM = 260.4
		S4 FW = 344	S4 FM = 156.6
		S5 FW = 401	S5 FM = 349.8

Comments:

The results under 'Actual Mean Fixations' obtained from data capture show that the sub-hypothesis for S3 vs S4 was correct.

Abbreviations:

FW/DW	Fixations Windows/Dwell Time Windows	FM/DM	Fixations MFD/Dwell Time MFD

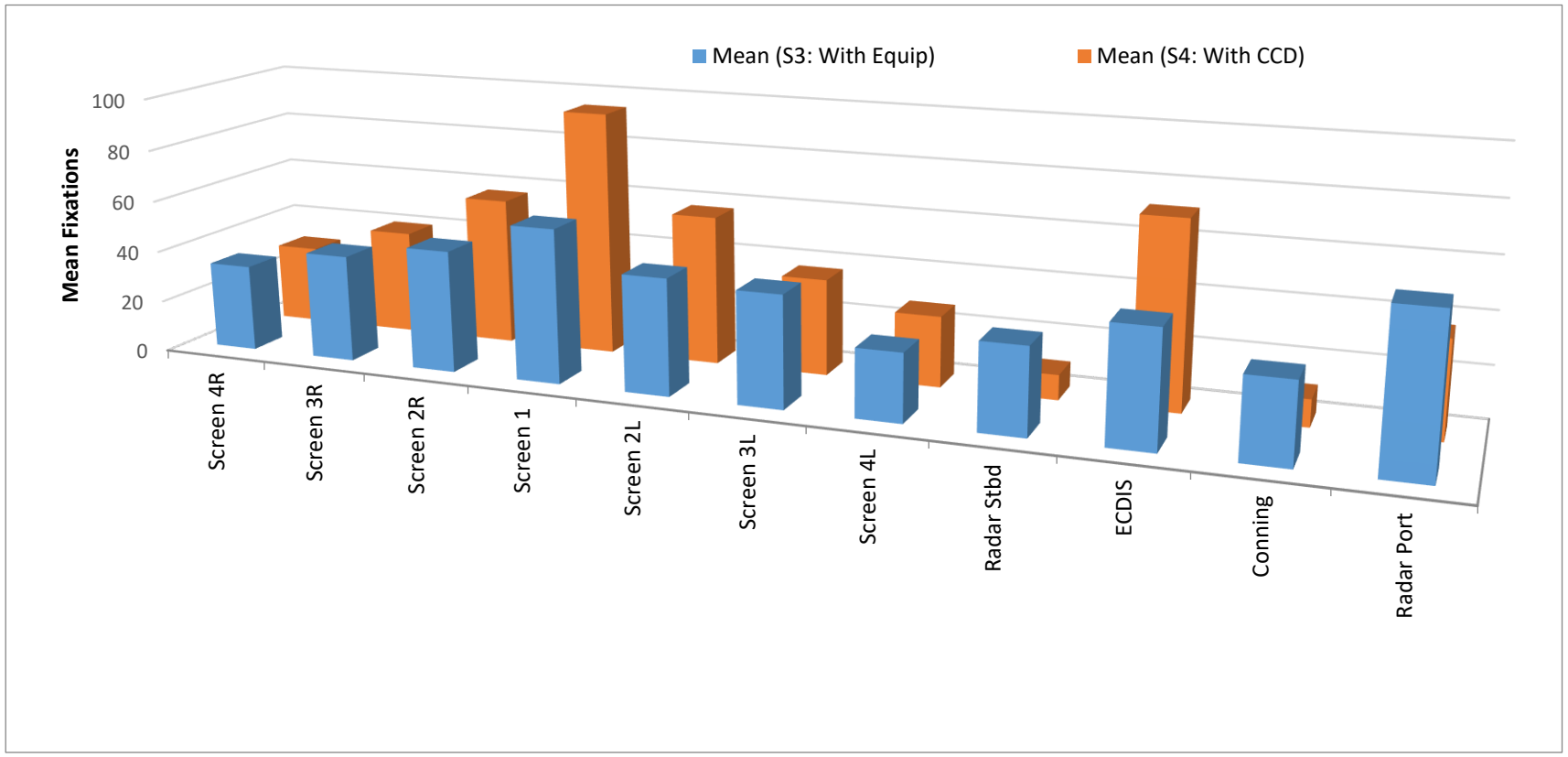

Figure 31 - Mean Number of Fixations for S3: With MFDs Vs S4: with CCD

6.3.3 Mean Fixations for S3 (With MFDs) vs S5 (NAESTO Course)

In this case, we compare the fixations in simulation with all MFDs (S3) and when MFDs were modified by CCDs and used during a watchkeeping session in a NAESTO course (S5). This scenario was developed to validate the impact of using the CCD concept together with the impact of guidance provided for the given scan pattern. Here, the mean number of fixations on visual screens in the NAESTO course S5 was 401, an improvement on the 294.92 in S3 for the same period (Figure 32 and Table 7). This improvement proves the concept of increased fixations on visual channels through guidance provided to participants on the issues relevant to maintaining lookout and distractions that may be caused by MFDs.

Table 7 - Mean Fixations for S3 (With MFDs) vs S5 (NAESTO Course)

Fixations – Windows	**Fixations – MFDs**	**Actual Mean Fixations (ms)**	
S1 FW = Max	S1 FM = 0	S1 FW = 613.3	S1 FM = 34.86
S3 FW < S5 FW	S3 FM > S5 FM	S2 FW = 164.5	S2 FM = 243.6
		S3 FW = 294.2	S3 FM = 260.4
		S4 FW = 344	S4 FM = 156.6
		S5 FW = 401	S5 FM = 349.8

Comments:

The results under 'Actual Mean Fixations' obtained from data capture show that the sub-hypothesis for S3 vs S5 was correct.

Abbreviations:

FW/DW	Fixations Windows/Dwell Time Windows	FM/DM	Fixations MFD/Dwell Time MFD

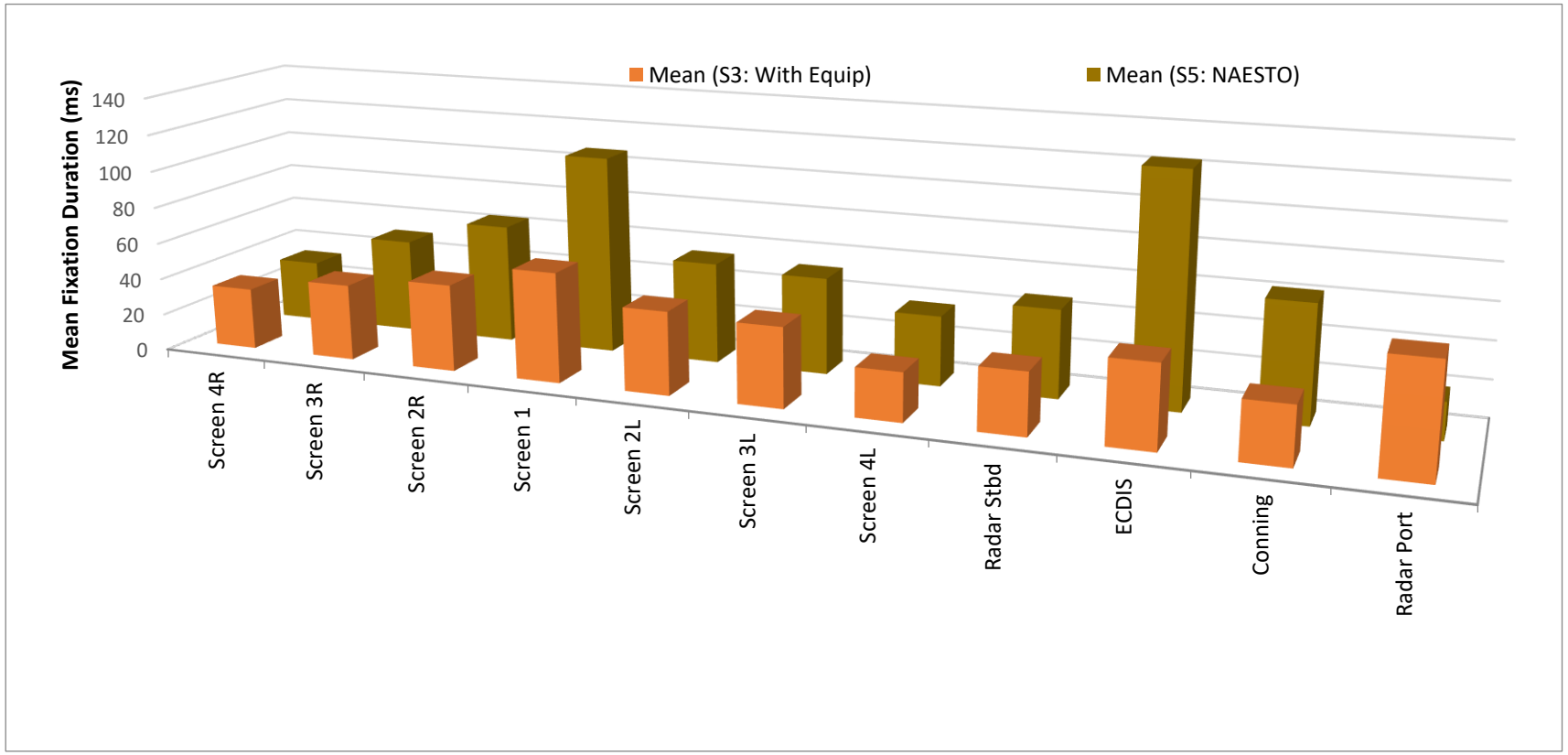

Figure 32 - Mean Number of Fixations for S3: With MFDs Vs S5: NAESTO Course

6.3.4 Mean Fixations for S3 (With MFDs) vs S2 (Real Ships)

On real ships, visual screen fixations (S2) were recorded at 164.5, showing a very low value for maintaining a lookout by sight. This is even less than the time spent in the simulator for a bridge with all MFDs available (S3), which was 294.2. The highest mean fixations were recorded on Stbd Radar MFD together with Screen 2R where a peak mean was 77.8, as these were located at the right front of the OOW position (Figure 33).

Another anomaly worth noting for real ships (S2) is the amount of fixations on Radar (stbd) is quite high showing that the OOWs were replying on radar for the lookout function. This can be a consequence of fatigue resulting from watchkeeping in port for cargo operations prior to departure or simply OOWs complacency because of which they only used Radar for lookout. Another reason could be (over) reliance on the second person positioned on the bridge as a lookout.

This is alarming and requires attention by the OOWs, but proves that the research hypothesis was correct and require action, i.e., training the OOWs in the scan pattern technique so that they know how to proportion their time between visual lookout and other tasks.

The findings were as per the hypothesis given in Section 3.4 and shown on the next page in Table 8.

S1D = 0. That is, in S1, there were zero distractions caused by MFDs as they were all blanked out.

Table 8 - Mean Fixations for S3 (With MFDs) vs S2 (Real Ships)

Fixations – Windows	**Fixations – MFDs**	**Actual Mean Fixations (ms)**	
S1 FW = Max	S1 FM = 0	S1 FW = 613.3	S1 FM = 34.86
S3 FW = S2 FW	S3 FM = S2 FM	S2 FW = 164.5	S2 FM = 243.6
		S3 FW = 294.2	S3 FM = 260.4
		S4 FW = 344	S4 FM = 156.6
		S5 FW = 401	S5 FM = 349.8

Comments:

The results under 'Actual Mean Fixations' obtained from data capture show that the sub-hypothesis for S3 vs S2 was not totally correct but is still comparable and not far from the hypothesis based on anecdotal evidence. This was probably a consequence of a difference in AOIs between the simulator bridge (S3) and the real ships (S3). Another anomaly worth noting is that the number of fixations on radar (stbd) in S2 is quite high, showing that the OOWs were relying on radar for the lookout function. This may have resulted from:

- OOW fatigue caused by cargo watch in port, after which departure stations and bridge watch followed.
- OOW complacency leading them to use only radar for lookout.
- (Over) reliance on the second person (lookout rating) positioned on the bridge to maintain a lookout.
- Assumptions that no other traffic will cause concern due to repeated journeys on the same route.

Abbreviations:

FW/DW Fixations Windows/Dwell Time Windows FM/DM Fixations MFD/Dwell Time MFD

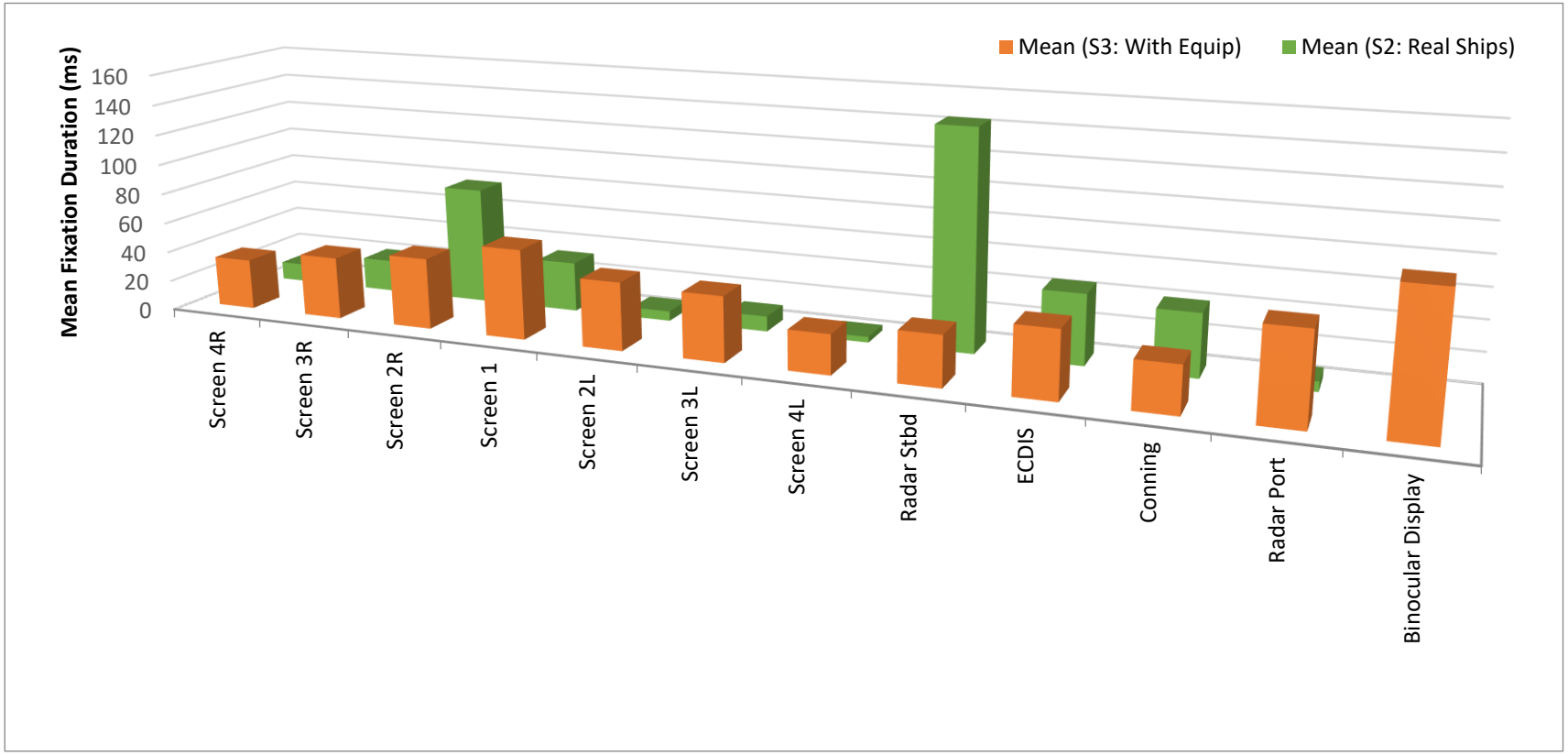

Figure 33 - Mean Number of Fixations for S3: With MFDs Vs S2: Real Ships

Table 9 - Fixation Frequency

		Area of Interest (AOI)															
		Screen 4R	Screen 3R	Screen 2R	Screen 1	Screen 2L	Screen 3L	Screen 4L	Radar Stbd	ECDIS	Conning	Radar Port	Binoculars	Radar Port Overlay	Conning Overlay	ECDIS Overlay	Radar Stbd Overlay
S1: No MFDs N = 14 SD = 34.052	Mean(ms*)	68.71	98.93	88.71	110.43	83.93	86.64	76.00	2.21	1.57	3.21	0.79	20.79				
	Min	14	10	9	42	4	8	4	0	0	0	0	0				
	Max	126	238	144	157	140	132	139	13	7	12	3	280				
S2: Real Ships N = 10 SD = 35.931	Mean(ms)	12.10	21.40	77.80	33.00	6.40	10.10	3.70	144.30	46.10	41.20	6.50	1.30				
	Min	0	0	0	0	0	0	0	8	0	8	0	0				
	Max	92	67	271	114	26	44	21	430	220	98	37	13				
S3: with MFDs N = 13 SD = 42.939	Mean(ms)	33.38	41.23	47.08	59.38	44.77	42.92	26.15	33.23	44.31	30.92	59.31	89.69				
	Min	5	5	7	6	8	10	1	0	0	2	3	1				
	Max	75	100	135	135	130	125	71	170	210	132	225	323				
S4: With CCDs/(MFDs) N = 10 SD = 30.639	Mean(ms)	30.3	40.3	57.1	94.5	57.5	37.1	27.2	9.6	71.5	10.4	36.9	13.4	31.50	44.20	31.20	12.70
	Min	3	6	12	38	22	2	2	0	0	0	0	0	0	4	0	0
	Max	46	63	85	168	94	73	34	72	287	99	142	36	100	106	100	40
S5: With CCDs (MFDs) NAESTO **N = 6 SD = 66.534**	Mean(ms)	33.33	51.00	64.67	107.67	54.50	52.17	37.67	47.33	124.00	62.67	19.83	92.00	26.33	85.00	25.17	48.83
	Min	0	1	2	4	7	1	0	0	0	0	1	0	0	0	0	0
	Max	96	99	145	205	108	150	74	126	460	231	58	399	138	295	95	230

***ms=Milliseconds**

Notes:

1. If the standard deviations (SDs) between groups are significantly different, it can affect the validity of the analysis, and adjustments may be needed.
2. The data in Table 9 was tested to see if the SDs are reasonable using MS Excel built in Data Analysis Toolpak assuming H_0 = All group's SDs are equal and H_1 = Each group's SD is different. Significance Level (p-value) used was 0.05.
3. p-value calculated and given in 9: is NOT less than 0.05 for S1…S4 whereas for S5, it is (0.045805) i.e. marginally less than 0.05. This is because the sample was taken during a NAESTO course where the participants were involved in a realistic collision avoidance exercise instead of the standard scenario used in S1, S3 and S4. It is therefore fair to assume that H0 is NOT rejected. It was therefore assumed that there was no significant difference in SDs between groups.

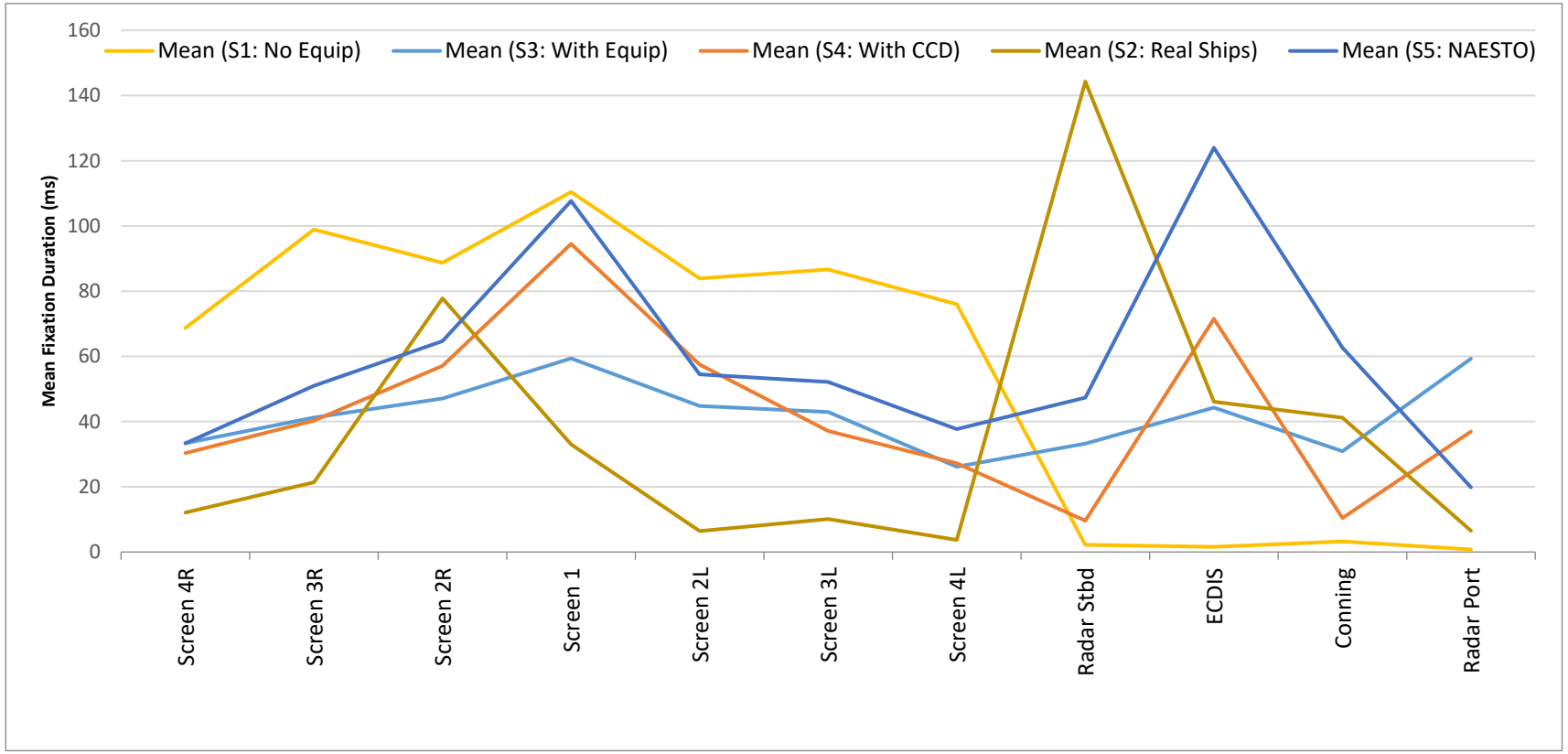

Figure 34 - Comparison of Fixations for All Phases

6.4 Dwell Time Comparison

The raw averages of mean dwell time percentage on each AOI for the five data collection exercises given in Table 14, Figure 39. An analysis of the outputs is discussed in the sections that follow.

6.4.1 Mean Dwell Time for S1 (No MFDs) vs S3 (with MFDs)

The graph in Figure 35 shows a comparison of mean dwell time between the simulation without any MFDs (S1) and the simulation with all MFDs switched on and available, as required during normal training and watchkeeping (S3). The results indicate that when MFDs were made available, the dwell time on visual screens reduced from an average of 10.816 ms for S1 to 5.870 ms for S3, i.e., reduced by 54% (100 x 5.870/10.816).

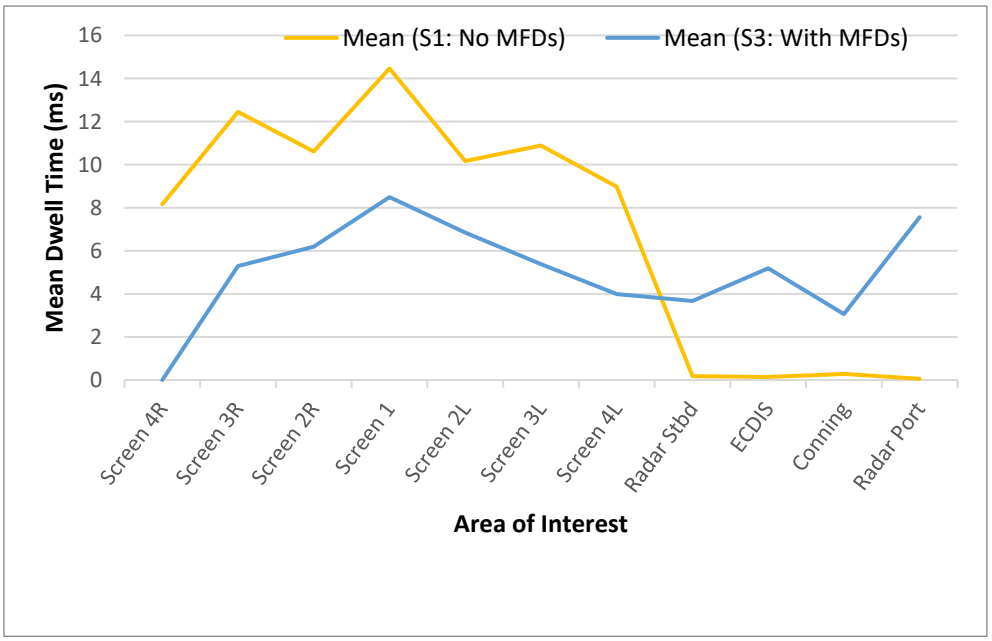

Figure 35 - Mean Dwell Time % for Data Capture S1: No MFDs Vs S3: with MFDs

The results were as per the hypothesis given in Section 3.4 and shown on the next page in Table 10.

S1D = 0. That is, in S1, there were zero distractions caused by MFDs as they were all blanked out.

Table 10 - Mean Dwell Time for S1 (No MFDs) vs S3 (with MFDs)

Dwell Time – Windows	**Dwell Time – MFDs**	**Actual Dwell Time (ms)**	
S1 DW = Max	S1 DM = 0	S1 DW = 10.816	S1 DM = 0.571
S1 DW > S2 DW, S3 DW, S4 DW, S5 DW	S1 DM < S2 DM, S3 DM, S4 DM, S5 DM	S2 DW = 2.554	S2 DM = 15.94
		S3 DW = 5.870	S3 DM = 6.231
		S4 DW = 6.610	S4 DM = 4.102
		S5 DW = 6.357	S5 DM = 6.997

Comments:

The results under 'Actual Dwell Time' obtained from data capture shows that the sub-hypothesis for S1 vs S1, S2, S3, S4, S5 was correct.

Abbreviations:

FW/DW Fixations Windows/Dwell Time Windows FM/DM Fixations MFD/Dwell Time MFD

6.4.2 Mean Dwell Time for S3 (With MFDs) vs S4 (with CCD)

Here, a comparison is made between the dwell time for simulation with all MFDs available as required during normal training/watchkeeping and when MFDs were modified by CCDs. Again, the average dwell time on visual screens, as shown in Figure 36, was higher for S4 with CCDs (6.610 ms) in comparison with S3 MFDs (5.870 ms), i.e., by 11% (100 x 5.870/6.610).

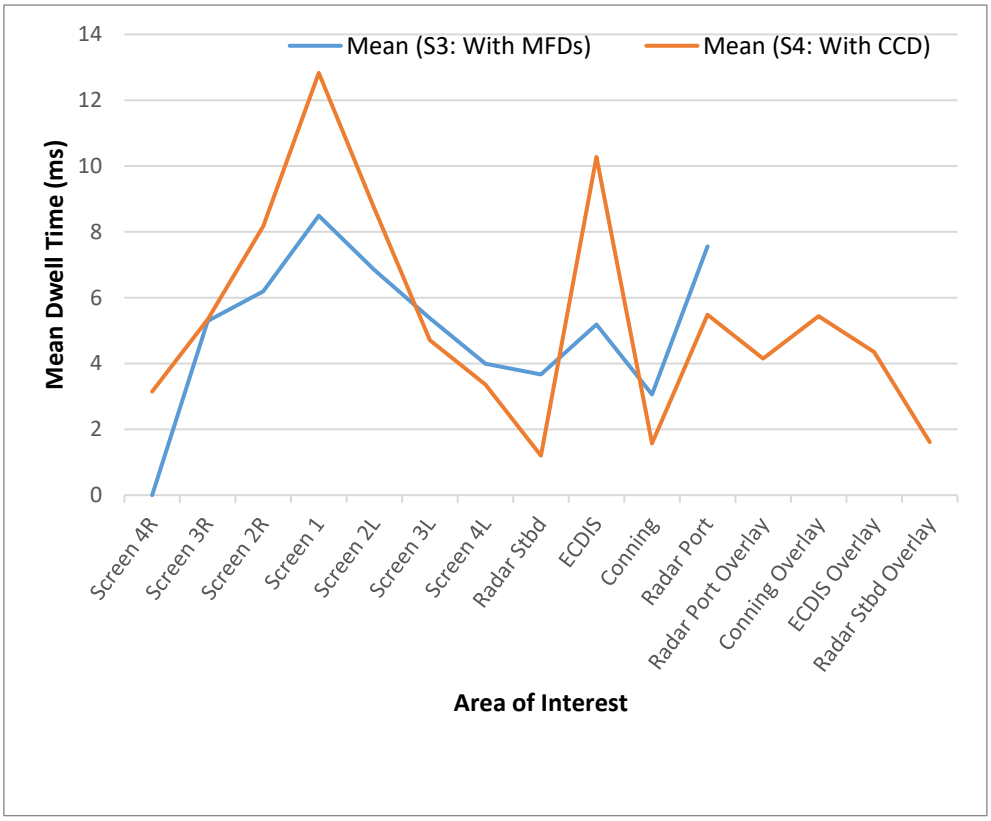

Figure 36 - Mean Dwell Time % on each AOI for S3: With MFDs Vs S4: with CCD

The results were as per the hypothesis given in Section 3.4 and shown on the next page in Table 11.

S1D = 0. That is, in S1, there were zero distractions caused by MFDs as they were all blanked out.

Table 11 - Mean Dwell Time for S3 (With MFDs) vs S4 (with CCD)

Dwell Time – Windows	**Dwell Time – MFDs**	**Actual Dwell Time (ms)**	
S1 DW = Max	S1 DM = 0	S1 DW = 10.816	S1 DM = 0.571
S3 DW < S4 DW	S3 DM > S4 DM	S2 DW = 2.554	S2 DM = 15.94
		S3 DW = 5.870	S3 DM = 6.231
		S4 DW = 6.610	S4 DM = 4.102
		S5 DW = 6.357	S5 DM = 6.997

Comments:

The results under 'Actual Dwell Time' obtained from data capture show that the sub-hypothesis for S3 vs S4 was correct.

Abbreviations:

FW/DW	Fixations Windows/Dwell Time Windows	FM/DM	Fixations MFD/Dwell Time MFD

6.4.3 Mean Dwell Time for S3: With MFDs vs S5: NAESTO

In this case, a comparison is made between the average dwell time between the simulation with all MFDs available (S3) and when MFDs were modified by CCDs but used during a watchkeeping session in a NAESTO course (S5) instead of the standard scenario that was created for this research. Here, the average dwell time on visual screens was 5.870 ms with MFDs (S3) and when used in the NAESTO course, it was 6.357 ms (S5) Figure 37. This shows a slight increase in average dwell time by 8%, which proves the concept of increased dwell time on visual channels through providing guidance on scan pattern and the use of CCDs.

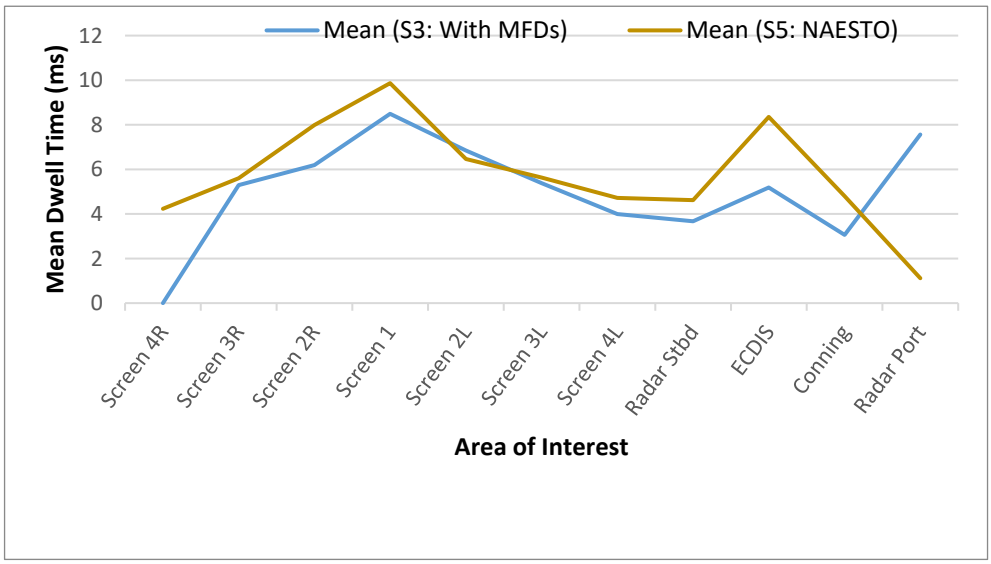

Figure 37 - Mean Dwell Time % on each AOI for S3: With MFDs Vs S5: NAESTO

The results were as per the hypothesis given in Section 3.4 and shown on the next page in Table 12.

S1D = 0. That is, in S1, there were zero distractions caused by MFDs as they were all blanked out.

Table 12 - Mean Dwell Time for S3: With MFDs vs S5: NAESTO

Dwell Time – Windows	**Dwell Time – MFDs**	**Actual Dwell Time (ms)**	
S1 DW = Max	S1 DM = 0	S1 DW = 10.816	S1 DM = 0.571
S3 DW < S5 DW	S3 DM > S5 DM	S2 DW = 2.554	S2 DM = 15.94
		S3 DW = 5.870	S3 DM = 6.231
		S4 DW = 6.610	S4 DM = 4.102
		S5 DW = 6.357	S5 DM = 6.997

Comments:

The results under 'Actual Dwell Time' obtained from data capture show that the hypothesis for S3 vs S5 was correct.

Abbreviations:

FW/DW Fixations Windows/Dwell Time Windows FM/DM Fixations MFD/Dwell Time MFD

6.4.4 Mean Dwell Time for S3 (With MFDs) vs S2 (Real Ships)

In real ships (S2), average dwell time on visual screens was recorded at 2.554 ms showing a very low period of time spent here on maintaining a lookout by sight. This is even less than the time spent in S3, i.e., 5.870ms. The average time spent in S2 by the same watchkeepers on the MFDs (S3) was 4.743 ms, 46% more than they spent on maintaining a visual lookout (Figure 38). This is alarming and requires attention but proves that the research hypothesis is correct and the proposed solution, i.e., a combination of scan pattern training and CCD, is appropriate. As ships' bridges must operate with equipment (MFDs), the option to have no equipment displays was not available.

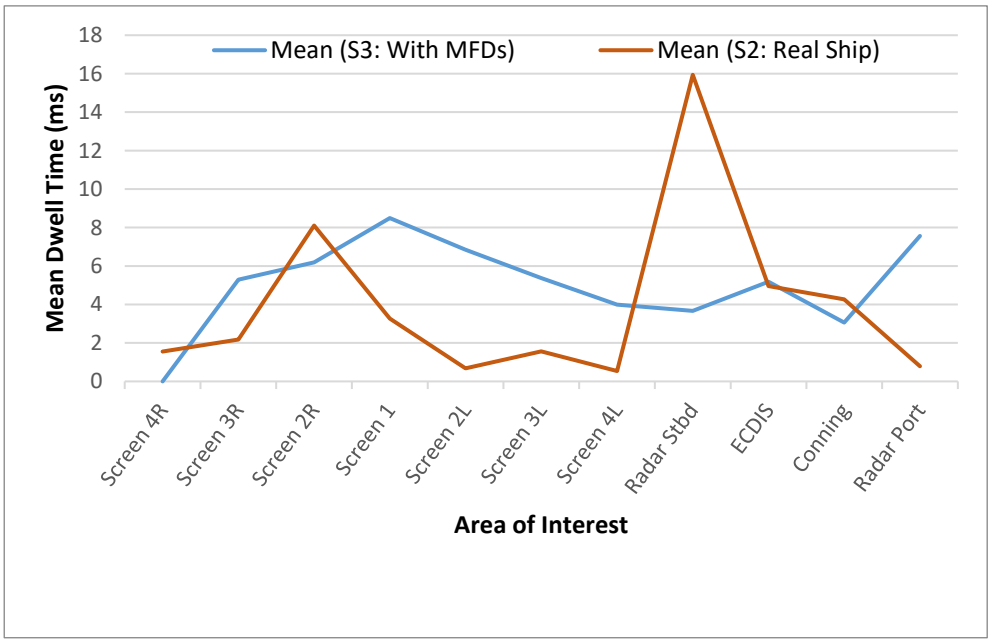

Figure 38 - Mean Dwell Time % on each AOI for S3: With MFDs Vs S2: real ships

Table 13 - Mean Dwell Time for S3 (With MFDs) vs S2 (Real Ships)

Dwell Time – Windows	Dwell Time – MFDs	Actual Dwell Time (ms)	
S1 DW = Max	S1 DM = 0	S1 DW = 10.816	S1 DM = 0.571
S3 DW = S2 DW	S3 DM = S2 DM	S2 DW = 2.554	S2 DM = 15.94
		S3 DW = 5.870	S3 DM = 6.231
		S4 DW = 6.610	S4 DM = 4.102
		S5 DW = 6.357	S5 DM = 6.997

Comments:

The results under 'Actual Dwell Time' obtained from data capture show that the hypothesis for S3 vs S2 showed the same anomalies as stated in fixation comparison for S3 and S2.

Abbreviations:

FW/DW Fixations Windows/Dwell Time Windows FM/DM Fixations MFD/Dwell Time MFD

Table 14 - Dwell Duration Mean (ms)

		Area of Interest (AOI)															
		Screen 4R	Screen 3R	Screen 2R	Screen 1	Screen 2L	Screen 3L	Screen 4L	Radar Stbd	ECDIS	Conning	Radar Port	Binoculars	Radar Port Overlay	Conning Overlay	ECDIS Overlay	Radar Stbd Overlay
S1: No MFDs N= 14 SD=23.472	Mean(ms)	8.157	12.450	10.614	14.464	10.164	10.886	8.979	0.179	0.143	0.279	0.057	2.200				
	Min	1.7	0.6	0.5	4.9	0.2	0.6	0.3	0.0	0.0	0.0	0.0	0.0				
	Max	15.3	30.7	17.1	27.4	18.3	19.1	15.0	0.9	0.7	0.9	0.3	30.2				
S2: Real Ships N= 10 SD=8.636	Mean(ms)	1.550	2.180	8.100	3.270	0.680	1.560	0.540	15.940	4.960	4.270	0.790	0.160				
	Min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.9	0.0	0.0				
	Max	12.6	5.5	20.5	12.0	2.8	5.9	3.0	32.2	19.5	7.0	5.0	1.6				
S3: with MFDs N= 13 SD=23.192	Mean(ms)	4.900	5.292	6.192	8.492	6.846	5.377	3.992	3.669	5.185	3.062	7.562	11.677				
	Min	0.5	0.5	0.5	0.4	0.5	0.5	0.1	0.0	0.0	0.3	0.3	0.0				
	Max	10.6	12.0	16.0	16.4	19.3	14.7	10.4	18.8	23.8	10.8	29.8	39.5				
S4: With CCDs (MFDs) N= 14 SD=20.851	Mean(ms)	3.150	5.340	8.170	12.830	8.710	4.710	3.360	1.200	10.280	1.570	5.480	1.980	4.150	5.440	4.350	1.610
	Min	0.2	0.5	1.3	4.3	2.6	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0
	Max	10.2	13.4	13.9	21.2	18.4	13.0	8.9	8.8	45.1	15.3	19.8	4.7	13.5	13.0	12.1	4.6
S5: With CCDs (MFDs) on NAESTO N= 10 SD=20.319	Mean(ms)	4.233	5.600	7.983	9.867	6.467	5.633	4.717	4.617	8.350	4.800	1.117	16.100	1.467	4.733	1.083	2.833
	Min	0.0	0.0	0.1	0.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Max	6.1	8.9	14.9	18.0	9.2	7.9	6.3	17.5	31.5	16.6	3.2	42.1	7.4	19.3	3.3	11.5

Notes:

1. If the standard deviations (SDs) between groups are significantly different, it can affect the validity of the analysis, and adjustments may be needed.
2. The data in Table 14 was tested to see if the SDs are reasonable using MS Excel built in Data Analysis Toolpak assuming H_0 = All group's SDs are equal and H_1 = Each group's SD is different. Significance Level (p-value) used was 0.05.
3. p-value calculated and given in Appendix 9: Statistical Analysis Data is NOT less than 0.05 for S1, S3, and S4 whereas for S2 and S5, it is (0.00202, 0.008233) i.e. less than 0.05. This is because the sample was taken on real ships where not only the scenario was different than S1…S3 but the experiment was uncontrolled as was the case for S5 i.e. NAESTO course where the participants were involved in a realistic collision avoidance exercise instead of the standard scenario used in S1, S3 and S4. It is therefore fair to assume that H_0 is NOT rejected. It was therefore assumed that there was no significant difference in SDs between groups.

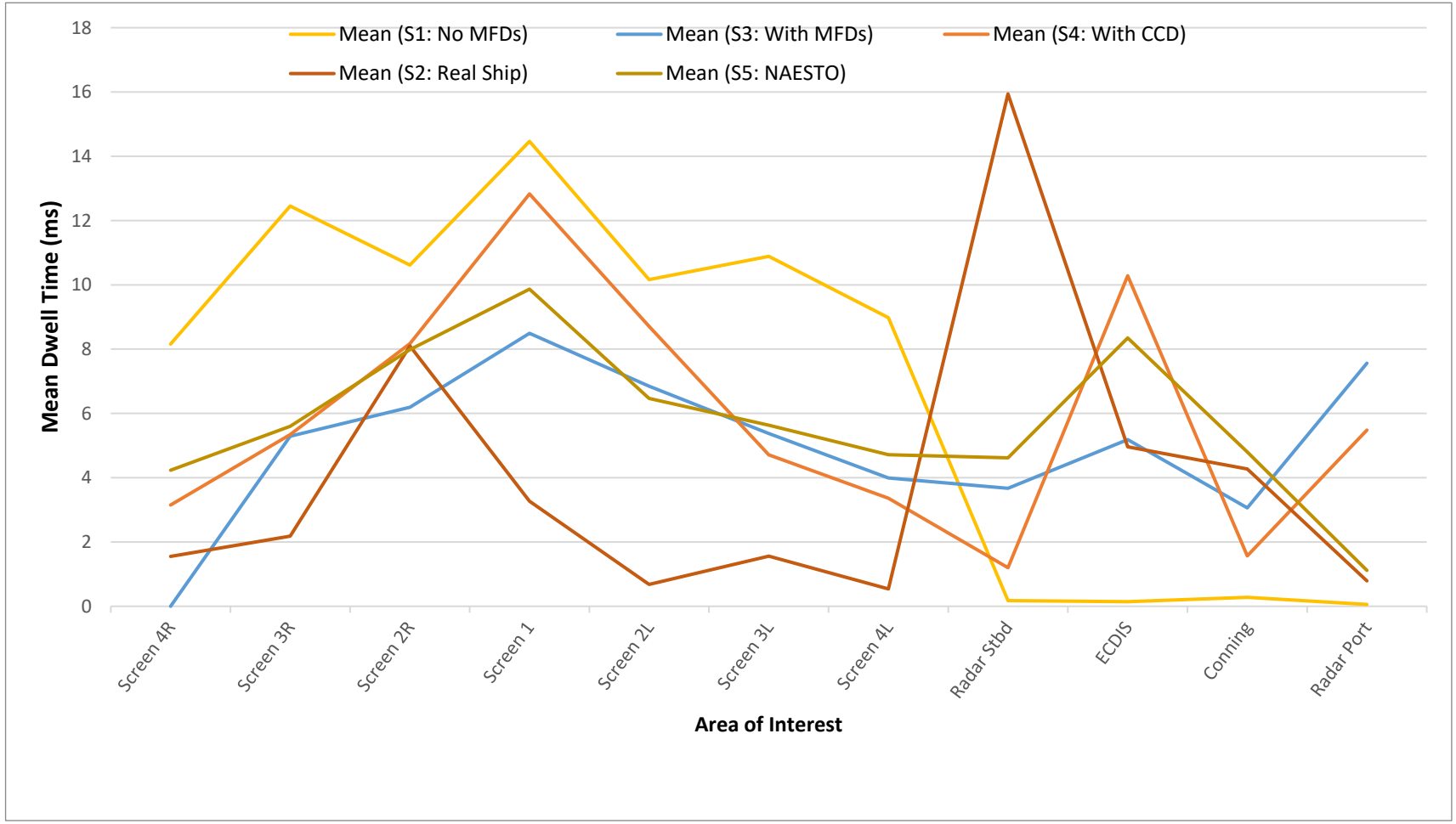

Figure 39 - Comparison of Mean Dwell Time (%) for all Phases

6.5 Distraction Evaluation Ration (DER)

The watchkeeper's primary responsibility is safe navigation, which includes collision avoidance, whilst following the approved passage plan. In order to achieve it, they must remain constantly alert to all external vessel movement within their FOV to detect any traffic that may cause concern. Whilst the ship's performance and the time required to take collision avoidance action varies from one ship to another, the human reaction time (US DoT, 2016) is estimated at 12.5 seconds from the time the OOW decides to take action. In contrast to aircraft flying at speeds of several hundred knots, ships' speeds are generally around 15-25 knots. Due to the slow speed of ships, a situation with a risk of collision takes longer to develop, but as a consequence of the slow relative impact of an action, this situation will also take longer to resolve, and if a conflict target is not detected at an early stage, then the threat will continue to remain in force. Lack of timely reaction for the ships navigation could be an indication of another underlying issue, such as the onset of empty field myopia. The on-duty watchkeepers must avoid this at all costs by shifting their glance to refocus, following the recommended WWS method for visual scan patterns discussed in Window Wiper Scan (WWS) Method.

Table 15 - Aviation Industry Standard Ratios for Looking out vs looking at MFDs

	Minimum (FAA*)	Maximum (FAA)	Minimum (CAA**)	Maximum (CAA)
Vis Screens	16	16	18	20
MFDs	4	5	3	3
Total	20	21	21	23
% Time on MFDs	20.0%	23.8%	14.3%	13.0%
% Time on Vis Screens	80.0%	76.2%	85.7%	87.0%
Ratio Vis Screen: MFDs	4:1	3.2:1	6:1	6.7:1

*** Federal Aviation Authority (FAA), USA.**

**** Civil Aviation Authority (CAA)UK.**

Aviation pilots are trained to timeshare their lookout time (Colvin et al., 2003) for no more than 3 seconds on the equipment displays for every 18-20 seconds in the USA (FAA, 2015), and 4-5 seconds on MFDs against 16 seconds on lookout in the UK (see Table 15). These values give a ratio of between 1:3 in USA to 1:6.7 in the UK for time on MFDs compared to looking outside. Keeping in mind that ships operate on the surface of water at average speeds ranging from 15 to 25 knots, their relative approach speed can be much slower than that of aircraft, so arguably less time may be spent on looking out than on MFDs on ships' bridges. The same can be equally applied as a counter argument to spending more time on looking out to identify the target, as it will take a ship a lot longer than an aircraft to run into danger. However, if an extremely heavily research-evidenced aviation industry approach is taken, the same proportions can be ruled-in for surface ship navigation, i.e., the ratio of between 1:3 to 1:6.7 for time on MFDs to looking outside; that is., for every 3 – 5 seconds spent on the MFDs, there should be 16-20 seconds spent on looking out.

Eye movement data from participants in the study reported here, described by number of fixations and dwell time percentages, are shown as Table 9 and Table 14 respectively in the preceding sections. Significant differences were noted in participants' average fixations and dwell time among selected AOIs. The steadiest, most consistent approach to maintaining a proper lookout was observed in the phase where no MFDs were available (S1), so there were zero distractions from MFDs. All other phases show random results for both the fixations and the dwell time on each AOI. In all cases with MFDs or CCD (S4, S5), Radar Stbd and ECDIS appeared to attract the highest number of fixations and dwell time (see graphs in Figure 34 and Figure 39). This draws attention to an extremely important observed weakness in watchkeeper behaviour; the watchkeepers consistently spend a greater amount of their time on MFDs. Hence, the proposed CCD concept is a necessity to reduce this time.

Table 16 - Fixations & Dwell Time Comparison

	Average Mean Fixations					Average Mean Dwell Time					Ideal Duration
	S1: No MFDs	S3: With MFDs	S4: With CCD	S5: NAESTO	S2: Real Ship	S1: No MFDs	S3: With MFDs	S4: With CCD	S5: NAESTO	S2: Real Ship	Simulator
Vis Screens	613.36	294.92	344	401	164.5	75.714	36.192	46.27	44.5	17.88	84
MFDs	34.86	260.38	156.6	449.83	243.6	3.407	31.446	22.4	35.15	33.2	24
Total	648.22	555.3	500.6	850.83	408.1	79.121	67.638	68.67	79.65	51.08	108
% Time on MFDs	5.4%	46.9%	31.3%	52.9%	59.7%	4.3%	46.5%	32.6%	44.1%	65.0%	22.2%
% Time on Vis Screens	94.6%	53.1%	68.7%	47.1%	40.3%	95.7%	53.5%	67.4%	55.9%	35.0%	77.8%
Ratio **MFDs:Vis Screen**	1:17.6	1:1.1	1:2.2	1:0.9	1:0.7	1:22.2	1:1.2	2.1:1	1:1.3	1:0.5	1:3.5

Aviation research also highlights that despite training to achieve these ratios, pilots don't actually use this time-sharing ratio. A study carried out by Yu et al. (2014) showed that a group of fully qualified, mission-ready pilots spent 59.92% of their time on the equipment and 39.18% looking out. This gives a ratio of 3:2, far different than the ratio standard set by Civil Aviation Authority, UK (CAA) (6:1). As a principle, therefore, a rule that is applied to aviation can also be applied to ships to train the watchkeepers, but the actual results may depend on a large number of variables, including fatigue, traffic density, area of operation, number of watchkeepers on bridge, etc.

Although maintaining a proper lookout is the primary task for all watchkeepers, this study exposes them to new concepts, but until STCW Code mandates this through inclusion in their training, they are unlikely to be trained systematically on these concepts and therefore unlikely to be assessed using techniques proposed here.

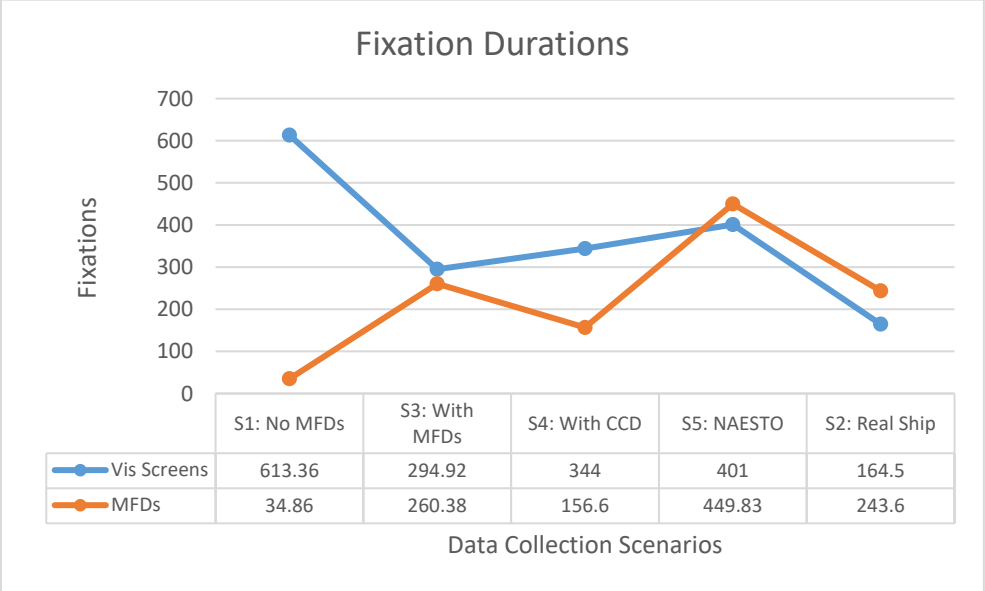

Figure 40 - Comparison of Fixation Durations

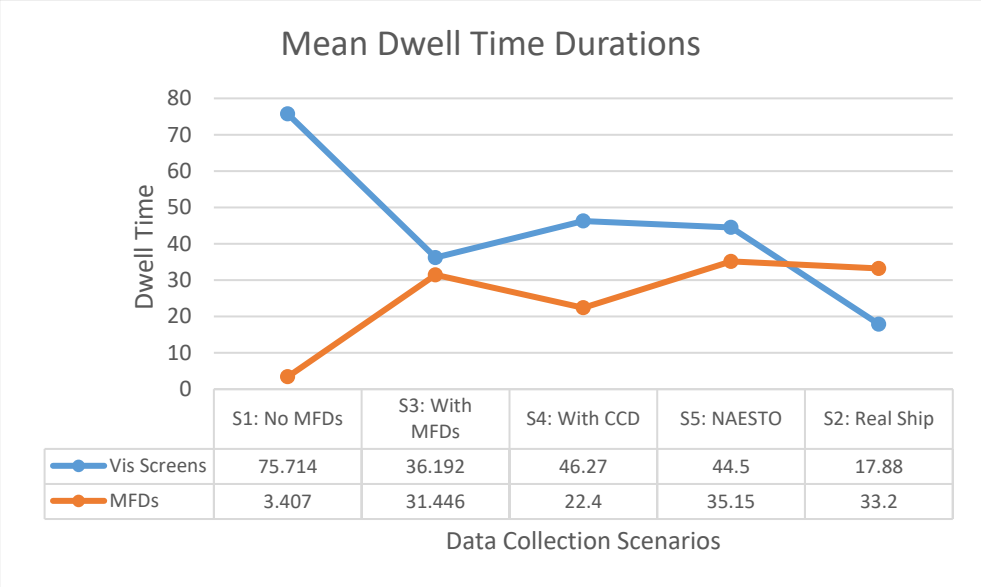

Figure 41 - Comparison of Average Mean Dwell Time

The ratios between the dwell time and fixations on visual screens and MFDs during this research are shown in graphs (Figure 40 & Figure 41,

Table 16). It is evident that the ratio (0.7/0.5:1) between the fixations/dwell time on visual screens and MFDs on real ships (S2) was the poorest, leaving a large gap of time when the watchkeepers were not looking out, so possibly exposing themselves to either empty field myopia or not doing their job by 'not maintaining a proper lookout'. Surprisingly, the second closest value (0.9/1.3:1) was obtained from the NAESTO course (S5), where the provision of basic training through a briefing about the scan pattern and timesharing showed some improvement in comparison with S2, S3 and even S4. A further improvement in this ratio is observed with the CCD (S4) concept, where it is 2.2/2.1:1 but further improvement is required to bring it in line with the aviation industry standard of between 3:1 and 6.7:1. This can be achieved through further training, combined with improved CCDs, as evidenced in the ratios (17.6/22.2:1) shown for data without MFDs (S1), showing significant room for improvement.

6.6 Concluding Remarks

This chapter provides analysis of the ETD data captured in bridge simulators as well as on real ships. It also explains how this was implemented in ship's bridge simulators prior to data capture for S4 and S5. Further, it provides a sensitivity analysis to analyse the ETD participant data captured during this study to ensure it complies with the required statistical standards, highlighting issues faced during the whole project.

This chapter follows on from Chapter 5: Implementing CCD Concept, and provides analysis of data captured during this research. It shows a comparison of fixation duration and dwell time between the five research scenarios stated in Section 3.6. Based on the results of this analysis, it then calculates a DER for various data capture scenarios used in this research. It then highlights the target DER that the watchkeepers need to achieve to ensure optimum lookout focus. The analysis of captured ETD data demonstrates that the combination of the author's proposed WWS method with the CCD concept showed improvement in the time spent on maintaining a proper lookout.

Chapter 7: Discussion and Conclusions

7.1 Introductory Remarks

All commercial ships must comply with IMO requirements for bridge equipment design and installation as discussed in Chapter 2: Literature Review. At the same time, seafarer training must comply with the STCW Code, which shows significant gaps in training for the watchkeeper to maintain a proper lookout (IMO, 1978) and therefore comprehensive SA. The human factor is included as a contributory cause (Costa et al., 2018) in almost every navigational accident. Literature review shows that maintaining SA to avoid collision is the root cause and therefore not only an issue for the maritime industry (Hrvoje et al., 2021) but is equally significant for the aviation (CAA, 2013) and road transport industries (Yang et al., 2012).

It has been observed that the issues related to MFD distractions in road vehicles are very similar to those that distract the watchkeepers' in ship's bridge. There are however significant differences between driving on roads and navigating a ship at sea. For example, the cars have brakes, they drive much faster on dedicated road with clear direction for flow of traffic. Ship and aircraft navigation and collision avoidance does not have these characteristics. Any stimulus that diverts a driver, pilot or watchkeeping officer's attention from their primary task to maintain vigilance about collision is considered as a distraction (Burack et al., 2012). The MFDs cause distractions which these three operators must avoid to maintain focus on the road, failing which they are likely to be involved in an accident (Vetturi et al., 2020).

The literature review confirms that there exists a better comparison between maritime watchkeeping and the aviation pilots (Martinez-Marquez et al., 2021). Both navigate in unmarked territories, rely on visual and/or radar observations to inform their SA and thus avoid navigational accidents – a characteristic that does not apply in the exact same way to road vehicle driving. Consequently, a comprehensive literature review of watchkeeping in aircraft was undertaken to draw from its principles that can apply to the maritime watchkeeping, both in terms of watchkeeper skills as well as the display of information on MFDs. It was also established that ETDs have been extensively used during simulator training and research for pilot's behaviour, but no equivalent studies

are available in the maritime sector (Martinez-Marquez et al., 2021). It has been concluded that the aviation industry is far more advanced than the maritime industry in terms of training pilots as well equipment layout and presentation of information through MFDs (FAA, 2019; ECFR, 2021).

Based on the findings from literature review, it has been learned that the watchkeepers need to spend time on looking out of the windows to visually detect targets (Findlay, 2009) between a cycle of seeing nothing to seeing something. In order to do this successfully, the watchkeeper must overcome distractions. This can be achieved by training watchkeepers' brain to focus their brain to select the stimulus visible to their eye (Simons and Chabris, 1999). For doing this, they have between 1-4 seconds to ensure their sensory memory holds the information about stimulus so that it can be transferred to STM (Williams, 2020; Lavie, 2010) for processing for action. If within this time, the flow of information from sensory memory to STM is interrupted through another stimulus, the information will not reach STM, hence SA will not be updated. The watchkeeper must therefore enhance this cognitive ability through training (Colvin et al., 2005) in simulators to inhibit distractors through continuous and deliberate mental effort (Williams, 2020).

It has been established through this study that a measurement of DER by using ETDs during training can significantly improve a watchkeepers behaviour towards maintaining SA (Hareide and Ostnes, 2018) by controlling their cognitive ability. The same methodology can be used to evaluate the MFDs installed on existing ships as well as for developing a new design (Costa et al., 2018) based on the CCD concept presented in this thesis. However, unless presented with concrete research, it is a significant challenge to convince the maritime world through IMO to make changes to both the bridge design and the training content and assessment for watchkeepers. This can easily be achieved if IMO develops GBS for bridge equipment displays and other MFDs used on ship's bridge (IMO, 2019). Whilst the former will require time to implement the research findings after convincing all stakeholders, the latter, however, can prove comparatively easier to implement. This is based on the fact that training providers have some discretion to follow 'training good practice' to improve the effectiveness of lookout through techniques established through this research – a solution that can be implemented without any significant cost or resource implications while bringing about a significant benefit in the reduction of accidents. To achieve

this, the research findings have already been shared with the wider industry audience through the publications listed in Appendix 8: Published Papers & Presentations.

7.2 Research Objectives Achieved

The primary aim of this research was to evaluate the impact of information displayed on various displays (MFDs) on the ability of experienced navigational watchkeepers to maintain a proper lookout and SA (Martinez-Marquez et al., 2021) both during the day and at night. In order to achieve this, accident reports from various maritime authorities such as MAIB, ATSB, and EMSA were studied, together with an extensive literature review to identify issues relevant to the watchkeeper's inability to maintain a proper lookout on the ship's bridge as a contributory cause to navigational accidents. This part of the study provided a general demonstration of the rationale for the research carried out for this thesis. The literature review particularly highlighted the lack of research in this area. Although the issues have been identified, no solutions have ever been presented, thus maintaining a status quo for existing ships bridge equipment layout and the MFD design. The anecdotal evidence obtained through observation of watchkeepers spending more time on looking at MFDs on simulated bridges during OOW training was converted into experimental research and real ship-based data driven proof, supported by literature review presented in Chapter 2: Literature Review

A review of the IMO Standards and classification societies' requirements for equipment display (MFD) and bridge layout revealed that these requirements are designed to provide MFD specifications at a very high level (DNV, 2012; BV, 2016) but lack detailed insight into both the impact on watchkeepers' ability to maintain a proper lookout and the amount of light pollution that these will cause (Khalique and Bury, 2023), thus impacting dark adaptation. The author conducted a detailed review of these requirements, together with a review of relevant literature to present the best practice guidance for watchkeepers to achieve and maintain dark adaptation, overcoming the light pollution caused by MFDs and other sources of light on a ship's bridge.

Further analysis of the requirements for bridge layout and the information displayed on MFDs revealed a lack of user (watchkeeper) input (Costa et al., 2018) into both

their design and location. The most important factor identified was the duplication of information presented to the watchkeeper, causing distractions in addition to cognitive overload (Fan et al., 2023), thus impacting SA and therefore decision making (Lim et al., 2018). A broad-spectrum questionnaire was used to capture user input from experienced watchkeepers, including active captains serving on ocean-going ships, to design the prototype CCD, which showed significant reduction in MFD-caused distractions and therefore potential to improve SA.

It was also evident from this study that the STCW Code (IMO, 1978), which is the foundation for watchkeeper training globally has the following weaknesses:

- The term 'proper lookout' is not defined in the Code, the IRPCS or any other maritime guidance provided to watchkeepers.
- The Code does not provide any specific requirement to train watchkeepers on maintaining a proper lookout.
- There is no existing method followed in the maritime industry globally that will inform watchkeepers on:
    - (i) The need to maintain a proper lookout at all times.
    - (ii) Consequences of failure to maintain a proper lookout.
    - (iii) A method to maintain a proper lookout.
    - (iv) Impact of illumination on watchkeepers' ability to maintain dark adaptation.

A new definition of the term 'proper lookout' was introduced through this thesis together with the WWS method adopted from the aviation industry but adjusted to suit the maritime watchkeeper. The experiment participants were then briefed on both these developments as well as the use of CCD on MFDs prior to capturing further data in the experiment. This innovation showed improvement in watchkeepers behaviour shown by improved DER given in Distraction Evaluation Ration (DER).

The data capture phases are summarised below:

- ETDs were used to study the impact of MFDs to confirm the proportion of time watchkeepers were spending on MFDs in contrast to the amount of time spent on looking outside the bridge windows. This data was captured both on simulators as well as on real ships.

The data on real ships was used to validate the accuracy and adequacy of simulator data.

- The MFD design was changed to provide the 'bridge of the future' or CCD concept, in which the information displayed on MFDs was rationalised to show the most relevant information required by the watchkeeper. Simultaneously with the modification of the MFDs in the simulated bridges, all research participants were provided guidance and training on the definition of proper lookout, as well as the method for maintaining a lookout through the proposed WWS method. The ETDs were again used to capture watchkeepers' eye motion data to gauge the impact of this change on the proportion of time spent on looking outside the bridge windows and the MFDs.
- A further data capture exercise was conducted, applying everything mentioned above but during a normal watchkeeping training programme in a NAESTO course.
- The participants' gaze path was studied visually to understand changes in their gaze path prior to and after providing guidance on the WWS method. Improvement was observed in the amount of time spent on looking outside the window, with less time spent on looking at MFDs.
- Fixations and dwell time data was analysed for each participant and all AOIs using triangulation of data from gaze path, duration of fixations and saccades, together with the questionnaire, to fully understand the impact and provide a holistic approach from more than one standpoint. This analysis revealed an improvement in watchkeeper behaviour through implementation of the WWS method together with the CCD concept.

7.3 Contribution to Knowledge/Practice

Several studies, as elaborated during the literature review associated with this thesis, show that a staggering 65% of ship collisions are attributed to the watchkeeper not maintaining a proper lookout (Wang and Fu, 2022). The root cause of underlying

issues appeared to be associated with a lack of a definition of the term 'proper lookout' in the IRPCS/STCW Code that forms the basis of a mandatory requirement to maintain an effective lookout at all times. This, in turn, leads to a lack of appreciation of the shortfalls in watchkeeping behaviour that needs this small but crucial improvement so that watchkeeping soft skills can be enhanced and the underlying issues addressed.

A new definition of this term has been offered as part of this study. The objective of this suggestion is to include it in the IRPCS and therefore in seafarers' watchkeeping training. The author hypothesised that modern MFDs cause distractions, which divert watchkeepers' focus away from maintaining a lookout. This hypothesis was described in Section 3.4, equations 3.1 and 3.2 and has been proven correct through evidence obtained during collection of data using ETDs in navigation bridge simulators, as well as on real ships. The collected data was then analysed by comparison with similar observations in bridge simulators where no MFDs were available, while maintaining bridge watches in the same navigational and collision avoidance conditions. DER values from the aviation industry were used as a benchmark to compare with the maritime watchkeeping DER to obtain a benchmark for maritime DER of 1:3.5 (see Table 16 - Fixations & Dwell Time Comparison).

Alongside the establishment of a benchmark DER, a survey was carried out utilising the users of bridge equipment, i.e., experienced watchkeepers, to establish the most important information required for navigation and collision avoidance during normal watchkeeping. Based on this user input as recommended by Costa et al. (2018), the MFDs in the simulators were modified to provide a prototype of the bridge of the future where only the most relevant information was presented to the watchkeeper to reduce distractions. This concept was introduced as CCD where only the most important information was displayed at all times to the watchkeeper to declutter the display thereby reducing distractions. The watchkeepers were given the option to switch to full MFD information if & when dictated by navigational requirements.

It was observed during data capture that the scan pattern followed by watchkeepers did not have any standard format. Aviation industry practices for pilot's watchkeeping were studied, particularly their methods to scan the sky to identify any collision threats. A method known as Window Wiper Scan (WWS) was adopted, together with the introduction of CCDs throughout the bridge simulator.

The final data capture using the same methodology as for initial data collection was carried out. However, the participants were briefed on the WWS method and the significance of maintaining a proper lookout by highlighting the proposed definition of the term 'proper lookout'. Analysis and comparison of the data led to the following:

1. Aviation pilots spend 4-5 seconds on MFDs versus 16 seconds on maintaining physical/visual lookout – DER 1:6.7 between looking at MFDs and looking outside.
2. DER on Real Ships (S2) – 1:0.7 – proves a significant improvement is required to avoid accidents attributed to 'poor lookout'.
3. In bridge simulator:
    a. DER with no MFDs (S1) – 1:17.6
    b. DER with MFDs (S3) – 1:1.1
    c. DER with CCD concept plus WWS method implemented (S4) – 1:2.2.
    d. DER in a real training exercise in bridge simulators (S5) – 1:0.9.

According to Ren et al., (2008), '*it is only possible to observe human errors indirectly by observation of human behaviours'*. The thesis authors' research findings confirm the optimum DER for the maritime industry to be 1:3.5 (

Table ***16***); it is a ratio to aim for during training as well as onboard real ships. This DER provides an easy to use mechanism to observe watchkeeper behaviour that has a potential to lead towards human error, as indicated by Ren et al., (2008).

This same DER can also be used to test the MFD design (Hareide and Ostnes, 2018) to ensure they do not cause more distractions than this optimum value. However, as evidenced through research in the aviation industry, the aimed DER is almost impossible to maintain consistently due to variations in the tasks that the pilots have to perform (EASA, 2021). This is evidenced through this research where in S4, the DER with CCD concept plus WWS method implemented was found to be 1:2.2. The same principle would therefore apply to the maritime watchkeepers wherein they will require significant behavioural changing training in the simulators, followed on by

continuous application of the methods presented in this study together with consistent practice throughout their career.

These findings from the research have been shared with the industry through published research papers, magazine articles and seminar/conference presentations listed in Appendix 8: Published Papers & Presentations. It is anticipated that the MCA will take a lead on recommending inclusion of this definition in the IRPCS's future revision, together with introducing it to seafarer training through its Marine Guidance Notes (MGNs). In summary:

- Recommendations to the legislators/regulators (e.g. UK MCA) to include definition of the term 'proper lookout' in IRPCS/STCW Code. This will lead to changes in training in watchkeeping practices for seafarers.
- Recommendations to the maritime industry to adopt the WWS method for scanning the horizon to improve and maintain better-quality watchkeeping behaviours.
- Recommendations to the bridge equipment display (MFD) manufacturers as well as to the IMO are proposed to revisit the bridge MFD design to:
    - Declutter displays by reducing duplication of information. This will also have an automatic impact on reduction in distractions caused by MFDs in night vision. However, this particular aspect will need to be studied further for new proposed display designs.
    - Provision of only the necessary information for navigation and collision avoidance at all times, with an option to call upon additional information when required.
    - Adoption by IMO of GBS for MFDs so that equipment manufacturers would not need to wait for an update of IMO equipment standards to implement changes in response to technological changes.
- It is recommended that ETDs should be used during simulator training to monitor watchkeeping trainees to guide them in improving their watchkeeping behaviour by applying proper lookout techniques, together with the WWS method. Ideally, this should be applied at a wider level

whereby maritime watchkeepers' training includes a support system for simulator instructors and assessors to use ETDs in their assessment. This system can make use of the real-time display of fixations and scan path of eye movement fed from the ETD and displayed at the instructor's station, allowing the instructor to provide realistic feedback to the watchkeepers during simulations.

7.4 Recommendations for Future Research

Based on the work carried out during this study, some areas that require further work are summarised here.

It has now been established that the MFDs on a ship's bridge 'distract' watchkeepers from performing their primary function of maintaining a proper lookout and therefore reduces their ability to maintain a fully informed SA. In the UK, aviation industry pilots are required to timeshare their lookout time for no more than 4-5 seconds on MFDs versus 16 seconds on maintaining physical/visual lookout – a ratio of 1:6.7 between looking at MFDs and looking outside, which has been noted in this thesis as the DER. It has been established that when MFDs are turned off on the ship's bridge (in a simulator), this ratio is 1:17.6 but drops down to 1:1.1 when MFDs are switched on to display all IMO mandated data on MFDs. The worrying factor is that when the same data collected on real ships shows a ratio of 1:0.7, verifying that a considerable improvement in DER is required on real ships. In order to overcome the issue of watchkeepers spending a large proportion of their time on MFDs, based on the evidence obtained through this research, it is proposed that:

a. Once the watchkeepers have been briefed about the WWS method and have practiced this new approach for some time, further data should be captured on each bridge by using ETDs to analyse if there is an improvement in their behaviour for maintaining a lookout. Once the results are established from data captured on real ships, the outputs will go a long way towards informing the global shipping community on changes that do not cost anything but are likely to provide signification improvement in navigational safety.

b. It is therefore paramount that separate studies are carried out to investigate the following based on research presented in this thesis:

   - The MFDs and other instrument panels on each ship's bridge must be analysed to assess for any distractions caused by them. Results of these findings should be made known to the watchkeepers so that they can mitigate identified weaknesses through a simple risk management approach. This approach should include prioritisation and distribution of information displayed on the bridge according to OOWs' location as well as identifying focal points for maintaining a full SA. This may involve conducting multiple ETD based studies to assess differences in different focal points on the bridge as learned from aviation industry's fully qualified pilots' who showed a 3:2 ratio between MFDs and lookout of cockpit (Yu et al., 2014).
   - Applying the approach adopted in this study, establish weaknesses in the visual scanning patterns maintained at various levels of OOW competence and make recommendations to improve these techniques in a format similar to the aviation industry's VFR and IFR.

c. The primary research proposes the application of the CCD concept, but it will be extremely difficult to implement it on real ships due to technological limitations and the global nature of IMO standards controlling the design of MFDs, requiring agreements at IMO level and then implementation at national level across the globe. An easier route to follow could be if IMO develops GBS for MFDs allowing manufacturers to expedite changes in line with technological advances. This latter will also require input from bridge equipment manufacturers, classification societies, as well as government bodies such as the MCA, ATSB, and USCG, etc. Nevertheless, changes in procedures relevant to the WWS method will still have wider benefits, while the changes in MFD design are being further investigated and implemented.

d. The changes in MFD design will also trigger a change in the training structure for watchkeepers, such as updating the NAESTO Course standard

in the UK, whereby monitoring of watchkeepers' eye movement should become part of the training to improve their behaviour towards better application of the proposed 'proper lookout' definition and associated procedures presented in this thesis. This is not withstanding the fact that both the MFD and bridge layout design in simulators follow the IMO standards for real ships. This means the simulator layout and training delivered in simulators can be changed to test the prototypes of any proposed changes, but the real impact can only be studied when these changes have gone through further rigorous research as well as agreed and implemented at IMO level and beyond.

e. Bridge navigation simulators have been used for training watchkeepers for decades but until they are effectively used to prepare them for real-life scenarios, incidents associated with a failure to maintain an effective lookout will continue to take place. To efficiently use the limited time available for training in simulators, this research looks into making recommendations for improvement for training standards, such as:
   - The impact of bridge instrumentation on the watchkeeper – is it a distraction from their primary lookout function? Do the OOWs appreciate that they are being distracted?
   - Do these distractions have any impact on their SA and therefore the OOW's decision making ability?
   - Can the bridge be operated without instrumentation or with limited instruments?
   - Do watchkeepers with different levels of experience or qualifications, such as a new OOW, an experienced OOW, a chief mate, master or pilot; adopt different approaches to maintaining a lookout?
   - If there are differences, where are the significant gaps?
   - How can these gaps be reduced or closed entirely?
   - What changes can be made to the bridge layout to improve OOWs situational awareness?

f. The current research was based on the use of ETDs to monitor watchkeepers' eye movement and did not include many other factors, such as level of fatigue for the participants, the area of the ship's operation and the related need to assess workload with respect to heavy traffic density or coastal navigation. It is suggested that future work should include these areas, as well as the use of Functional Near-Infrared Spectroscopy (fNIRs) or similar devices to measure differences in stress levels and mental workload (Hareide and Ostnes, 2018) on participants when the proposed changes are implemented.

g. The impact of illumination on watchkeepers' capacity for dark adaptation was not included in the original scope of this research; hence, the recommendations are only based on a literature review. Any future research, therefore, should incorporate dedicated data capture that measures the impact of illumination on dark adaptation.

7.5 Conclusion

The work presented here has initially documented a literature review underlining the issues related to the inability of watchkeepers to maintain a proper lookout. This weak link has been allowed to exist through two reasons. One - a lack of proper definition of this term in IRPCS/STCW Code, and two - a lack of user input into bridge equipment design, such as the layout and particularly presentation of navigational and collision avoidance information for the watchkeeper.

The maritime watchkeeper's work includes the primary task of maintaining a proper lookout, but due to a lack of its definition, and no guidance is provided by regulators on performing this function, leaving a skill gap that prevents watchkeepers from attaining full situational awareness. This also appears to result from a lack of research on this topic, combined with the fact that modern bridges now have a large number of MFDs drawing watchkeepers' focus away from their primary task of maintaining a lookout. A definition of proper lookout is presented in this thesis for inclusion in the STCW Code and/or International Regulations for Preventing Collisions at Sea (IRPCS).

ETDs have been used in the aviation industry to understand pilots' behaviour (Martinez-Marquez et al., 2021) in maintaining a proper lookout and assessing the correct approach to time-sharing between looking at visual screens (i.e., views of the real world, e.g., through windows) and MFDs. This report shows that certain MFDs draw watchkeepers' focus for significant durations, distracting them from their primary task. A Distraction Evaluation Ratio (DER) resulting from distractions caused by MFDs on a simulated ship's bridge was obtained in this research which can assist in verifying time spent on maintaining a lookout by sight. The results show that if the DER is below certain levels, it can either be used to prompt a warning for the watchkeeper to alter their watchkeeping behaviour or, alternatively, trigger an increase in the level of manning on the bridge.

ETDs can also be used to evaluate MFD locations and layout, together with the overall bridge design in addition to monitoring trainees' attention allocation during simulator based watchkeeping training. If ETDs are utilised as an integral part of simulator training, not only can SA be built into it but it will also provide instant feedback to the trainees to improve their watchkeeping behaviour.

Assessments for aviation pilots require a demonstration of correct, adequate and systematic lookout that incorporates recommended visual scanning techniques (EASA, 2021), but there is no equivalent or comparable requirement in the maritime industry. This thesis presents evidence that when watchkeepers are trained in an appropriate technique, the DER can be improved so that the watchkeepers spend appropriate time on visual scanning of environment around the ship. This, however, needs to be applied at a wider level whereby maritime watchkeeper training includes a support system for simulator instructors and assessors to use ETDs in their assessment. This system can make use of the real-time display of fixations and scan path of eye movement fed from the ETD and displayed at the instructor's station, allowing the instructor to provide realistic feedback to the watchkeepers during simulations. At the same time, MFD locations and the information displayed on them can be rationalised by equipment manufacturers through utilising the data acquired with ETDs to mitigate distractions caused by MFDs, as presented in the CCD concept in this report.

The following is a summary of outputs from this study:

- A definition of the term ‘proper lookout’ that can be applied in all navigational watchkeeping situations.
- A scan method to apportion time between looking outside the bridge window and the time that can be spent on looking at the MFDs.
- A method that can be used during simulator training to train and assess watchkeepers on guidance provided for the Window Wiper Scan method.
- The CCD concept, which can be adopted by bridge equipment manufacturers to reduce information overload, improve the DER for maintaining a visual lookout and reduce interruptions to dark adaptation.

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Appendix 1: Work Package Summary

WP	Title	Aims
WP1	Project Setup	Project Initiation - Completion of project proposal
WP2	Development of exercises for data collection	Detailed specifications of exercises for data collection
WP3	Ergonomic issue identification	Research into the principles of Human Centred Design (HCD) and how to apply them to the interfaces on a ship's bridge
WP4	Simulator-based data acquisition - Lookout horizon scanning, with and without distractions	Data collection for human-machine interaction on ship's bridge to: • understand the factors that divert an officer's attention away from their primary role of maintaining a proper lookout to maintain SA at all times. • identify an 'optimised' visual scanning pattern to allow the watchkeeping officer to maintain an efficient lookout whilst watch keeping;
WP5	Prototype, ideal interface, concept bridge design	Design and install 'bridge of the future' prototype (Implement bridge design changes based on WP2, WP3, WP4 findings)
WP6	Simulator-based data acquisition - Upon installation of the 'bridge of the future', observations generated from sessions in the ship simulator.	Evaluate the layout of the information displayed for the officer and identify possible improvements considering research carried out in the aviation industry.
WP7	Report writing and dissemination	Disseminate research findings

Appendix 2: Eye Tracking Device (ETD) Specifications

Table 17 - ETD Specifications (Imotions, 2022)

Sample rate	**60 Hz / 120 Hz**
Accuracy	0.5°
Eye tracking technique	Dark pupil
Binocular eye tracking	Yes
Parallax compensation	Yes
Calibration procedure	0-point, 1-point and 3-point
Dimensions	173 x 58 x 156 mm; 138 to 180 mm (head width ear to ear)
Scene camera, video resolution	1280x960p @ 24FPS, 960x720p @ 30 FPS;
Scene camera, video format	H.264
Scene camera, field of view	60° horizontal, 46° vertical
Audio	Integrated microphone

BeGaze Software

The BeGaze software version 3.7 (January 2017) supplied by SensoMotric Instruments (SMI) was used to process ETD data in this research.

Appendix 3: Scan Path Data

Figure 42 - Gridded Areas of Interest (AOIs)

After exporting data from BeGaze, the scan path for each participant was observed for the first and final 3 minutes to differentiate between the following:

- The location (visual channels, Equipment (MFDs) or CCD) where participants spent their time looking.
- An estimate of the amount of time spent on each location.
- Whether there was a path/pattern in the eye movement of participants during their time within the experiment.

Each participant's graph was selected separately to visually inspect it and write comments about their behaviour in this Appendix. In order to avoid cluttering, a graphical representation for a selected scan path for each experiment phase is given here for the first 10 fixations only based on the distribution of bridge area into blocks shown in Figure 42 – Gridded AOIs. To plot the graph, the x-axis was given values 1, 2, 3 to 9 for A, B, C to H, whereas y-axis values were kept as 1, 2, 3 to 8 to make use of SPSS software for analysis.

S1: Phase 1: No Equipment

No training/briefing on scan path given to participants prior to data capture.

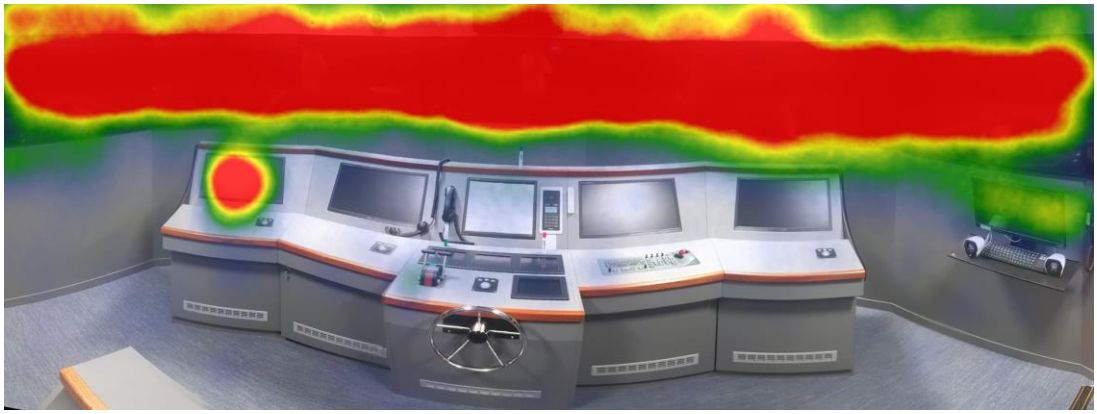


Figure 43 - Heat Map - S1: No Equipment

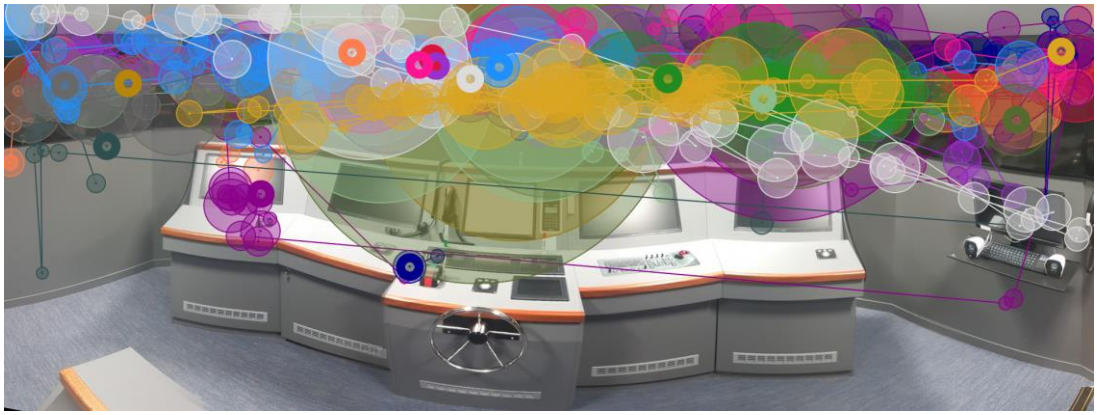


Figure 44 - Scan Path - S1: No Equipment (30 to 60s)

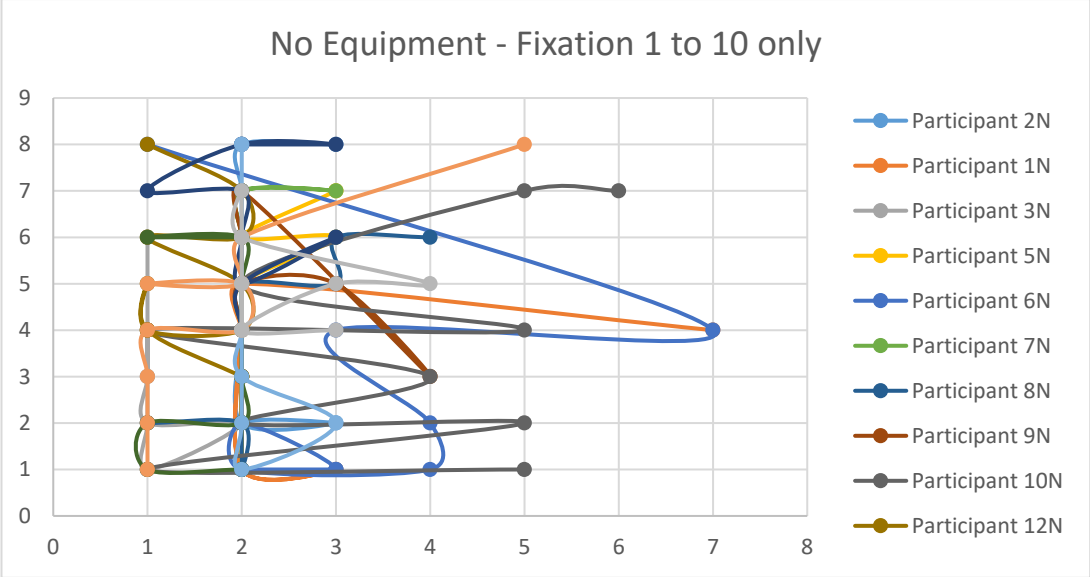


Figure 45 - Scan Path S1: No Equipment

Table 18 - S1: Scan Path Analysis

Participant	Comments
Participant 1N	Haphazard scan path
Participant 2N	Most of the time spent on 2 visual channels, nothing on MFDs
Participant 3N	Most of the time spent on 2 visual channels, nothing on MFDs
Participant 4N	Most of the time spent on 2 visual channels, nothing on MFDs
Participant 5N	Most of the time spent on 2 visual channels, nothing on MFDs
Participant 6N	Haphazard scan path
Participant 7N	Most of the time spent on 2 visual channels, nothing on MFDs
Participant 8N	Haphazard scan path
Participant 9N	Haphazard scan path
Participant 10N	Haphazard scan path
Participant 11N	Data Corrupted
Participant 12N	Most of the time spent on 2 visual channels, nothing on MFDs
Participant 13N	Most of the time spent on 2 visual channels, nothing on MFDs
Participant 14N	Haphazard scan path
Participant 15N	Most of the time spent on 2 visual channels, nothing on MFDs
Participant 16N	Most of the time spent on 2 visual channels, nothing on MFDs

S2: Phase 2: Real Ships

No training/briefing on scan path given to participants prior to data capture.

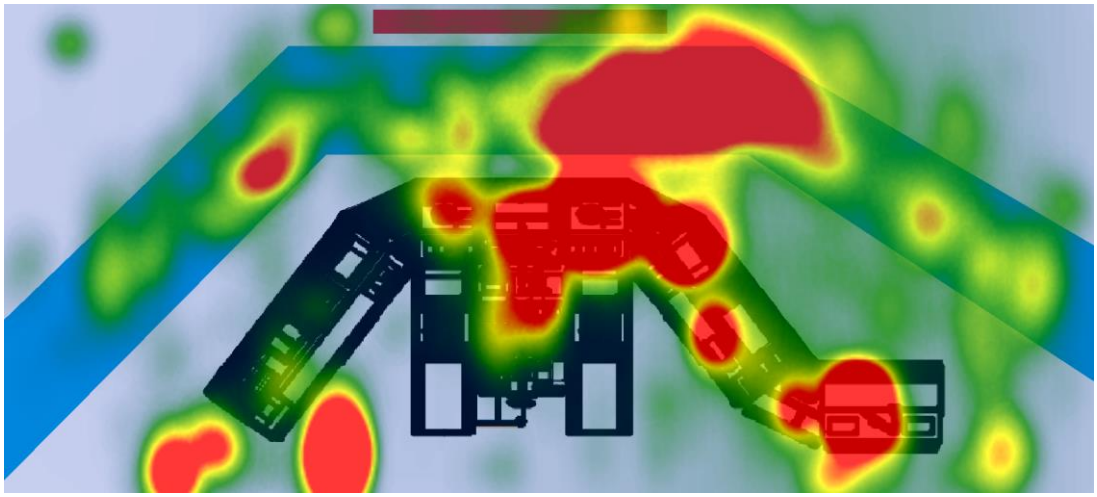


Figure 46 - Heat Map – S2: Real Ships (30 to 60s)

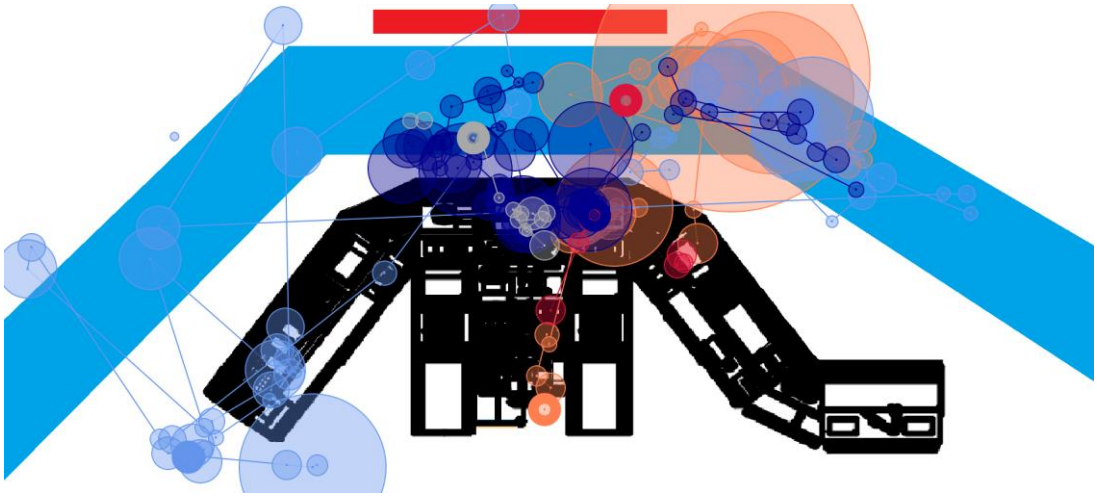


Figure 47 - Scan Path – S2: Real Ships (30 to 60s)

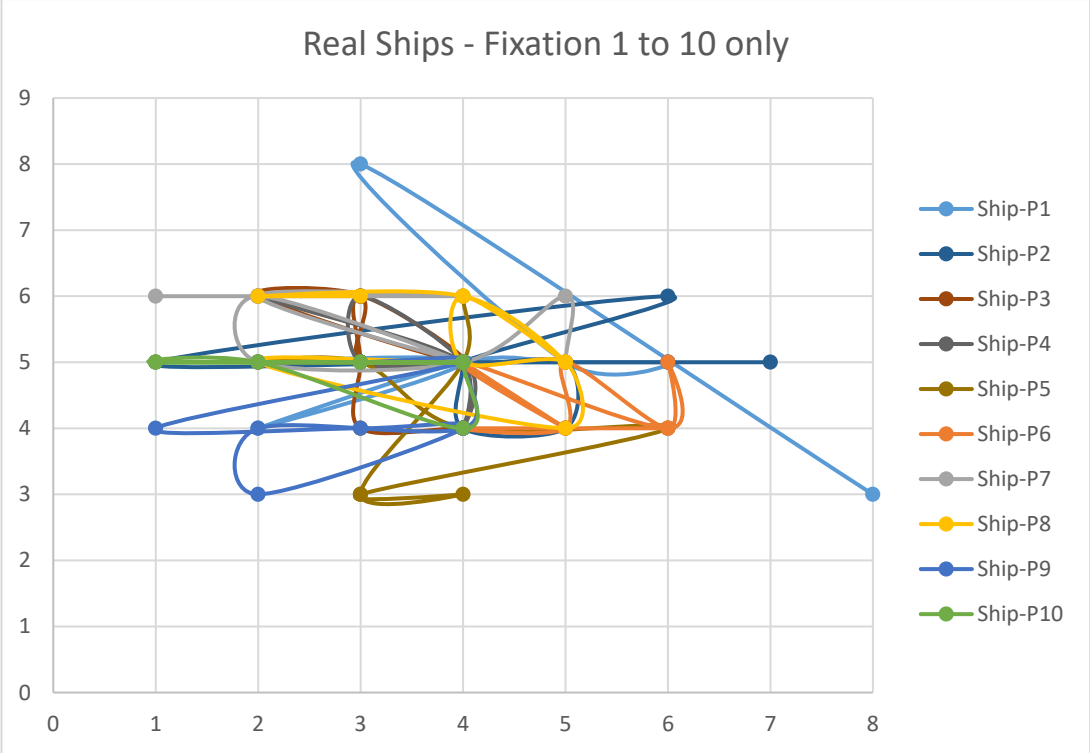


Figure 48 - Scan Path S2: Real Ships

Table 19 - S2: Scan Path Analysis

Participant	Comments
Ship-P1	Most of the visual scanning time spent on limited visual screens space, in front of the participant. Equal amount of time split between visual screen and MFDs
Ship-P2	Most of the visual scanning time spent on limited visual screens space, in front of the participant. Equal amount of time split between visual screen and MFDs
Ship-P3	Visual scan spread over the visual channels and MFDs. No pattern for scanning visual channels or MFDs
Ship-P4	Visual scan spread over the visual channels and MFDs. No pattern for scanning visual channels or MFDs
Ship-P5	Most of the visual scanning time spent on limited visual screens space, in front of the participant. Equal amount of time split between visual screen and MFDs
Ship-P6	Most of the visual scanning time spent on limited visual screens space, in front of the participant. Equal amount of time split between visual screen and MFDs
Ship-P7	More time spent on MFDs. Very little time on maintaining a lookout
Ship-P8	Most of the time spent on MFDs, very little time spent on maintaining a lookout
Ship-P9	Most of the visual scanning time spent on limited visual screens space, in front of the participant. Higher amount of time spent on MFDs than on visual lookout.
Ship-P10	Most of the visual scanning time spent on MFDs with some scattered time spent on visual lookout.

S3: Phase 3: With Equipment

No training/briefing on scan path given to participants prior to data capture.

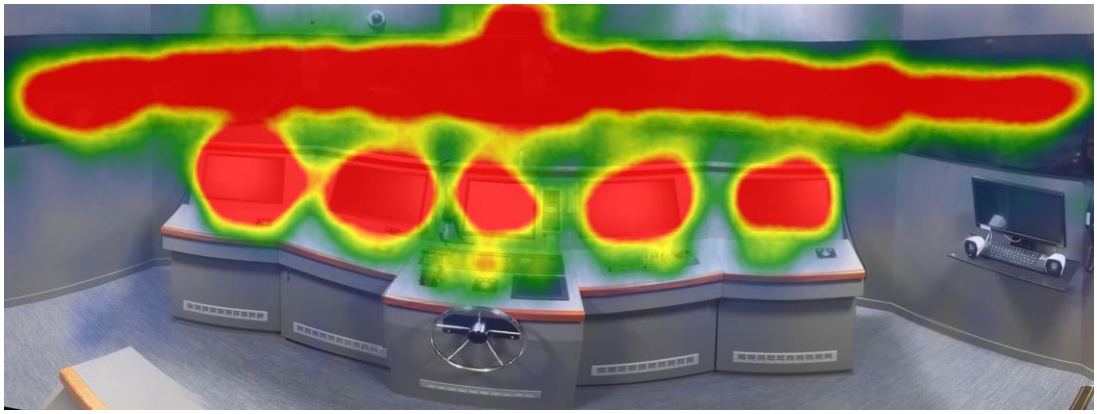


Figure 49 - Heat Map – S3: with MFDs

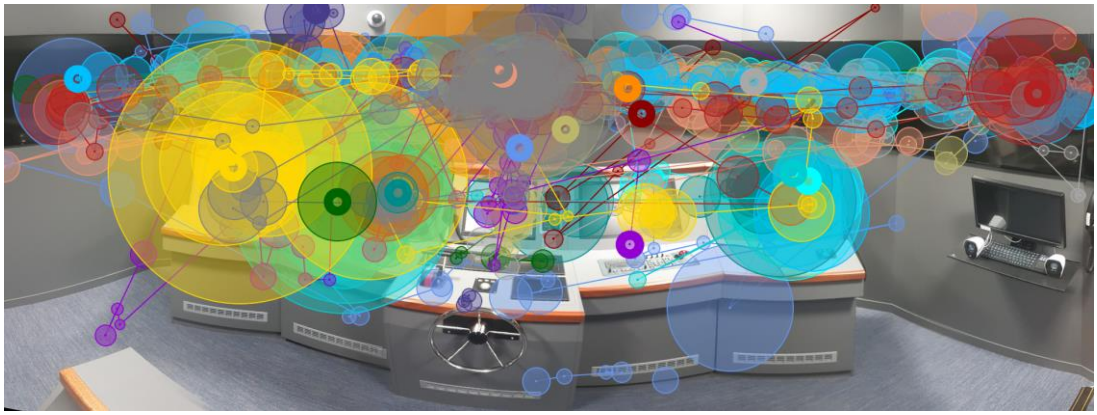


Figure 50 - Scan Path – S3: with MFDs (30 to 60s)

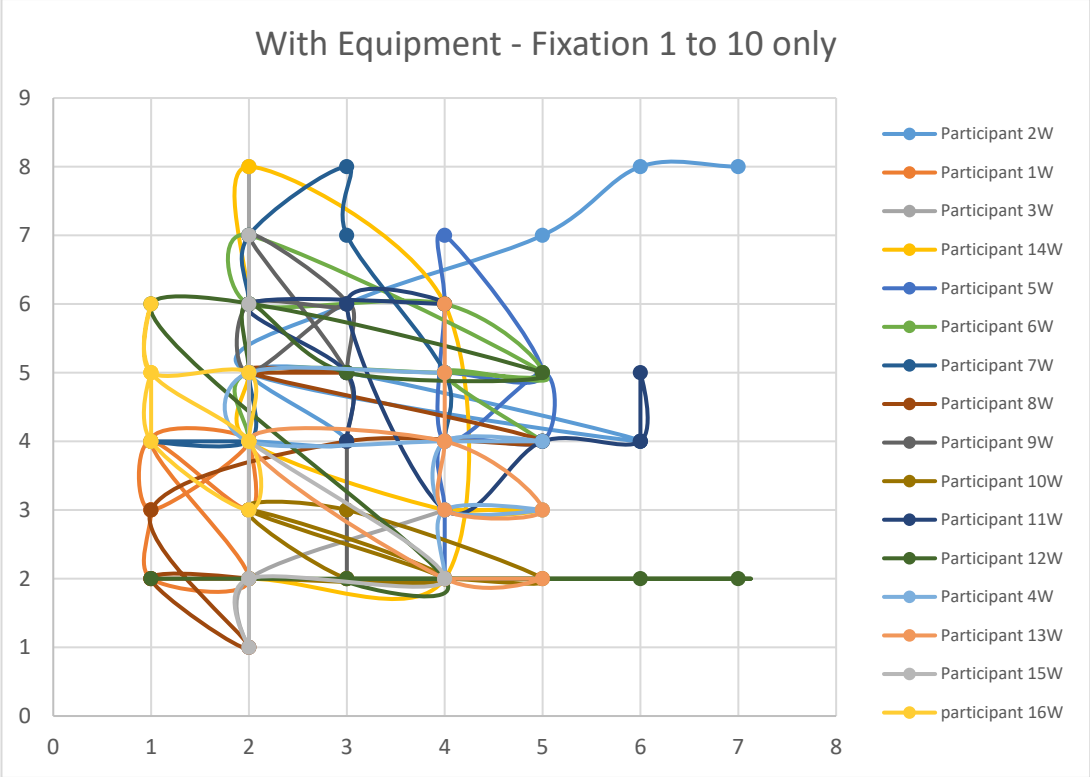


Figure 51 - Scan Path S3: with MFDs

Table 20 - S3: Scan Path Analysis

Participant	Comments
Participant 1W	Haphazard scan path
Participant 2W	Haphazard scan path
Participant 3W	Most of the time spent on 2 visual channels, nothing on MFDs
Participant 4W	Equal time spent on MFDs and visual channels, no pattern for scan path
Participant 5W	Equal time spent on MFDs and visual channels, no pattern for scan path
Participant 6W	More time spent on visual channels than MFDs, no pattern for scan path
Participant 7W	More time spent on MFDs than visual channel MFDs, no pattern for scan path
Participant 8W	More time spent on visual channels and MFDs, no pattern for scan path
Participant 9W	Most of the time spent on 2 visual channels, nothing on MFDs
Participant 10W	More time spent on MFDs than visual channel MFDs, no pattern for scan path
Participant 11W	More time spent on MFDs than visual channel MFDs, no pattern for scan path
Participant 12W	Equal time spent on MFDs and visual channels, no pattern for scan path
Participant 13W	Most of the time spent on 2 visual channels, nothing on MFDs
Participant 14W	Time equally spent on 2 visual channels and MFDs
Participant 15W	Equal time spent on MFDs and visual channels, no pattern for scan path
participant 16W	Most of the time spent on 2 visual channels, nothing on MFDs

S4: Phase 4: With CCD

Training/briefing on Scan path given to participants prior to data capture.

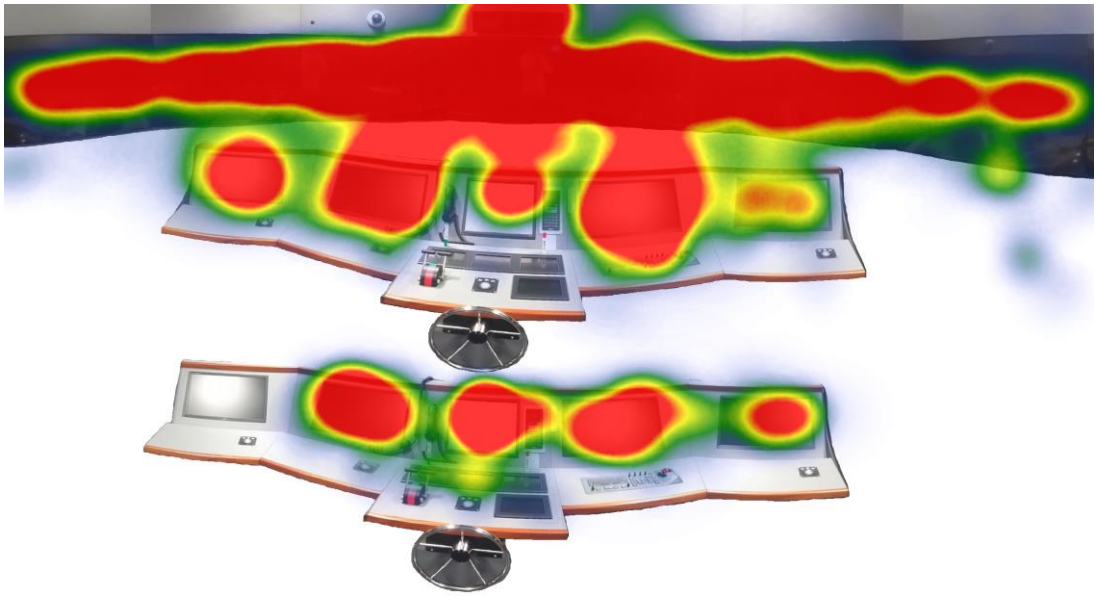


Figure 52 - Heat Map – S4: with CCD

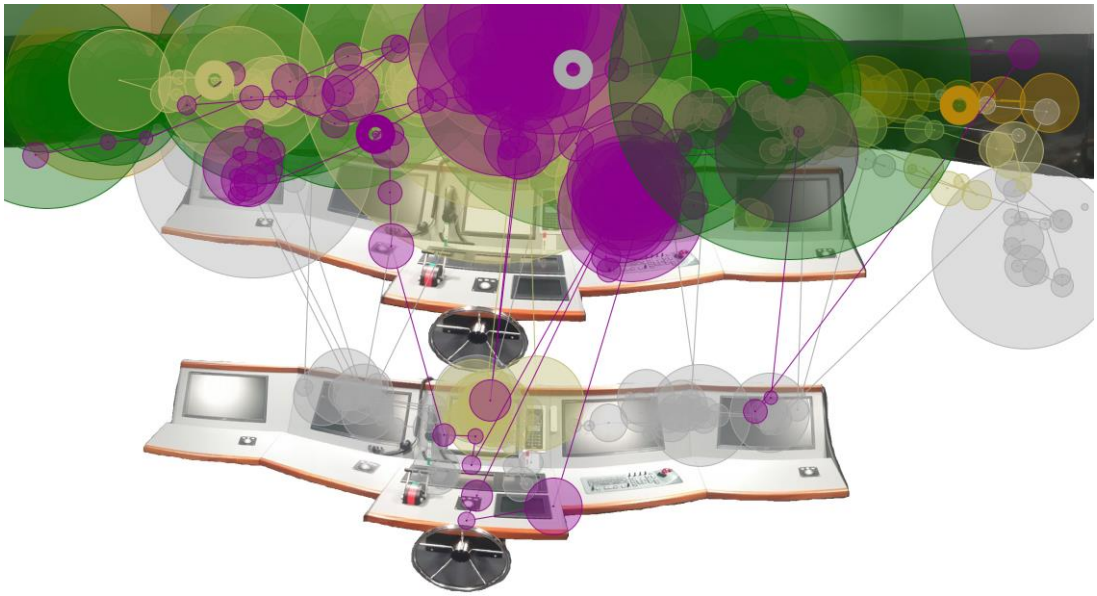


Figure 53 - S4: with CCD

(30s to 2min - duration increased to show a full sweep/scan of the bridge/MFDs)

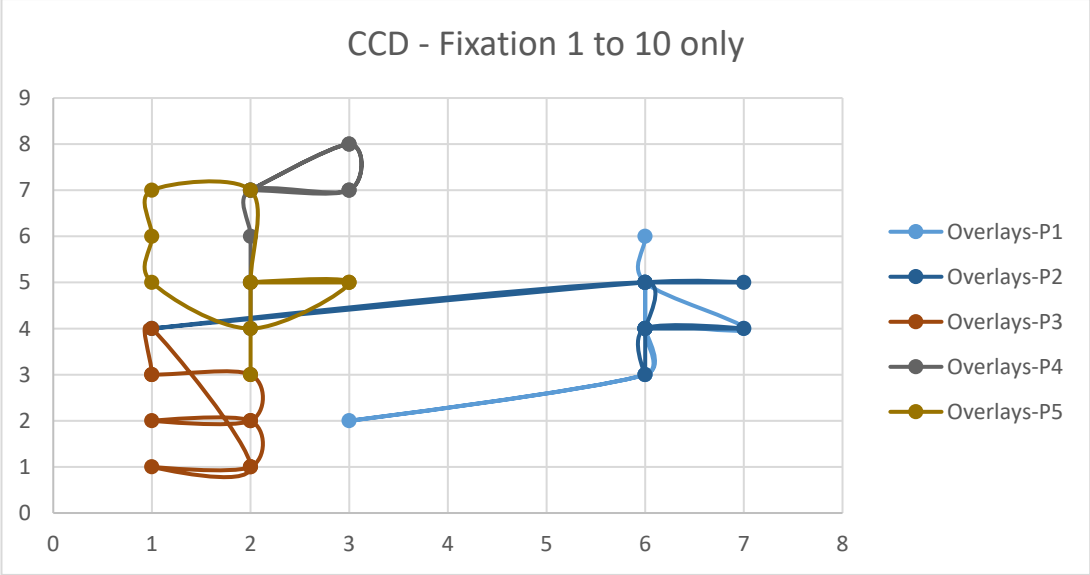


Figure 54 - Scan Path S4: with CCD

Table 21 - S4: Scan Path Analysis

Participant	Comments
Overlays-P1	Considerably more time spent on visual channels than CCDs. ECDIS CCD was the biggest distraction in the experiment. Participant followed Window Wiper Scan (WWS) pattern
Overlays-P2	Participant did not follow the guidance for scan path initially but subsequently followed it to some extent. Overall, more time spent on visual channels but spent considerable time on MFDs
Overlays-P3	Genuinely followed the guidance for scan path. Most of the time spent on visual channels with some time spent on CCD switching to Basic Display for MFDs where required.
Overlays-P4	Genuinely followed the guidance for scan path. Most of the time spent on visual channels with some time spent on Conning and ECDIS CCD where required.
Overlays-P5	Initially followed Scan path guidance but then spent considerable time on ECDIS primary display MFD.

S5: Phase 5 - NAESTO Course

Training/briefing on Scan path given to participants prior to data capture.

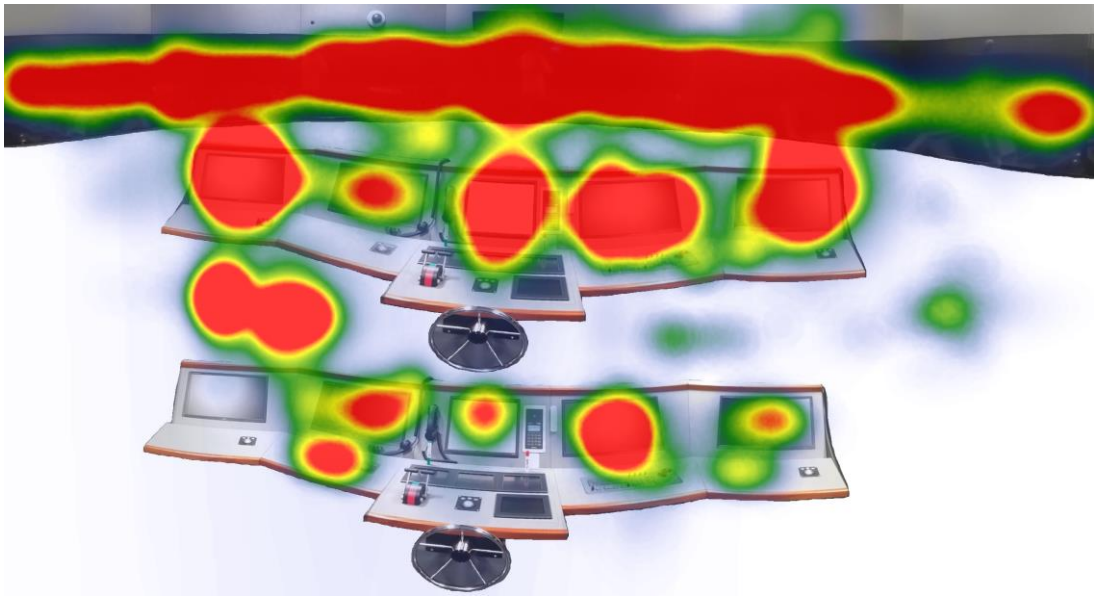


Figure 55 - Heat Map – S5: CCD NAESTO Course

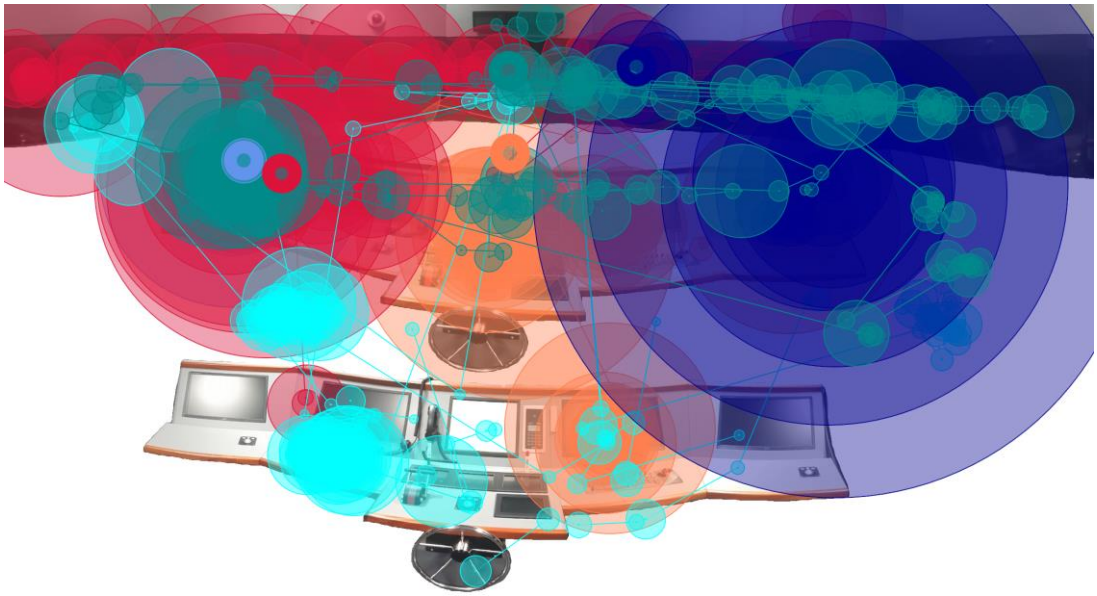


Figure 56 - Scan Path – S5: CCD NAESTO Course (30s to 2m)

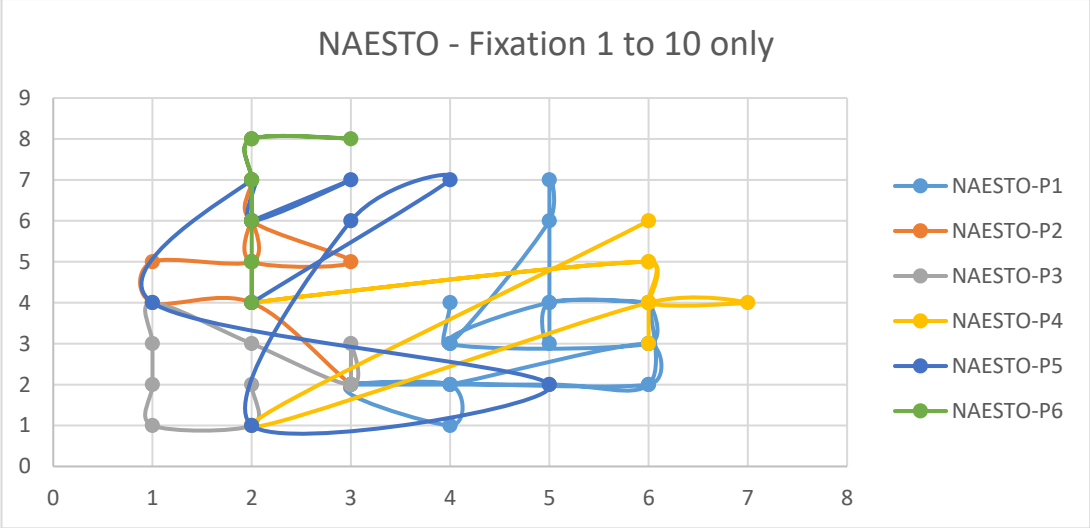


Figure 57 - Scan Path S5: CCD NAESTO Course

Table 22 - S5: Scan Path Analysis

Participant	Comments
NAESTO-P1	No scan pattern despite providing training/briefing.
NAESTO-P2	Appears to follow a path for scan
NAESTO-P3	Appears to follow a path for scan
NAESTO-P4	Shows some compliance with guidance provided
NAESTO-P5	Shows some compliance with guidance provided
NAESTO-P6	Shows some compliance with guidance provided

Appendix 4: LJMU Participant Information Sheet

Liverpool John Moores University

Participant Information sheet

LJMU's Research Ethics Committee Approval Reference	
School/Faculty	School of Engineering
Principal Investigator	Abdul Khalique *a.khalique@ljmu.ac.uk* Head of Maritime Centre
Researchers	Abdul Khalique *a.khalique@ljmu.ac.uk*

You are being invited to take part in this research study. It is important that you understand the reasons for LJMU to undertake this study and more importantly, your input into it. Please take time to read all information in this sheet, discuss it with the researchers or others to satisfy yourselves. The researchers will be pleased to provide you with further details if required.

1. What is the purpose of study?

It has long been known that increased understanding of a danger allows for the development of measures to help mitigate it. An OOW must maintain a proper lookout to ensure a thorough situational awareness. The Masters and OOWs are operating in increasingly time and resource-pressured conditions to process large quantity of information, particularly in complex traffic scenarios. The primary un-answered

question is: ‘are the lookouts’ actually doing their job? The accident reports suggest otherwise, therefore we need to go back to the drawing board to find out why is this happening? The guiding principles for the bridge design and information display layout are defined by IMO but they don’t specify the exact location of the controls and/or displays, which therefore does not allow for the naval architects to design them in a standard format. The current ship bridge design therefore lacks consideration of user experience, in comparison with other industries, e.g. aviation. At the same time, the lookouts are not given any advice or training on the methods to maintain an optimum lookout therefore situational awareness. As a consequence, there appears to be a need for developing new and consistent frameworks for the design of modern ship bridges, their systems as well as guidance and training to maintain lookout. The research will therefore investigate how the human/user-centred design can be incorporated in ship bridge design to reduce the associated human error and improve safety at sea.

2. Why have I been invited to participate?

You have been invited because you are aged 18 or above. In addition, you are an watchkeeper whose primary role is to maintain lookout on ship’s bridge and use information from bridge equipment to maintain situational awareness and take actions to avoid navigational incidents or accidents.

3. Do I have to take part?

No, it is up to you to make this decision. Participation is completely volunteer. If you chose to participate, you will be provided with a copy of this information sheet and will be asked to sign a ‘Researcher Consent Form’. You can discontinue the study for any reason without any explanation and without it affecting your rights/any future service you receive. The data gathered during this research will not be withdrawn as it will be used anonymously.

4. What will happen to me if I take part?

You will be given a briefing on the study procedures with an opportunity to ask any questions. The study will take place within LJMU’s ship’s bridge simulators

located in Room G01, James Parsons Building, Byrom Street, L3 3AF, Liverpool. All participants will undergo the following process when involved in the study:

- On arrival in the simulator, you will be given some induction on the use of simulator and the expectations from you during the exercises.
- Upon satisfactory completion of the induction process, you will be given an Eye Tracking Device (ETD) and a Heartbeat Monitoring Device (HMD).
    - The ETD is like a pair of glasses within cameras fitted within the frame. This device will be connected to a mobile phone type device. The glass within ETD can be removed if required. When the exercise commences, ETD will record the location of your gaze through out the watchkeeping period which is unlikely to exceed 30 minutes. At the end of this period, the ETD will be removed to download data onto a PC. This exercise may be repeated for a different watchkeeping scenario.
    - The Heartbeat/Breath Rate Monitoring Device is like a wristwatch (i.e. the Fitbit or similar) which will be kept on for the duration of exercise.

5. Will I be recorded and how will the recorded media be used?

All exercises in the simulator are recorded for both voice and video. However, this data will not be shared with anyone at all. The data recorded with ETD and HMD will be recorded which will be used for data analyses and result illustrations along with age, gender, maritime experience and qualifications to inform the study outputs. No unspecified use of this data will be made without your written permission and no one outside the project will be allowed access to the original data.

6. What are the possible disadvantages and risks of participating in this study?

No disadvantages or risks are anticipated during this study. If wearing of ETDs or HMD causes any discomfort, you have the option to ask for the exercise to be stopped.

When in simulators, some personnel have experienced nausea or seasickness during the simulations. Again, you may ask the researchers involved with these exercises to stop them at your request.

7. What are the possible advantages of taking part in this study?

This is your opportunity to experience the use of simulators in a very controlled fashion. A £10 Amazon voucher will be offered to you for taking part in this study. Most importantly, your participation in this study will be your contribution to shaping the design of the bridge of the future and therefore have a significant positive impact on safety of navigation.

8. How will the data gathered during this study be used whilst maintaining confidentiality of my personal details?

The information you provide as part of this study is the 'research study data'. Any research study data from which you can be identified (e.g. audio and/or video recordings) is known as 'personal data'. The personal data does not include data that cannot be identified to an individual (e.g. data collected anonymously or where identification has been removed).

If necessary, personal data will be stored confidentially for 5 years after the study has finished. Personal data will be accessible to the research team which will not be transferred outside of the University.

You will not be identifiable in any ensuing reports or publications. Anonymous information which is not identifiable will be stored in locked cabinets and only the researcher and Principal Investigator and others directly linked to this study will have access to the data. ETD and HMD data will only be accessible to the researchers, and the data/information will be deleted from the device once transferred to storage.

Anonymised data might be used for additional or subsequent research studies and we might share anonymised data with other investigators (e.g. in online databases). All personal information that could identify you will be removed or changed

before sharing information with other researchers or making the results/outputs public. The data provided will not be withdrawn as it is not identifiable.

9. How will the research outputs or results will be used?

This project is funded by MarRI-UK whose objective is to act as an innovation vehicle for UK industry and academia to jointly tackle innovation and technology challenges by focusing on research and innovation to address the opportunities between "discovery and research" and "commercialisation" of Maritime Technologies and Systems. The outputs of this study may therefore form part of Doctorate level thesis to satisfy qualification requirements as well as publishing them in magazines, journals or conference papers.

10. Who is organising and funding this study?

This project is funded by MarRI-UK.

11. Who has reviewed this study?

This study has been reviewed by, and received ethics clearance thought, the Liverpool John Moores University Research Ethics Committee (Ref: 120/MME/007)

12. What if something goes wrong?

You can raise any concerns to any of the researchers involved in this study who will do their best to resolve them. The researchers will acknowledge receipt of your concerns within 10 working days and give you an indication of who they intend to deal with it. If you wish to make a complaint, you can contact the chair of the Liverpool John Moores University Research Ethics Committee (researchethics@ljmu.ac.uk).

13. Data Protection Notice

The data controller for this study will be Liverpool John Moores University (LJMU). The University will process your personal data for the purpose of research which is a task we perform in the public interest. The LJMU Data Protection Office provides an oversight of LJMU activities involving the processing of personal data and can be contacted at secretariat@ljmu.ac.uk. This

ensures that we are responsible for looking after your information and using it properly. LJMU's data protection officer can also be contacted at secretariat@ljmu.ac.uk.

Your rights to access, change or move your information are limited, as we need to manage your information in specific ways in order for the research to be reliable and accurate. If you withdraw from the study, we will keep the information about you that we have already obtained. You can find out more about how we use your information by contacting secretariat@ljmu.ac.uk.

If you are concerned about how your personal data is being processed, please contact LJMU in the first instance at secretariat@ljmu.ac.uk. If you remain unsatisfied, you may with to contact the Information Commissioner's Office (ICO). Their contact details, and details of data subject rights are available on ICO website at https://ico.org.uk.

14. Contact for further information.

Abdul Khalique
Head of Maritime Centre
Room 2.35B James Parsons Building, , 3 Byrom St, Liverpool L3 3AF United Kingdom
Email: a.khalique@ljmu.ac.uk
Phone: +44 (0)797 017 3891

Appendix 5: Research Consent Form

Liverpool John Moores University

Research Consent Form

Name of Researcher(s)	Abdul Khalique *a.khalique@ljmu.ac.uk* Head of Maritime Centre

Please read this form carefully. If you do not understand anything or would like more information, please ask the researchers named above.

	Circle
1. I confirm that:	
a) I have been provided with the information about the project in writing via the Participation Information Sheet dated 09/10/2020 or verbally by the researcher(s).	Yes / No
b) I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.	Yes / No
2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving a reason and that this will not affect my legal rights.	Yes / No
3. I understand that any personal information collected during the study will be anonymised and remain confidential.	Yes / No

4. I freely give my consent to participate in this research and have been given a copy of this form for my records. Yes / No

Participant Name		Signature		Date	

Appendix 6: Key Performance Indicators

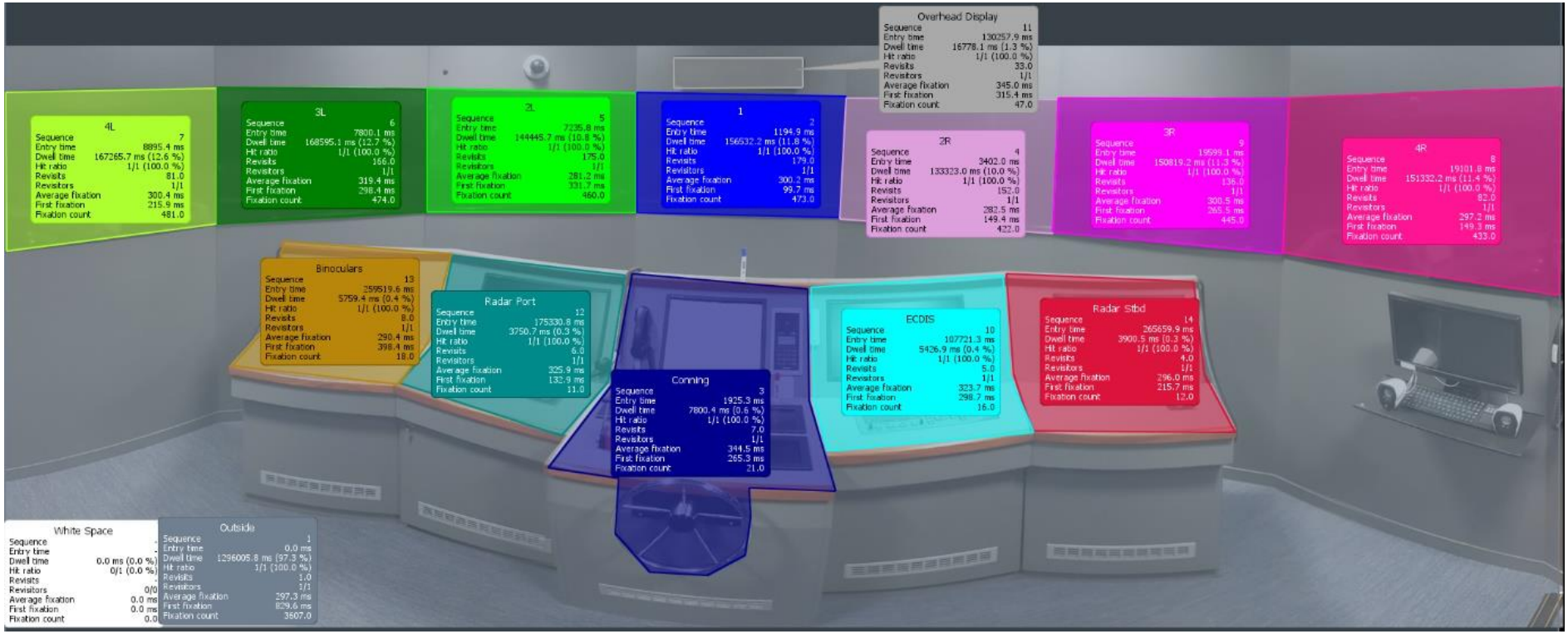


Figure 58 - Key Performance Indicators Example – Full Data

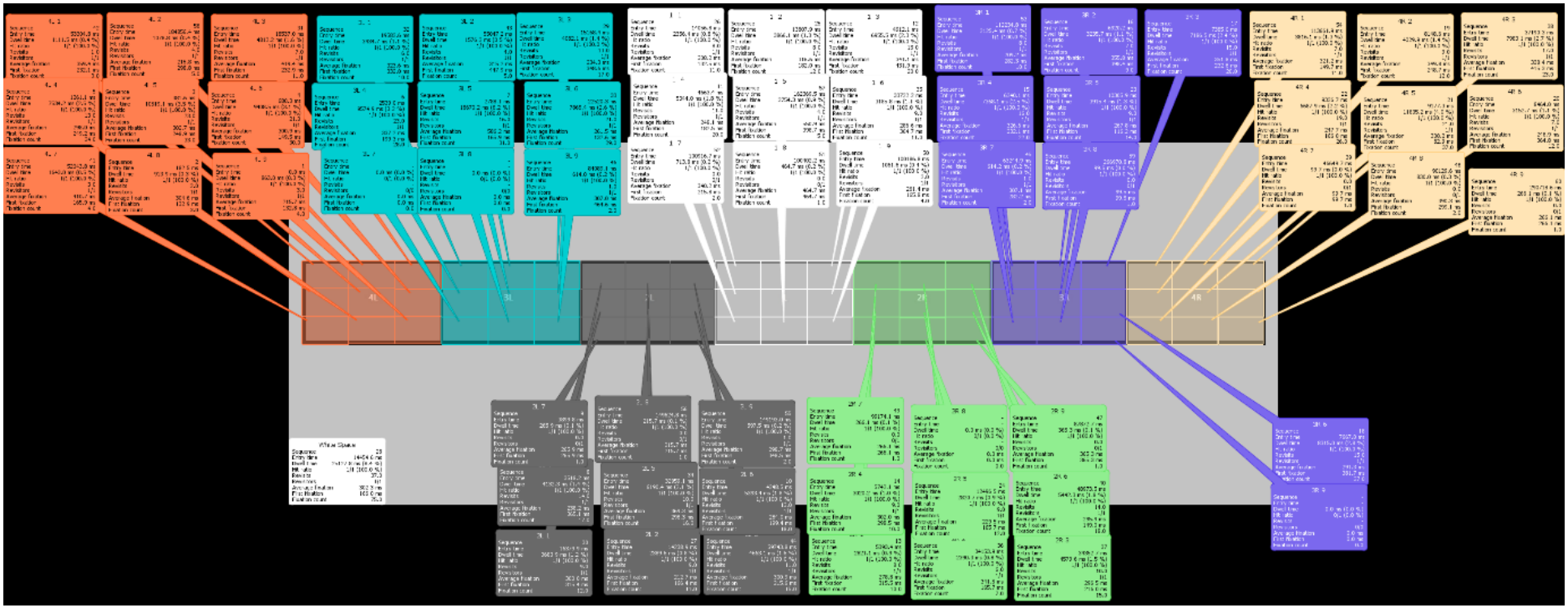


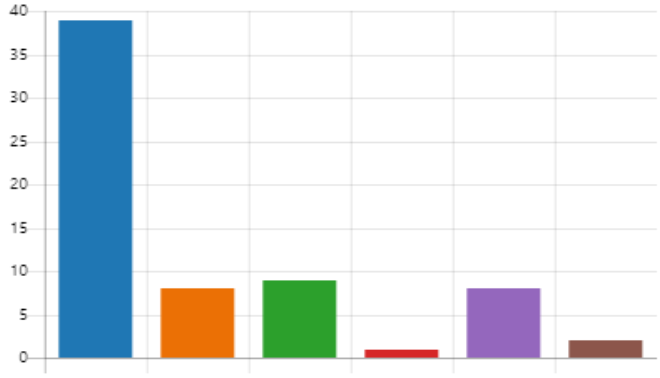
Figure 59 - Key Performance Indicators Example 2 – 5 Minute

Appendix 7: Questionnaire

1. Part 1 Area 1: Participant Background

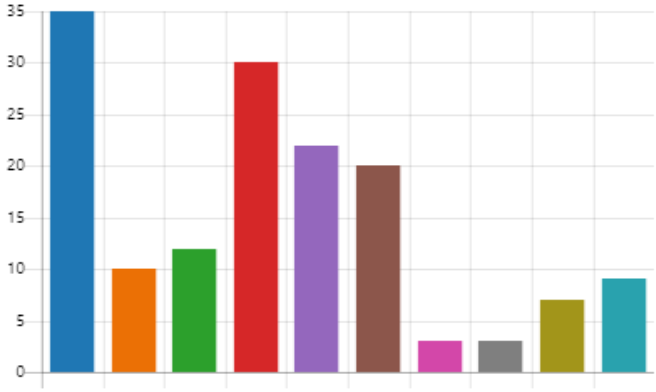
Select your rank:

Master/Captain/Pilot/Skipper	39
Chief Officer	8
Second Officer	9
Third Officer	1
Cadet/Trainee	8
Other	2



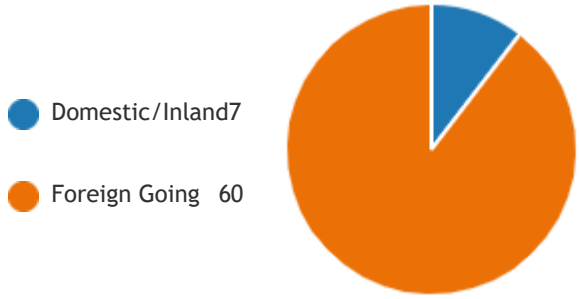
2. Select the type(s) of ships you mostly worked on:

Cargo Ship	35
Cruise Ship	10
Passenger Ferry	12
Tanker (oil or gas)	30
Container	22
Bulk Carrier	20
Fishing Vessel	3
Super Yacht	3
Tug/Harbour Vessel	7
Workboat	9

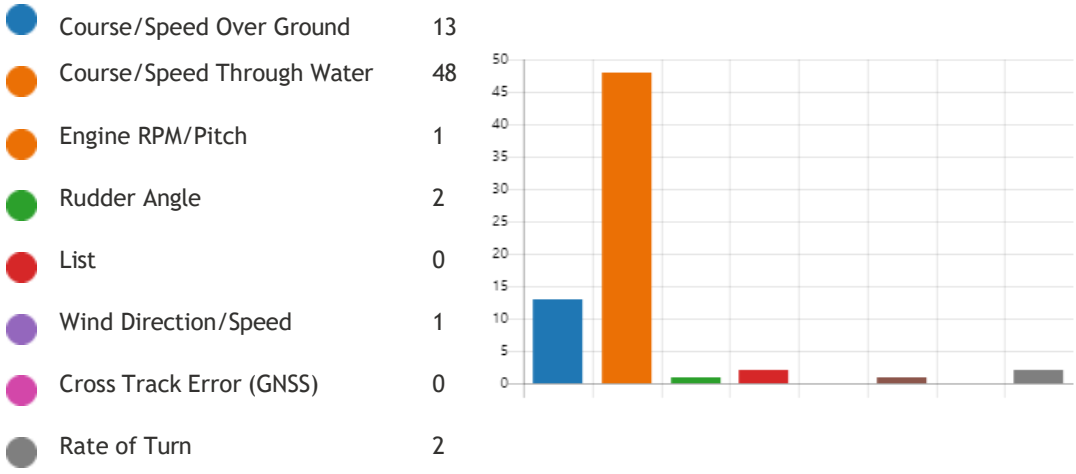


3. Area 2: Vital Own Ship Experience Information

Select the area of trade of your ship

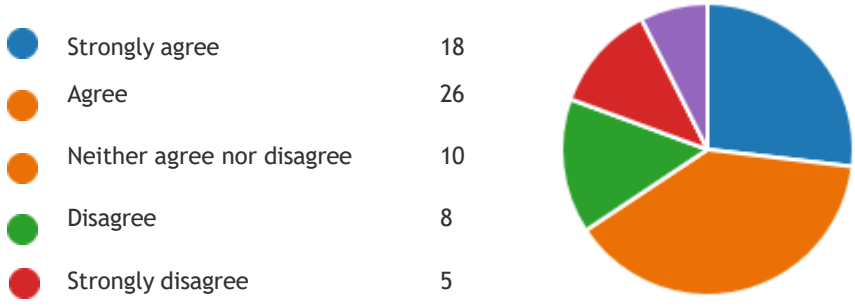


4. To assist the watchkeeping officer in making collision avoidance decisions, identify the most important information from the following list:



5. Area 3: Most Significant Collision Avoidance Information

Do you feel that the watchkeeping officer's needs are a prime consideration in the current bridge design standards?



6. Do you feel that the watchkeeping officer's needs are fully understood by the regulators for bridge design regulations?

Strongly agree	4
Agree	21
Neither agree nor disagree	15
Disagree	19
Strongly disagree	8

7. Can multiple interfaces for the bridge equipment make you question your decision making?

Strongly agree	9
Agree	30
Neither agree nor disagree	11
Disagree	14
Strongly disagree	3

8. Do you feel that multiple interfaces for the bridge equipment distract a watchkeeping officer from completing their primary navigation task? Please provide reasons for your choice in the box provided.

Strongly agree	11
Agree	24
Neither agree nor disagree	15
Disagree	14
Strongly disagree	3

9. Please provide reasons for your choice in Q8

66

Responses

Latest Responses

"Current bridge environment rarely provides prioritisation or hierarch… "Some interfaces are important to have and some are not urgent… "If the bridge has an integrated system most relevant information can …

10. Does the current level of bridge equipment utilising modern technology aid decision making for collision avoidance?

Strongly agree	15
Agree	39
Neither agree nor disagree	8
Disagree	5
Strongly disagree	0

11. On a ship's bridge, technology is provided to facilitate the job of watchkeeper?

Strongly agree	18
Agree	41
Neither agree nor disagree	5
Disagree	3
Strongly disagree	0

12. Decision making in close quarter situations is harder when bridge equipment is showing multiple warnings and alarms?

Strongly agree	19
Agree	28
Neither agree nor disagree	7
Disagree	11
Strongly disagree	2

13. The alarms and warnings provided by bridge equipment can lead to human error?

Strongly agree	15
Agree	29
Neither agree nor disagree	12
Disagree	8
Strongly disagree	3

14. Part 2 Area 4: Most Significant Collision Avoidance Equipment

At the start of your bridge watch, state the most important information that you will check for collision avoidance.

67 Responses

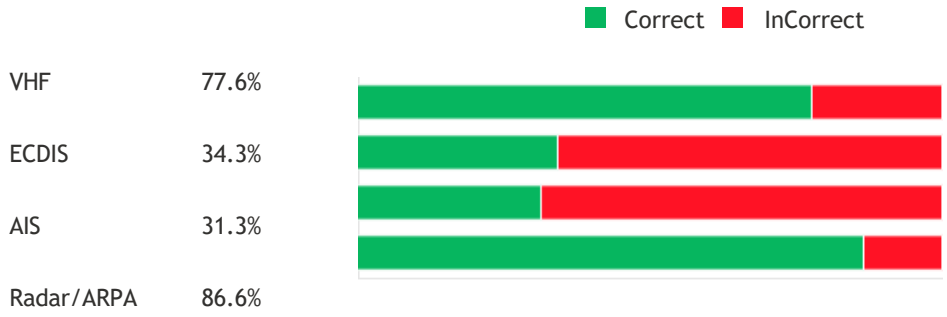
Latest Responses

"Following the initial visual orientation of the environment, x-band foll… "ARPA display"

"Compass error, GPS error, Radar performance, weather forecast (Viz)."

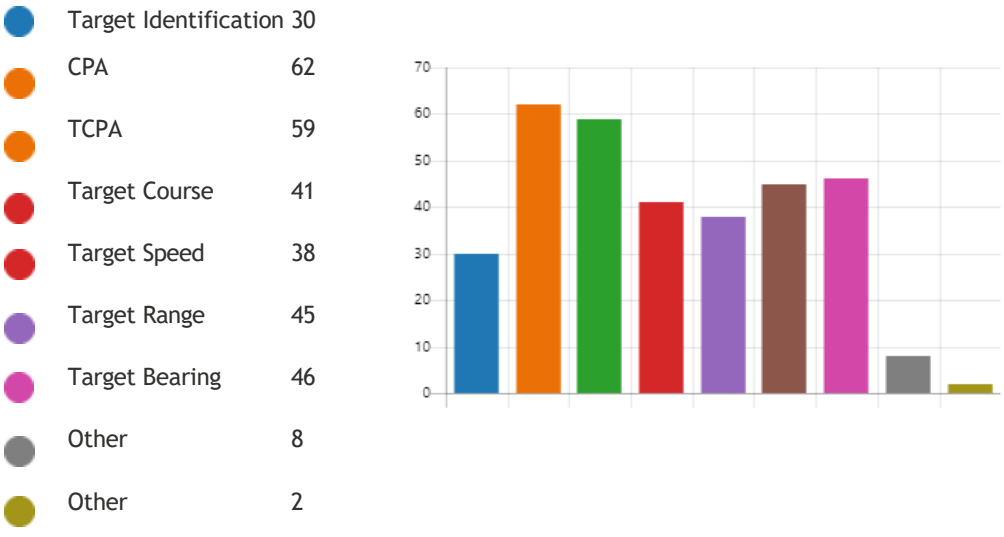
15. Place the following bridge equipment in order of importance for use in collision avoidance.

28% of respondents (19 of 67) answered this question correctly.



16. For the piece of equipment that you selected as the most important in the previous question (Q15), select the information that it provides that you feel is of the most importance to collision avoidance: (e.g. ARPA: Target identification, CPA, TCPA, course, speed, range, bearing)

[Q15: Place the following bridge equipment in order of importance for use in collision avoidance.]



17. **If you have selected 'other' for Q16, then please type what information is the most important for collision avoidance.**

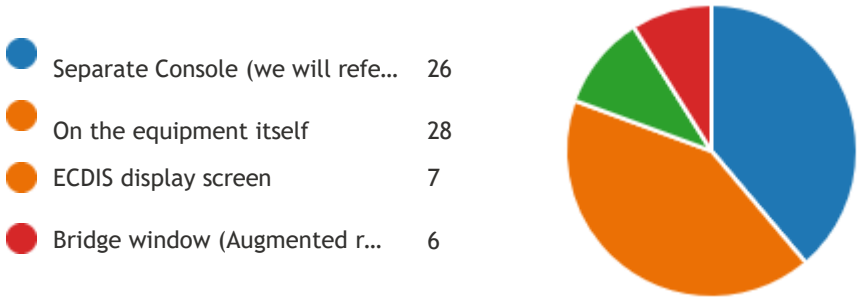
60

Responses

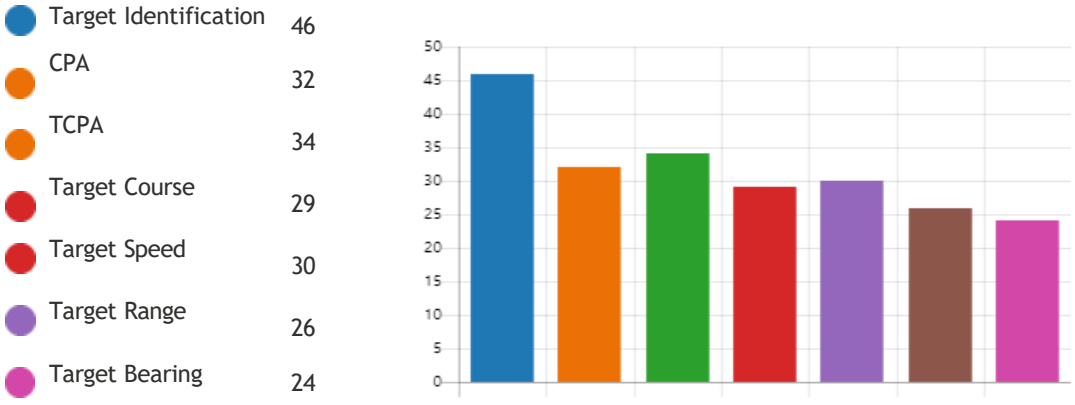
Latest Responses

"N/A"
"NA"
"N/A"

18. **Choose the BEST location where you think this information (in Q15) could be made available for the use of the watchkeeping officer.**

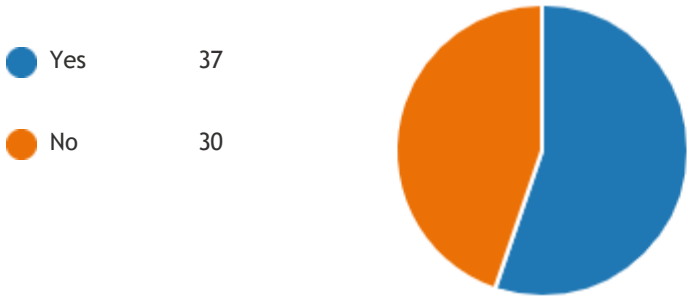


19. **For the piece of equipment that you selected as the second most important in the previous question (Q15), select the information that it provides that you feel is of the most importance to collision avoidance: (e.g. AIS: Target identification, CPA, TCPA, course, speed, range, bearing)** ***[Q15: Place the following bridge equipment in order of importance for use in collision avoidance.]***

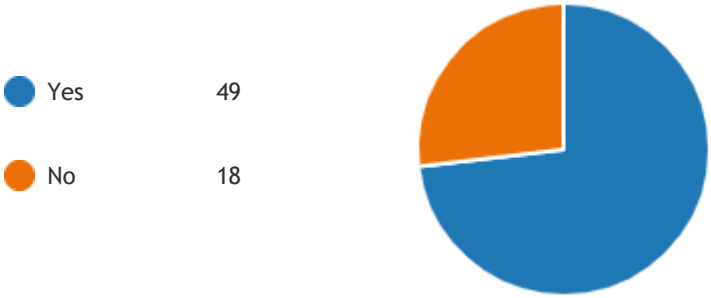


20. Area 5: Audio Visual Equipment Distractions

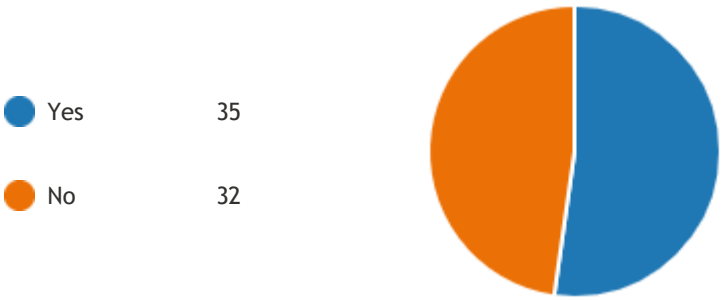
ECDIS – Is the size of the ECDIS display suitable to show the vital information required in critical navigational situations?



21. ECDIS - Can the information shown on ECDIS display be readily interpreted in critical navigational situations?



22. ECDIS - Would it benefit the watchkeeping officer if the most important information from ECDIS was displayed on the CCD (Centre Console Display)? If your answer is Yes, in Q22, provide a list of the items of information that you believe would be most useful.



23. In Q21, you have stated that it will benefit the watchkeeping officer if the most important information from ECDIS was displayed on the CCD (Centre Console Display). Please state the information that can be very useful on CCD

35

Responses

Latest Responses

"Radar Report, AIS data"

"Range, bearing, course, CPA, TCPA of all targets within a designated r…

24. ECDIS - Do you think the audio/visual alarms and warnings on ECDIS lose their impact over time?

25. Radar/ARPA - Is the size of the Radar/ARPA display suitable to show the vital information required in critical navigational situations?

26. Radar/ARPA – Is the information displayed on the Radar/ARPA display readily available in critical navigational situations?

Yes	62
No	5

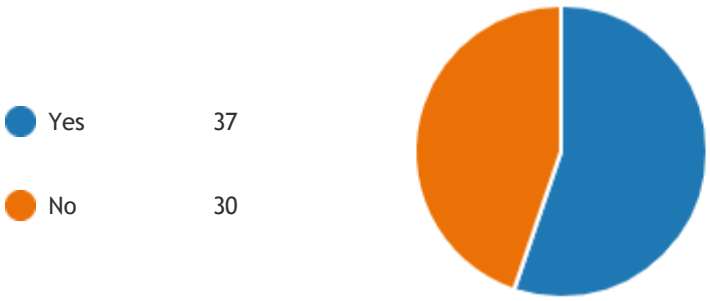
27. Radar/ARPA – Do you think the audio/visual alarms and warnings on Radar/ARPA lose their impact over time?

Yes	29
No	38

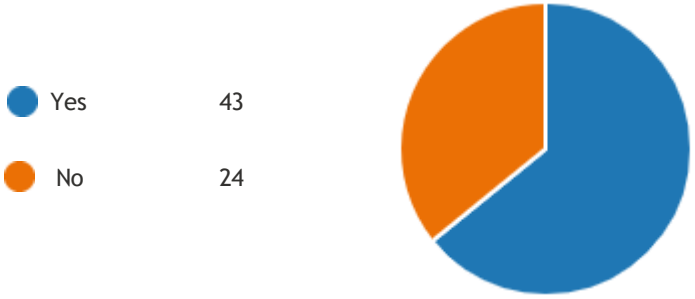
28. AIS – Is the size of the AIS display suitable to show the vital information required in critical navigational situations?

Yes	28
No	39

29. AIS - Is the information displayed on the AIS display readily available in critical navigational situations?

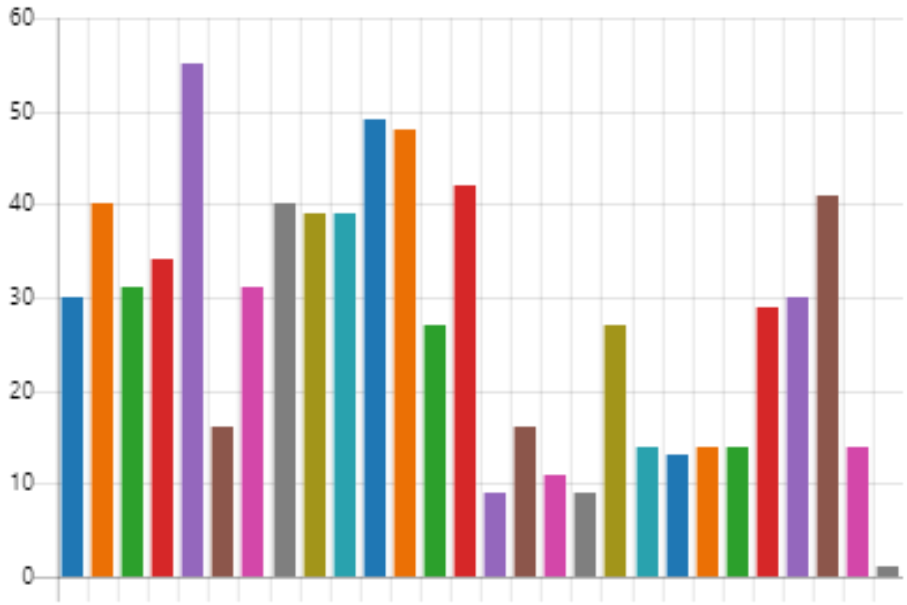


30. AIS - Do you think the audio/visual alarms and warnings on AIS lose their impact over time?



31. For the equipment listed below, identify the information that will most benefit the watchkeeping officer if displayed additionally on the CCD (Centre Console Display).

●	GNSS Lat/Long	30	●	Navtex Messages	9
●	GNSS Course/Speed	40	●	BNWAS Timer	16
●	GNSS Cross Track Error	31	●	AIS Own Course	11
●	GNSS Distance to Next WayPo...	34	●	AIS Own Speed	9
●	Gyro Course	55	●	AIS Target Info - Target ID	27
●	Magnetic Course	16	●	AIS Target Info - Target Course	14
●	Course setting on Autopilot	31	●	AIS Target Info - Target Speed	13
●	ARPA Target Info - Target ID	40	●	AIS Target Info - Target CPA	14
●	ARPA Target Info - Target Cou...	39	●	AIS Target Info - Target TCPA	14
●	ARPA Target Info - Target Speed	39	●	ECDIS - Course to Steer	29
●	ARPA Target Info - Target CPA	49	●	ECDIS - Cross Track Error	30
●	ARPA Target Info - Target TCPA	48	●	Ship's Log - Speed	41
●	Echo Sounder Depth	27	●	Ship' Log - Distance	14
●	Echo Sounder UKC	42	●	Other	1



Appendix 8: Published Papers & Presentations

Published Articles and Papers

1. Guo, F., Yang, Z., Davis, E., Khalique, A., and Bury, A. (2021). Does Being Human Cause Human Errors? Consideration of Human-Centred Design in Ship Bridge Design. AHFE 2021. Lecture Notes in Networks and Systems, Vol. 259. Springer, Cham.
2. Khalique, A., Bury, A. (2022). Scanning: from screen to scene: Using the 'windscreen wiper' technique to maintain a proper lookout by sight. Featured Article Seaways: The International Journal of The Nautical Institute, November 2022 [Online]. Available at: https://www.nautinst.org/resources-page/scanning-from-screen-to- scene.html
3. Guo, F., Yang, Z., Davis, E., Mu, B., Wah, M., Khalique, A., and Bury, A. (2022). Towards an Ergonomic Interface in Ship Bridges: Identification of the Design Criteria. Presented at AHFE conference on July 24-28th, 2022.
4. Khalique, A., Bury, A., and Kaminski, K. (2023) LADDER — Lookout Awareness of Distractions The creation of a Distraction Evaluation Ratio [Poster]. Society of Maritime Industries (SMI) Annual Conference 14-15 March 2023, Edinburgh.
5. Khalique, A., Loughney, S., and Bury, A. (2023) Analysis and Optimisation of Best Practice for Proper Lookout at Night. Accepted for presentation in 15th International Conference on Marine Navigation and Safety of Sea Transportation (TransNav). Held on 21-23 June in Gdynia, Poland.
6. Khalique, A., and Bury, A. (2023) Utilising state of the art eye tracking equipment to improve outcomes for maritime watchkeeper's on nocturnal navigational watches. 10th International Conference on Human Interaction and Emerging Technologies. Held in Nice, France, August 22-24, 2023. Human Interaction and Emerging Technologies (IHIET 2023), Vol. 111, 2023, pp. 388–401.
7. Khalique, A., Bury, A. (2023). Light Pollution. Article Seaways: The International Journal of the Nautical Institute. July 2023.

Conference/Seminar Presentations Delivered

1. Khalique, A. (2022) ‘Lookouts Not Looking Out’. MarRI-UK webinar “Innovation through Maritime Research and Innovation UK”. [Online], Strathclyde, Scotland, United Kingdom, 13th October 2022.
2. Khalique, A. (2022) ‘Avoiding MFD (Multi-Function Display) Distractions’. Institute of Marine Engineering, Science & Technology (IMaREST) Northwest England Technical Event held at Liverpool John Moores University, Liverpool, England, United Kingdom, 5th December 2022.
3. Khalique, A. (2023) ‘Utilising state of the art eye tracking equipment to improve outcomes for maritime watchkeeper’s on nocturnal navigational watches’. 10th International Conference on Human Interaction and Emerging Technologies (IHIET 2023) Held in Nice, France, August 22-24, 2023.

Appendix 9: Statistical Analysis Data

Table 23 - Descriptive Statistics - Fixations

	S1 SD	*S2 SD*	*S3 SD*	*S4 SD*	*S5 SD*
Mean	34.05235	46.1831	49.50268	31.947	86.43491
Standard Error	9.465398	11.93169	11.1687	7.410036	28.4521
Median	32.1791	26.15679	36.66165	22.63822	47.10272
Standard Deviation	36.65933	46.21126	43.2562	28.69894	110.1945
Sample Variance	1343.906	2135.48	1871.099	823.6294	12142.83
Kurtosis	4.784846	-0.47535	5.52342	3.283933	7.046009
Skewness	1.922249	0.978535	2.119839	1.833035	2.510516
Range	140.4537	132.8384	175.3946	109.4191	431.5797
Minimum	0.974961	4.110961	3.426892	0.316228	0
Maximum	141.4287	136.9493	178.8215	109.7353	431.5797
Sum	510.7853	692.7465	742.5402	479.2051	1296.524
Count	15	15	15	15	15
Confidence Level (95.0%)	20.30126	25.59094	23.95448	15.89295	61.02368

Table 24 - T-Test: Two-Sample Assuming Unequal Variances (Fixations)

	S1	***S1 vs S2 SD***	***S1 vs S3 SD***	***S1 vs S4 SD***	***S1 vs S5 SD***
Mean	34.05235	46.1831	49.50268	31.947	86.43491
Variance	1343.906	2135.48	1871.099	823.6294	12142.83
Observations	15	15	15	15	15
Hypothesized Mean Difference	0	0	0	0	0
df	27	27	27	26	17
t Stat (Observed?)		-0.79649	-1.05534	0.175141	-1.74694
P(T<=t) one-tail		0.216347	0.150311	0.431163	0.049344
t Critical one-tail		1.703288	1.703288	1.705618	1.739607
P(T<=t) two-tail		0.432694	0.300622	0.862326	0.098687
t Critical two-tail		2.051831	2.051831	2.055529	2.109816

Table 25 - T-Test: Two-Sample Assuming Equal Variances (Fixations)

	S1 SD	S1 vs S2 SD	S1 vs S3 SD	S1 vs S4 SD	S1 vs S5 SD
Mean	34.05235	46.1831	49.50268	31.947	86.43491
Variance	1343.906	2135.48	1871.099	823.6294	12142.83
Observations	15	15	15	15	15
Pooled Variance		1739.693	1607.503	1083.768	6743.367
Hypothesized Mean Difference		0	0	0	0
df		28	28	28	28
t Stat		-0.79649	-1.05534	0.175141	-1.74694
P(T<=t) one-tail		0.216224	0.150146	0.431115	0.045805
t Critical one-tail		1.701131	1.701131	1.701131	1.701131
P(T<=t) two-tail		0.432448	0.300291	0.86223	0.091609
t Critical two-tail		2.048407	2.048407	2.048407	2.048407

Table 26 - F-Test: Two-Sample for Variances (Fixations)

	S1 SD	*S2 SD*	*S3 SD*	*S4 SD*	*S5 SD*
Mean	34.05235	46.1831	49.50268	31.947	86.43491
Variance	1343.906	2135.48	1871.099	823.6294	12142.83
Observations	15	15	15	15	15
df		14	14	14	14
F		0.629323	0.718245	1.631688	0.110675
P(F<=f) one-tail		0.198388	0.271979	0.185277	9.71E-05
F Critical one-tail		0.402621	0.402621	2.483726	0.402621

Table 27 - Descriptive Statistics (Dwell Time)

	S1 SD	*S2 SD*	*S3 SD*	*S4 SD*	*S5 SD*
Mean	3.501145	5.66244	5.005012	4.50637	5.88753
Standard Error	0.717078	1.631036	0.840127	0.936169	1.408999
Median	4.770842	2.390351	4.366378	3.835637	3.641245
Standard Deviation	2.777233	6.316976	3.253799	3.625767	5.45703
Sample Variance	7.713022	39.90419	10.58721	13.14619	29.77918
Kurtosis	-1.53569	1.029873	2.384665	7.610251	0.473648
Skewness	-0.08191	1.427283	1.152727	2.410144	1.153987
Range	7.957855	19.921	12.98985	15.97545	17.56531
Minimum	0.101635	0.505964	0.411221	0	0
Maximum	8.05949	20.42697	13.40107	15.97545	17.56531
Sum	52.51717	84.9366	75.07518	67.59555	88.31295
Count	15	15	15	15	15
Confidence Level (95.0%)	1.53798	3.498225	1.801894	2.007883	3.022003

Table 28 - T-Test: Two-Sample Assuming Unequal Variances (Dwell Time)

	S1	*S1 vs S2 SD*	*S1 vs S3 SD*	*S1 vs S4 SD*	*S1 vs S5 SD*
Mean	3.501145	5.66244	5.005012	4.50637	5.88753
Variance	7.713022	39.90419	10.58721	13.14619	29.77918
Observations	15	15	15	15	15
Hypothesized Mean Difference	0				
df		19	27	26	21
t Stat		-1.21305	-1.36153	-0.85243	-1.50944
P(T<=t) one-tail		0.119989	0.0923	0.200879	0.073043
t Critical one-tail		1.729133	1.703288	1.705618	1.720743
P(T<=t) two-tail		0.239978	0.184601	0.401758	0.146087
t Critical two-tail		2.093024	2.051831	2.055529	2.079614

Table 29 - T-Test: Two-Sample Assuming Equal Variances (Dwell Times)

	S1 SD	*S2 SD*	*S3 SD*	*S4 SD*	*S5 SD*
Mean	3.501145	5.66244	5.005012	4.50637	5.88753
Variance	7.713022	39.90419	10.58721	13.14619	29.77918
Observations	15	15	15	15	15
Pooled Variance		23.8086	9.150114	10.42961	18.7461
Hypothesized Mean Difference		0	0	0	0
df		28	28	28	28
t Stat		-1.21305	-1.36153	-0.85243	-1.50944
P(T<=t) one-tail		0.117623	0.092101	0.200603	0.071195
t Critical one-tail		1.701131	1.701131	1.701131	1.701131
P(T<=t) two-tail		0.235247	0.184203	0.401207	0.142389
t Critical two-tail		2.048407	2.048407	2.048407	2.048407

Table 30 - F-Test: Two-Sample for Variances (Dwell Time)

	S1 SD	*S1 vs S2 SD*	*S1 vs S3 SD*	*S1 vs S4 SD*	*S1 vs S5 SD*
Mean	3.501145	5.662439965	5.005011981	4.506370162	5.887530029
Variance	7.713022	39.90418605	10.58720736	13.14618869	29.77917993
Observations	15	15	15	15	15
df		14	14	14	14
F		0.193288533	0.728522766	0.586711615	0.259007186
P(F<=f) one-tail		0.002020231	0.280656152	0.1649494	0.008233446
F Critical one-tail		0.402620943	0.402620943	0.402620943	0.402620943

Appendix 10: Gantt Chart

PROJECT TITLE	Human Factor: Eliminating Instrumental Distractions on Ship's Bridge To Improve OOW's Situational Awareness Focus	CANDIDATE NAME	Abdul Khalique	Person Number	791617	DATE	10/02/2020

WP ID	Task ID	TASK TITLE	TASK Depend...	START DATE	DURATION IN MONTHS	DURATION IN DAYS	DUE DATE	TASK DURATION RATIO	Status Completion Date
WP1		**Project Setup**		**10/02/20**	**10**	219	**10/12/20**		
WP1.1	T1.1	Project Initiation - Completion of project proposal		10/02/20			18/09/20		**25/09/2020**
	M0	Meeting with supervisor(s) to discuss project initiation	T1.1	11/03/20		160	11/05/20	**73%**	**24/09/2020**
	M1	Meeting with supervisor(s) to finalise project proposal	T1.1	07/09/20			25/09/20		**25/09/2020**
	T1.2	Meeting with simulator staff to set up exercises	M1	07/09/20		15	25/09/20	**7%**	**15/09/2020**
	T1.3	Training in the use of ETD (Eye Tracking Devices) in simulator		22/09/20		9	02/10/20	**4%**	**05/10/2020**
	T1.4	Setting up and testing simulator exercises for data collection	T1.3	03/10/20		15	23/10/20	**7%**	
	M2	Meet with Wartsila and Stena Line to discuss project requirements		03/10/20			07/11/20	**0%**	
	D1	Technical report on WP1 tasks with detailed specifications of exercises for data collection	T1.4	26/10/20		34	10/12/20	**16%**	
WP2		**Ergonomic issue identification and data analysis**		**10/02/20**	**10**	**219**	**10/12/20**		
WP2.1	T2.1	Project Initiation - combined with T1.1		10/02/20			18/09/20		
	M1	Meeting with project supervisor to discuss project initiation (Combined with M1)	T1.1, T2.1	11/03/20		160	11/05/20	**73%**	
	T2.2	Reviewing the current approach to ship's bridge design		11/03/20		239	08/02/21	**109%**	
WP2.2	T2.3	**Data collection 1** - human-machine interaction **in simulator** after completion of T1.1 to T1.5 and observation of participants in 60 half hour sessions (30 sessions for each exercise) in ship simulator	D1	02/11/20			26/02/21		
	M3	Meeting with supervisor(s) to discuss progress in WP2		08/02/21		85	26/02/21	**39%**	
	M4	Meet with Stena Line to discuss shipboard travel arrangements		02/11/20			30/11/20		
WP2.3	T2.4	**Data collection 2** - human-machine interaction **on real ships**. Time spent combined with T2.2	T2.3	30/11/20			02/04/21		
	T2.5	Review and comparison of data collected in WP2.2 and WP2.3 with findings of WP2.5	T2.3, T2.4	02/04/21		44	02/06/21	**20%**	
	D2	Production of conference paper on the research findings	T2.5						
WP3		**Phase 1 simulator-based data acquisition**		**09/11/20**	**6**	**130**	**07/05/21**		
WP3.1	M5	Meeting with supervisor(s) to discuss WP2 progress and planning for WP3	T2.5	09/11/20			20/11/20		
	T3.1	**Data collection 3** - Lookout horizon scanning, with and without distractions based on exercises created in T1.4 and observation of participants in T2.4	T1.4	09/11/20		80	26/02/21	**62%**	
	T3.2	Review of data collected in WP3.1	T3.1	01/03/21		20	26/03/21	**15%**	
	D3	Report for data set composed of observations in T3.1	T3.1	29/03/21		30	07/05/21	**23%**	
WP4		**Phase 1 simulator acquired data analysis**		**10/05/21**	**4**	**90**	**10/09/21**		
WP4.1	M6	Meeting to analyse data collected in WP3.1 and prepare D4		10/05/21		55	21/05/21	**61%**	
	T4.1	Analysis of data collected in WP3.1		10/05/21			23/07/21		
	D4	A report based on data analysed inWP4.1.		26/07/21		35	10/09/21	**39%**	
WP5		**Prototype, ideal interface, concept bridge design**		**10/05/21**	**6**	**130**	**05/11/21**		
WP5.1	M7	Meeting with supervisor(s) to discuss design and implementation of 'bridge of the future'	D3, D4	10/05/21		65	21/10/21	**50%**	
	T5.1	Design and install 'bridge of the future' prototype	M7	10/05/21			06/08/21		
	D5	A report on the human factors centred prototype bridge based on WP4	T5.1	09/08/21		65	05/11/21	**50%**	
WP6		**Demonstration of a concept "bridge of the future" and Phase 2 of simulator-based data acquisition**		**08/11/21**	**8**	**175**	**08/07/22**		
WP6.1	M8	Meeting to discuss data collection in the 'bridge of the future'		08/11/21		60	19/11/21	**34%**	
	T6.1	Set up and test simulator exercises in the 'bridge of the future' for data collection	D5	08/11/21			28/01/22		
	T6.2	**Data Collection 4:** Upon completion of T6.1, observations generated from 30 half an hour sessions within ship simulator.	T6.1	31/01/22		45	01/04/22	**26%**	
	D6	Analysis of data obtained in T6.2		04/04/22		20	29/04/22	**11%**	
	M9	Meeting with supervisors to review the data collected for report preparation		04/04/22			29/04/22		
	D7	Report on finding in WP6.1 in comparision with Distraction Evaluation Ratio (DER) in comparison with data collected in WP4.	D6	02/05/22		50	08/07/22	**29%**	
WP7		**Report writing and dissemination**		**11/07/22**	**8**	**175**	**11/03/23**		
WP7.1	M10	Meeting with supervisor(s) to discuss D8 to D11	All deliverables	11/07/22		46	12/09/22	**20%**	
	D8	A technical report of recommendations to industry, to be included in the final project report/dissertation		11/07/22			12/09/22		
WP7.2	D9	A journal paper, submitted for peer review		11/07/22		81	31/10/22	**40%**	
WP7.3	D10	An article for Seaways or similar magazine		11/07/22		81	31/10/22	**20%**	
	M10	Project final meeting with supervisor, presentations and completon of final project report/dissertation		29/08/22		175	11/03/23	**20%**	
	M11	Meet with Wartsila and Stena Line to provide feedback on research findings		29/08/22			11/03/23		
	D11	Conference/journal paper, aligned with D9		11/07/22			11/03/23		
WP7.4	D12	An article in the Nautilus Telegraph or similar publication, combined with D10		11/07/22			11/03/23