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DEPARTMENT OF COMMERCIAL LAW – SHIPPING LAW UNIT

AN ANALYSIS OF THE FACTORS INHIBITING ECDIS FROM EFFECTUALLY ACHIEVING ITS INTENDED PRIMARY FUNCTION OF CONTRIBUTING TO SAFE NAVIGATION

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I hereby declare that I have read and understood the regulations governing the submission of M. Phil (Shipping Law) dissertations, including those relating to length and plagiarism, as contained in the rules of this University, and that this dissertation conforms to those regulations.

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List of Abbreviations

ABS	American Bureau of Shipping
AGCS	Allianz Global Corporate & Speciality (Insurance)
AIS	Automatic Identification System
AMSA	Australian Maritime Safety Authority
ARPA	Automatic Radar Plotting Aid
BIMCO	Baltic and International Maritime Council
BNWAS	Bridge Navigational Watch Alarm System
BPG	Bridge Procedures Guide (International Chamber of Shipping publication)
BRM	Bridge Resource Management
CATZOC	Category of Zone of Confidence
CIC	Concentrated Inspection Campaign
Circ.	IMO Circular
CIRM	Comité International Radio-Marine
COLREGs	International Regulations for the Prevention of Collisions at Sea, 1972
CPA	Closest Point of Approach
DOC	Document of Compliance (Issued to Companies under the ISM Code)
DR	Dead Reckoning
ECDIS	Electronic Chart Display and Information System
ECS	Electronic Chart System
ENC	Electronic Navigational Chart
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
gt	Gross Tonnage
H&M	Hull and Machinery (Insurance)
HMI	Human Machine Interface
IBS	Integrated Bridge System
ICS	International Chamber of Shipping
IEC	International Electrotechnical Commission
IHO	International Hydrographic Organisation
IMO	International Maritime Organisation
ISM	International Management Code for the Safe Operation of Ships and for Pollution Prevention (International Safety Management Code)
MAIB	Marine Accident Investigation Branch (UK)

MARPOL	International Convention for the Prevention of Pollution from Ships
MCA	Maritime and Coastguard Agency (UK)
MGN	Marine Guidance Note (MCA)
MIN	Marine Information Note (MCA)
MOU	Memorandum of Understanding
MSC	Maritime Safety Committee (IMO)
NI	Nautical Institute
OOW	Officer of the Watch (also Officer / Deck Officer)
P&I	Protection and Indemnity (Insurance)
PSC	Port State Control
RADAR	Radio Detection and Ranging
RCDS	Raster Chart Display System
RIN	Royal Institute of Navigation
RNC	Raster Navigational Chart
SAMSA	South African Maritime Safety Authority
SANHO	South African Navy Hydrographic Office
SCAMIN	Scale Minimum
SENC	System Electronic Navigational Chart
SMC	Safety Management Certificate (Issued to Ships under the ISM Code)
SMM	Safety Management Manual
SMS	Safety Management System
SOLAS	International Convention for the Safety of Life at Sea 1974, as amended
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers 1978, as amended
TSS	Traffic Separation Scheme
UKC	Under Keel Clearance
UKHO	United Kingdom Hydrographic Office
UNCLOS	United Nations Convention on the Law of the Sea
VDR	Voyage Data Recorder
VHF	Very High Frequency
WGS-84	World Geodetic System 1984

TABLE OF CONTENTS

CHAPTER 1 INTRODUCTION

I Background

This research is contextualised in the maritime domain, where since the introduction of legislation mandating the carriage of Electronic Chart Display and Information Systems (ECDIS) by merchant vessels, evidence has emerged of unintended consequences of this legislation – which threaten the safety of navigation.

Amendments to the International Convention for the Safety of Life at Sea (SOLAS) V/19 which came into force in 2011 mandated the carriage of ECDIS for ships on international voyages flying the flag of contracting states.[1] ECDIS carriage thus became compulsory for different vessel types and sizes on a rolling basis that began in 2012 and will be complete in mid-2018.[2] For ECDIS to meet SOLAS carriage requirements, ships must have a back-up system in place, which may be a second ECDIS.[3] There is thus an increasing percentage of the world's fleet that no longer carries paper charts and has transitioned to 'paperless' navigation using electronic charts, marking a fundamental change in the way that vessels navigate.

Despite an apparently robust legal framework regulating the use of ECDIS for safe navigation, the terms 'ECDIS-assisted accidents' and 'ECDIS-assisted groundings' have of late become part of maritime terminology.[4] In recent years, marine accident investigation reports have increasingly identified the failure of bridge watchkeepers to use ECDIS properly as a causal factor in vessel groundings.[5] Yet the International Maritime Organisation (IMO)'s performance standards for ECDIS state: 'The primary function of the ECDIS is to contribute to safe navigation'.[6] The real-time presentation of information displayed by ECDIS should improve officers' cognitive assessment of their navigational situation. Why, then, are these 'ECDIS-assisted accidents' occurring?

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[1] International Convention for the Safety of Life at Sea (SOLAS), 1974, as amended V/19 2.10. The first version of SOLAS was adopted in 1914; the current version was adopted in 1974 and entered into force in 1980. See *http://www.imo.org/en/about/conventions/listofconventions/pages/international-convention-for-the-safety-of-life-at-sea-(solas),-1974.aspx* and *http://www.imo.org/en/About/Conventions/Pages/Home.aspx,* accessed on 31/01/2018.

[2] Ibid.

[3] IMO Resolution MSC.232(82) 'Adoption of the Revised Performance Standards for ECDIS' (2006).

[4] Nielsen, Mads Ragnvald *How a Ship´s Bridge Knows its Position – ECDIS Assisted Accidents from a Contemporary Human Factors Perspective* (unpublished MSc thesis, Lund University, 2016) 10 available at *http://lup.lub.lu.se/student-papers/record/8895474*, accessed on 24/01/2018 (Nielsen).

[5] Marine Accident Investigation Branch (MAIB) (UK) Rep.24/2014 *Report on the investigation of the grounding of Ovit in the Dover Strait on 18 September 2013* (2014); MAIB Rep.22/2017 *Report on the investigation of the grounding of Muros Haisborough Sand North Sea 3 December 2016* (2017).

[6] IMO MSC.232(82).

Although shortcomings in ECDIS design have been identified, it appears that the problem is less with the technology, and more with the operators – and their lack of sufficient training in the use of ECDIS. ECDIS and associated integrated (highly automated) navigational bridge systems are increasingly complex, and deck officers require adequate training to be able to use them correctly and safely. Crucially, navigators must fully comprehend and appreciate the limitations of electronic aids to navigation and integrated systems. When officers have blind faith in ECDIS without fully understanding its operational restrictions, dangerous bridge watchkeeping practices emerge. Overreliance has been identified as a primary risk in the use of ECDIS, as it significantly reduces navigational safety.

II Research Aim and Objectives

The aim of this dissertation is to present an analysis of the factors inhibiting ECDIS from effectually achieving its intended primary function of contributing to safe navigation. Four research objectives were identified as being key in facilitating the achievement of the overall research aim. First, to identify applicable legislation and scrutinise the efficacy of the current legal framework regulating the use of ECDIS. The research is thus contextualised within the lex lata, the effectiveness of which is then assessed. Secondly, to analyse the potentially unsafe technical operational aspects and limitations of ECDIS. Thirdly, to critically evaluate the human factor and human error in the use of ECDIS. Collectively, these two objectives present the challenges in the use of ECDIS from a technical and a human factors perspective. The fourth research objective is to outline current industry initiatives to improve the safety of navigation with ECDIS, and consider additional measures to mitigate unsafe practices in the use of ECDIS by deck officers. Ways to enhance future navigational safety with ECDIS are thus contemplated.

III Research Focus and Dissertation Structure

This research adds value to an area of concern in the shipping industry that is both topical and urgent. The international commercial fleet of merchant vessels – carrying ninety percent of the world's trade[7] – is currently being navigated by deck officers who are not all competent in the safe use of their primary means of navigation. Evidence of this is presented in the case studies

[7] International Chamber of Shipping 'Shipping Facts' available at *http://www.ics-shipping.org/shipping-facts/shipping-and-world-trade* accessed on 24/01/2018.

and commentaries included in this dissertation, and the author's own insight from experience gained while working at sea and while teaching ECDIS training courses is also drawn upon.

Although the Manila Amendments[8] updated the STCW[9] Code to include a requirement for training in ECDIS by deck officers, the revisions did not go far enough in addressing the need for comprehensive instruction in a navigational system fundamentally different to the use of paper charts. ECDIS training has not been sufficiently integrated into the STCW framework and express provisions mandating how ECDIS should be used as an aid to navigation in maintaining a safe watch are inadequate. Recent research aimed at informing future ECDIS design investigated officers' experience with ECDIS and found that 'current ECDIS training regimes themselves could be another pertinent research area'.[10]

Dangerous trends of overreliance on ECDIS – including complacency in the execution of traditional bridge watchkeeping duties to ensure the safety of navigation – are increasingly common on modern bridges, particularly amongst the younger generation of deck officers.[11] Traditional navigation routines have largely been replaced with less interactive, less tactile watchkeeping practices. Monitoring the ship's satellite-derived position displayed on a computer screen on the bridge does not require watchkeeping officers to engage with their surroundings to the same degree and can result in a lack of situational awareness.

A challenge faced by stakeholders in the maritime industry is to ensure that legislation can keep up with technological developments in navigation systems. In an industry that has historically been reactive rather than proactive in enacting legislative reform to ensure the safety of maritime operations,[12] this is a cause for concern.

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[8] The Manila Amendments marked a major revision and were adopted in 2010. See *http://www.imo.org/en/OurWork/HumanElement/TrainingCertification/Documents/32.pdf* accessed on 31/01/2018. The amendments entered into force in 2012 under the tacit acceptance procedure, with a five-year transitional period until 01/01/2017. See IMO STCW.7/Circ.16 'Clarification of Transitional Provisions relating to the 2010 Manila Amendments to the STCW Convention and Code' (2011).

[9] The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW Code) was adopted in 1978 and entered into force in 1984.
See *http://www.imo.org/en/about/conventions/listofconventions/pages/international-convention-on-standards-of-training,-certification-and-watchkeeping-for-seafarers-(stcw).aspx* accessed on 31/01/2018.

[10] Nielsen 57.

[11] See the case studies and accident reports referenced in this dissertation (Chapters 2/III, 3/III/e, 3/IV/b,d, 3/V/i).

[12] The first version of the International Convention for the Safety of Life at Sea (SOLAS) was adopted in 1914, in reaction to the *Titanic* disaster
(see *http://www.imo.org/en/KnowledgeCentre/ReferencesAndArchives/HistoryofSOLAS/Pages/default.aspx*);
the International Convention for the Prevention of Pollution from Ships (MARPOL) was adopted in response to a series of tanker accidents in 1976-7
(see *http://www.imo.org/en/About/Conventions/ListOfConventions/Pages/International-Convention-for-the-Prevention-of-Pollution-from-Ships-(MARPOL).aspx*);
the International Management Code for the Safe Operation of Ships and for Pollution Prevention (the ISM Code) developed in response to, inter alia, the *Herald of Free Enterprise* tragedy in 1987 (see

The structure of this dissertation is based on the research objectives identified to assist in achieving the overall research aim of presenting an analysis of the factors inhibiting ECDIS from effectually achieving its intended primary function of contributing to safe navigation. Chapter 1 contextualises this research and identifies the research aim and individual research objectives. The research focus is discussed and justified, and the structure of the dissertation is outlined. In Chapter 2, applicable legislation is identified and case studies are used to scrutinise the efficacy of the current legal framework regulating the use of ECDIS. Potential legal implications for the use of ECDIS are also briefly considered. An analysis of the potentially unsafe technical operational aspects and limitations of ECDIS is presented in Chapter 3. The dangers of overreliance are illustrated by reviewing the importance of (inter alia) appropriate user settings, the accuracy of charts and positional information; and through the use of case studies. Chapter 4 consists of a critical evaluation of the human factor and human error in the use of ECDIS, cognisant of the reality that most maritime casualties are caused by human error. Considerations include types of human error, error management, the effects of automation on human performance (and decision-making) and safety management. In Chapter 5, current industry initiatives to improve the safety of navigation with ECDIS are outlined, which mostly focus on human-centred design considerations and the standardisation of systems. Additional measures to mitigate unsafe practices in the use of ECDIS by deck officers are then considered – primarily officer training concerns – and it is found that ECDIS training has not been sufficiently integrated into the STCW framework. Chapter 6 concludes that despite an apparently robust legal framework regulating the use of ECDIS, the current legislative provisions do not appear to be effective in preventing ECDIS-assisted accidents; and the current ECDIS training mandated by the STCW Code does not appear to be adequate to ensure officers' competence in its use for safe navigation.

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http://www.imo.org/en/OurWork/HumanElement/SafetyManagement/Pages/Default.aspx) all accessed on 24/01/2018.

CHAPTER 2 APPLICABLE LEGISLATION AND THE EFFICACY OF THE CURRENT LEGAL FRAMEWORK REGULATING THE USE OF ECDIS

I Introduction

Despite an apparently robust legal framework regulating the use of ECDIS for safe navigation, ECDIS-assisted maritime casualties continue to occur. In many of these incidents, the vessels and their crews were fully compliant with applicable international legislation – raising concerning questions for shipping safety in an increasingly technologically-dependent industry. The objective of this chapter is to identify applicable legislation and, through the use of case studies, to scrutinise the efficacy of the current legal framework regulating the use of ECDIS. Potential legal implications for the use of ECDIS are also briefly considered.

II Overview of Applicable Legislation

(a) International Convention for the Safety of Life at Sea (SOLAS), 1974, as amended

The SOLAS Convention is widely regarded as the core international treaty regulating the safety of merchant ships.[13] Chapter V of SOLAS covers the safety of navigation, and the definition of 'nautical chart or nautical publication' in regulation V/2.2 has been updated to:

> 'a special-purpose map or book, *or specially compiled database from which such a map or book is derived,* that is issued officially by or on the authority of a Government, authorized Hydrographic Office or other relevant government institution and is designed to meet the requirements of marine navigation'. (author's emphasis)

The mandatory carriage of ECDIS as required by SOLAS regulation V19/2.10 is subject to a staged entry into force between 2012 and 2018.[14] By July 2018, all cargo vessels greater than 10 000 gross tonnage (gt) must be equipped with ECDIS. For ECDIS to satisfy carriage requirements, it must meet certain specifications. The ECDIS must be type-approved and meet IMO performance standards.[15] The charts used by the ECDIS must be official, up-to-date Electronic Navigational Charts (ENCs) and the system must be maintained to ensure

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[13] See *http://www.imo.org/en/About/conventions/listofconventions/pages/international-convention-for-the-safety-of-life-at-sea-(solas),-1974.aspx*, accessed on 24/01/2018.

[14] IMO MSC.1/Circ.1503/Rev1 'ECDIS – Guidance for Good Practice' (2017).

[15] MSC.1/Circ.1503/Rev1 states: 'According to SOLAS regulation V/18, ECDIS units onboard ships must be type-approved. Type approval is the certification process that ECDIS equipment must undergo before it can be considered as complying with IMO performance standards. The process is carried out by flag Administration-accredited type-approval organizations or marine classification societies in accordance with the relevant test standards developed by, inter alia, the International Electrotechnical Commission (IEC) (e.g. IEC 61174).'

compatibility with the latest IHO standards.[16] There must also be an adequate, independent back-up arrangement in place for the ECDIS.[17]

The purpose of the back-up system is to ensure that the safety of navigation is not compromised in the event of an ECDIS failure[18] and it must provide for the ship to be safely navigated for the rest of the voyage. If the back-up is a second compliant[19] ECDIS, it must be connected to an independent position-fixing system[20] and have an independent power supply. An up-to-date folio of paper charts for the intended voyage also meets back-up requirements, although many companies are moving away from this option due to convenience and economic considerations.[21] In addition to SOLAS, ECDIS back-up systems must comply with flag state requirements.

SOLAS regulation V/9 (Hydrographic services) requires contracting governments to execute hydrographic surveys and prepare, issue and update nautical charts. International uniformity in charts must be ensured, based on the relevant resolutions and recommendations of the International Hydrographic Office (IHO). Regulation V/27 requires all nautical charts necessary for the intended voyage to be adequate and up-to-date.

(b) International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW), 1978, as amended

The primary purpose of the STCW Convention is to promote the safety of life and property at sea and the protection of the marine environment, by establishing international standards for seafarer training, certification and watchkeeping.[22] The regulations in the Convention contain basic requirements, which are supported by sections in the Code, where these requirements are explained and elaborated.[23] Part A of the Code is mandatory and contains the minimum standards of competence for seafarers, detailed in a sequence of tables. Part B is not mandatory, but contains recommended guidance in the implementation of the Convention.[24] The Manila Amendments to the STCW Convention and Code were adopted in 2010 and entered into force

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[16] MSC.1/Circ.1503/Rev1.
[17] Ibid; IMO MSC82/24 'Revised Performance Standards for ECDIS' 1.2 (2006).
[18] MSC82/24 Appendix 6 – Back-Up Requirements.
[19] Meets performance standards and carriage requirements.
[20] A separate GPS unit to that used by the primary ECDIS.
[21] The PAYS (Pay as You Sail) option for chart licencing offered by many ENC suppliers allows vessels to only pay for the charts they actively use on the ECDIS, which can result in significant cost savings. A world folio of charts is passively installed on the ECDIS and can be accessed if the vessel's port of destination changes during the voyage.
[22] See *http://www.imo.org/en/ourwork/humanelement/trainingcertification/pages/stcw-convention.aspx,* accessed on 24/01/2018.
[23] Ibid.
[24] Ibid.

in 2012, with a transitional period until 2017.[25] Amongst the significant changes adopted in the Manila Amendments were new requirements regarding training in modern technology, including ECDIS. The STCW Code also contains general provisions for training and assessment,[26] quality standards[27] and standards governing the use of simulators.[28]

Chapter VIII of the STCW Code contains general standards regarding watchkeeping. Requirements in Part 2 (voyage planning) include that the intended voyage be planned in advance and that the master ensures that the intended route is planned using adequate, appropriate charts containing,

> 'accurate, complete and up-to-date information regarding those navigational limitations and hazards which are of a permanent or predictable nature and which are relevant to the safe navigation of the ship'.[29]

Once the planned route has been verified, it must be clearly displayed on appropriate charts and continuously available to the officer of the watch (OOW), who is required to verify each course to be followed before utilising it.[30] Should it be necessary to deviate from the planned route, an amended route must be planned before deviating.[31]

Part 3 sets out general watchkeeping principles, including the requirement to consider any limitations in qualifications when deploying watchkeeping personnel. Watchkeepers are required to make the most effective use of available resources, including information, installations and equipment. Watchkeeping personnel must also understand the functions and operation of equipment and be familiar with handling it, as well as know how to respond to information from this equipment.[32]

Watchkeeping at sea is covered by Part 4, which states that officers are responsible for safely navigating the ship and should be particularly concerned with avoiding collision and stranding.[33] Officers are required to maintain a proper lookout at all times, in compliance with Rule 5 of the International Regulations for the Prevention of Collisions at Sea (COLREGs). While performing the navigational watch, the vessel's position must be 'checked at sufficiently frequent intervals, using any available navigational aids necessary'.[34] The OOW is required to

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[25] See STCW.7/Circ.16.
[26] Part A, Section A-I/6.
[27] Ibid A-I/8.
[28] Ibid A-I/12.
[29] STCW Code Chapter VIII Part 2.5.
[30] Ibid 2.6.
[31] Ibid 2.7.
[32] Ibid Part 3, 8.2-6.
[33] Ibid Part 4.10.
[34] Ibid 4.25.

fully comprehend the operation of all navigational equipment and be aware of its limitations,[35] and must use each of the electronic navigational aids as and when appropriate.[36]

Part A, Chapter II of the STCW Code contains standards regarding the master and deck department. Section A-II/1 sets out the mandatory minimum requirements for certification of officers in charge of a navigational watch on ships of 500gt or above, with the specific competencies to be demonstrated listed in Table A-II/1 (navigation at operational level). The ECDIS-related competency required at the operational level is for candidates to demonstrate proficiency in the use of ECDIS to maintain the safety of navigation. This includes a knowledge of the limitations of ECDIS and the dangers of overreliance, as well as familiarity with the functions required by the performance standards. Requirements for proficiency in the operation, interpretation and analysis of information obtained from ECDIS are detailed, including user settings, alarm parameters and integrated systems. Situational awareness while using ECDIS and confirmation of the ship's position by alternative means must be demonstrated.

Section A-II/2 sets out the mandatory minimum requirements for certification of masters and chief mates in charge of a navigational watch on ships of 500gt or above, with the specific competencies to be demonstrated listed in Table A-II/2 (navigation at management level). Senior officers are required to be competent in determining the vessel's position and the accuracy of the resultant positional fix by any means, including modern electronic navigational aids – with specific knowledge of their operation, limitations, error sources, detection of misrepresentation of information and methods of correction. Errors affecting the accuracy of positions derived from electronic aids to navigation must be understood and methods to minimise the errors properly applied. The primary method selected for position fixing must be the most appropriate in the prevailing circumstances and conditions. Knowledge of the interrelationship and optimum use of all available navigational data must be demonstrated. Senior officers are required to be proficient in maintaining the safety of navigation through the use of ECDIS and associated navigation systems to assist command decision-making. In this regard, actions must be taken to minimise risks to the safety of navigation. In addition, operational procedures for using ECDIS must be established, applied and monitored.

Although these tables set out specific competencies in the use of ECDIS – these are for certification purposes only. Section 4.1 of Part A regarding principles to be observed in keeping a navigational watch only contains two provisions relating specifically to ECDIS. First, the use

[35] Ibid 4.26.
[36] Ibid 4.36.

and operational condition of aids to navigation including ECDIS and other equipment affecting safe navigation are amongst the factors to be considered when deciding the composition of the bridge watch.[37] Secondly, 4.47 states:

> 'When using ECDIS, appropriate usage code (scale) electronic navigational charts shall be used and the ship's position shall be checked by an independent means of position fixing at appropriate intervals.'

Part B of the STCW Code contains extensive guidance regarding the use of simulators for training and assessment of competency,[38] including for the operational use of ECDIS.[39] Part B is not, however, mandatory.

The IMO developed a series of model training courses to assist in the implementation of the STCW Code, although the courses are flexible in application.[40] IMO Model Course 1.27 (Operational Use of ECDIS) is intended to provide the knowledge, skill and comprehension of ECDIS required to safely navigate ships whose primary means of navigation is ECDIS.[41] The course was designed to meet the STCW requirements in the use of ECDIS, as revised by the Manila Amendments.[42] The generic course must be accredited by the flag state – in South Africa, this is regulated by the South African Maritime Safety Authority (SAMSA)'s SA Maritime Qualifications Code in GOP-531.16: Guidance Note, Deck: Generic ECDIS Training.

The responsibilities of companies are outlined in Section A-I/14 of Part A of the STCW Code. Companies are required to provide written instructions to their ships, detailing the policies and procedures to be followed to ensure that newly employed seafarers are,

> 'given a reasonable opportunity to become familiar with the shipboard equipment, operating procedures and other arrangements needed for the proper performance of their duties, before being assigned to those duties.'[43]

These policies must include the allocation of time for familiarisation with ship-specific watchkeeping and safety procedures.[44] This familiarisation requirement should be considered with the similar provisions in the ISM Code.

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[37] Ibid 4.18.4.
[38] Section B-I/12.
[39] B-I/12.36-66.
[40] See *http://www.imo.org/en/OurWork/HumanElement/TrainingCertification/Pages/ModelCourses.aspx*, accessed on 24/01/2018.
[41] IMO Model Course 1.27.
[42] Ibid.
[43] Section A-I/14.2.
[44] Ibid.

(c) The International Management Code for the Safe Operation of Ships and for Pollution Prevention (International Safety Management [ISM] Code)

The ISM Code[45] provides a standard for the safe management and operation of ships and establishes safety management objectives. The duties of the company[46] are clearly defined in the Code – to establish a Safety Management System (SMS) and to implement a policy for achieving the safety management objectives. The master's responsibilities include implementation of the safety policy and fostering a safety culture onboard;[47] and the company is required to provide adequate resources to support him/her.[48] The SMS must ensure compliance with mandatory rules and regulations, and take account of codes, guidelines and standards recommended by the IMO, Administrations, classification societies and marine industry organisations.[49] Administrations are responsible for verifying compliance with the requirements of the ISM Code and issuing associated certificates.[50]

The SMS must include instructions and procedures to ensure the safe operation of vessels,[51] often contained in a ship-specific Safety Management Manual (SMM). The SMS must include practical guidance on navigational safety, including procedures for the use of ECDIS that incorporate, inter alia, chart and software updates.[52] The ISM Code requires the company to establish procedures to ensure that new personnel are given proper familiarisation with their duties,[53] which includes familiarisation with ECDIS equipment for deck officers.

This familiarisation training is achieved by type-specific ECDIS training courses which officers must attend before using the ECDIS equipment onboard for navigation. Type-specific training is not mandated by the STCW Code, but it is an ISM Code requirement.

(d) International Regulations for the Prevention of Collisions at Sea (COLREGs), 1972

The COLREGs entered into force in 1977 and apply to all vessels.[54] The requirements concerning lookout are covered in Rule 5, which states:

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[45] The ISM Code was adopted by the IMO by Resolution A.741(18) in 1993 and became mandatory when SOLAS Chapter IX (Management for the safe operation of ships) entered into force in 1998. See *http://www.imo.org/en/OurWork/Safety/Regulations/Documents/SOLAS98final.pdf* accessed on 31/01/2018.

[46] Defined in the Code (A1.1.2) as the ship-owner or any organization or person, such as the manager or bareboat charterer, who has assumed responsibility for operating the ship.

[47] ISM Code A5.

[48] Ibid A6.

[49] Ibid A1.2.3.

[50] Documents of Compliance (companies); Safety Management Certificates (ships).

[51] ISM Code A1.4.2.

[52] International Chamber of Shipping (ICS) *Bridge Procedures Guide* 5ed (2016) (ICS BPG).

[53] ISM Code A6.3.

[54] COLREGs A.1.

'Every vessel shall at all times maintain a proper look-out by sight and hearing as well as by all available means appropriate in the prevailing circumstances and conditions so as to make a full appraisal of the situation and of the risk of collision.'

(e) Flag State Requirements

Flag states are required to effectively exercise their jurisdiction and control in administrative, technical and social matters over vessels under their flag.[55] Before registration on their flag and thereafter at appropriate intervals, states must ensure that ships have the charts and navigational equipment onboard that are required for safe navigation.[56] To ensure the safety at sea of vessels flying their flag, states must enforce compliance with applicable international regulations, including those relating to seaworthiness, equipment and crew training.[57]

Generic and type-specific ECDIS training, as well as ECDIS back-up arrangements, are mandated (inter alia) by flag states. Discrepancies identified in these areas are discussed later in this dissertation.

(f) Port State Control

Although the primary responsibility for the safe operation of vessels lies with flag states and shipowners, Port State Control (PSC) has proven to be an effective regime for policing compliance with international maritime safety instruments.[58] The concept of PSC was introduced by the IMO through the STCW Convention, as Article X compels parties to apply the STCW requirements to all vessels calling at their ports. The IMO promoted a regional approach to PSC inspections to increase efficiency,[59] and nine regional MoUs[60] on PSC inspections currently exist.

Ships being detained during PSC inspections due to evidence of the improper and unsafe use of ECDIS onboard is becoming an increasingly frequent occurrence.[61] Between 2001 and 2017, the Australian Maritime Safety Authority (AMSA) executed eighty-seven ECDIS-related vessel detentions, with most of the deficiencies relating to the ISM systems onboard (including officers being unfamiliar with ECDIS operation) or equipment being defective, unofficial or

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[55] Part VII Art 94.1of the United Nations Convention on the Law of the Sea 1982 (UNCLOS), adopted in 1982, entered into force in 1994; Hare, John *Shipping Law & Admiralty Jurisdiction in South Africa* 2ed (2009) ss6-4.1 (Hare).
[56] UNCLOS Art94.4a.
[57] Ibid Art9.4.
[58] Hare ss6-4.2.
[59] See *http://www.imo.org/en/ourwork/msas/pages/portstatecontrol.aspx*, accessed on 24/01/2018.
[60] Memorandum of Understanding.
[61] Wingrove, Martyn 'Rise in ships detained for ECDIS deficiencies' (2016) available at *http://www.marinemec.com/news/view,rise-in-ships-detained-for-ecdis-deficiencies_43571.htm*, accessed on 24/01/2018.

unapproved for navigation.[62] AMSA detained eight vessels in the first five months of 2016 for ECDIS-related deficiencies, which was double the amount in the second half of 2015.[63]

(g) Technical Specifications: IMO Performance Standards, International Hydrographic Organisation (IHO) and International Electrotechnical Commission (IEC)

To meet the chart carriage requirements of SOLAS, ECDIS equipment must conform to the relevant IMO performance standards. Depending on the date of the shipboard installation of the ECDIS unit, it must comply with either IMO Resolution A.817(19), or Resolution MSC.232(82).[64]

Relevant IHO standards specify the requirements for the presentation, structure and format of chart data (including encryption).[65] The IHO S-52 standard ensures that the presentation of data on ECDIS screens is displayed in a uniform manner by all manufacturers, including colours and chart symbols. IHO S-57 defines the requirements for the construction of ENCs by hydrographic offices to ensure that all information required for safe navigation is contained therein, and specifies the data format for the transfer of digital hydrographic information. IHO S-63 ensures the authenticity of ENC data and contains provisions for security and piracy protection.[66]

The IEC imposes standards concerning technical specifications for shipborne electronic navigational aids and radio equipment, the most pertinent of which is the IEC Publication 61174: 'ECDIS – Operational and Performance Requirements, Method of Testing and Required Test Results'.

III Case Studies

The peril of ECDIS-assisted groundings of vessels that are compliant with international legislation regulating the use of ECDIS is illustrated in the following three case studies.

(a) Ovit

The chemical tanker *Ovit* ran aground on the Varne Bank in the Dover Strait in 2013. ECDIS was the primary means of navigation onboard and no paper charts were carried.[67] The *Ovit* complied with all applicable legislation for the use of ECDIS and was subject to regular audits,

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[62] The Nautical Institute & the Royal Institute of Navigation 'Know you ECDIS – or risk detention' (2017) Issue 14 *The Navigator* 8.
[63] Wingrove op cit.
[64] MSC.1/Circ.1503/Rev1.
[65] MSC.232(82).
[66] A full list of current IHO standards is maintained at *https://www.iho.int/mtg_docs/enc/ECDIS-ENC_StdsIn_Force.htm*, accessed on 24/01/2018.
[67] MAIB Rep.24/2014 42.

yet the master and deck officers were unable to use the system effectively[68] to ensure the safety of navigation. The *Ovit's* deck officers' ECDIS training satisfied the requirements of STCW and ISM,[69] yet they were unaware of the importance of critical safety settings and the significance of the system's alarms.[70] The chart scale was inappropriate and the audible alarm not functional. A passage plan checklist included in the *Ovit's* SMS had been completed, confirming that there were no routing hazards. The OOW was navigating by following the route shown on the vessel's ECDIS display – which passed directly over the Varne Bank[71] – and his situational awareness was so poor that it took him nineteen minutes to realise that the *Ovit* had grounded.[72]

In 2013, the *Ovit* incident was the third grounding investigated by the United Kingdom's Marine Accident Investigation Branch (MAIB) which identified deck officers' failure to use ECDIS properly as a causal factor. The report concluded that the training which the ship's officers attended was apparently either ineffective, or insufficient, or both. Design issues with the vessel's ECDIS were also identified, as some key features were difficult to use.

(b) CMA CGM Vasco de Gama

In August 2016, the ultra-large container ship *CMA CGM Vasco de Gama* grounded while approaching Southampton. At the time, she was the largest vessel on the UK ship registry.[73] The primary means of navigation onboard was ECDIS, the master and deck officers had attended generic and type-specific ECDIS training courses.[74] The vessel's SMM included procedures for navigation with ECDIS and no non-conformities in navigation or bridge procedures had been identified during the last internal audit.[75] Although the bridge team had completed checklists confirming that the ECDIS had been set up and was being used in accordance with company procedures, this was untrue.[76] The MAIB investigation into the grounding found that safety parameters and alarms were not effectively used, selected display options were not optimally configured and that manoeuvres in the planned route were not possible given the characteristics of the large vessel and the environmental conditions. ECDIS

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[68] Ibid 2.
[69] Ibid 15, 46.
[70] Ibid 46.
[71] Ibid 2.
[72] Ibid.
[73] MAIB Rep.23/2017 *Report on the investigation of the grounding of the ultra-large container vessel CMA CGM Vasco de Gama Thorn Channel, Southampton, England 22 August 2016* (2017) 1.
[74] Ibid 15.
[75] Ibid 16.
[76] Ibid 47.

was not being used effectively, or in accordance with company policy.[77] The MAIB report states:

> 'Many of the procedural omissions and navigation shortcomings associated with the use of ECDIS seen in this case have been regularly identified by the MAIB in previous investigations. These issues need to be addressed globally by the maritime industry. There is a strong case for the commissioning of an industry-wide study into the reasons why masters and bridge teams are choosing not to use many of the safety features offered by modern electronic navigation aids.'[78]

(c) Muros

In December 2016, the bulk carrier *Muros* ran aground while following a planned track on the ECDIS which crossed Haisborough Sand. The system and procedural safeguards within the ECDIS – which are intended to prevent the vessel from grounding – were disabled, overlooked or ignored.[79] The passage plan had been revised a few hours prior to the incident and had not been approved by the master (as required by the vessel's SMM). The OOW had conducted a visual inspection of the revised track using a small scale chart which was not sufficient to identify the grounding hazard, and she ignored the warnings generated by the system's automatic 'check route' function.

The OOW monitored the vessel's position solely by ECDIS, but the system's alarms had been disabled.[80] The officers deemed the absence of audible alarms advantageous and had not reported the deficiency.[81] The MAIB report found that the lack of alarms and disabling of other safety features (designed to alert navigators to imminent hazards) within the ECDIS significantly reduced its intended advantage over paper charts. The master and deck officers had all received generic and type-specific ECDIS training.[82] Internal and external audits had been conducted onboard earlier in the year, neither of which identified any non-conformities in navigation procedures.[83] The ECDIS onboard was certified as SOLAS-compliant and the system installation met the IHO and IEC technical requirements.[84] The MAIB report states:

> 'The MAIB has recently investigated several grounding incidents in which the way the vessels' ECDIS was configured and utilised was contributory. There is increasing evidence to suggest that first generation ECDIS systems were designed primarily to comply with the

[77] Ibid 48.
[78] Ibid.
[79] MAIB Rep.22/2017 20.
[80] Ibid 1.
[81] Ibid 13.
[82] Ibid 10.
[83] Ibid 12.
[84] Ibid.

performance standards required by the IMO, as these systems became a mandatory requirement on ships, with insufficient attention being given to the needs of the end user. As a consequence, ECDIS systems are often not intuitive to use and lack the functionality needed to accommodate accurate passage planning in confined waters. This situation has led to seafarers using ECDIS in ways which are at variance with the instructions and guidance provided by the manufacturers and/or expected by regulators.'

IV Efficacy of The Current Legal Framework Regulating the Use of ECDIS

(a) Overview

There appear to be three common safety-critical themes in these case studies: shortcomings in ECDIS design, inadequate officer training and the ineffectiveness of audits and inspections.

(b) ECDIS Design

Although the IMO performance standards provide general requirements for the technical operation of ECDIS, the details of how the system achieves these standards has been left up to individual manufacturers, resulting in significant disparities in functionality amongst ECDIS makes and models.[85] Manufacturers tend to include additional features to give them a competitive edge or in an attempt to improve user-friendliness.[86] Depending on the ECDIS in use, the procedures for accessing menus and executing basic operations are performed quite differently. Superfluous advanced features can saturate an ECDIS operator with unnecessary information[87] and detract attention from the data required for safe navigation.

Challenges faced by officers in the technical operation of ECDIS are described in Chapter 3. Parties within the maritime industry have initiated measures to address the design and operational shortcomings identified within ECDIS, focusing on human-centred design and standardisation of systems.[88]

(c) Officer Training

To reduce crewing costs, many shipowners recruit officers from emerging economies where wage demands are lower. Different interpretations of international guidelines and inconsistent standards of training and education can exist due to the global nature of the maritime industry.[89]

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[85] Bell, Richard 'ECDIS use onboard ship' The Standard Club (2017) available at *http://www.standard-club.com/media/2533822/ecdis-use-on-board-ship.pdf* accessed on 31/01/2018 (Bell).

[86] Squire, David 'The Human Element in Shipping' (2013) *Alert! – The International Maritime Human Element Bulletin* (A Nautical Institute project sponsored by Lloyd's Register EMEA) 18 available at *http://www.he-alert.org/filemanager/root/site_assets/standalone_pdfs_0355-/he00350.pdf* accessed on 31/01/2018 (Squire).

[87] Ibid.

[88] These are discussed in Chapter 5.

[89] Squire 18.

Even with the IMO's international standards in place, officer training and assessment are not considered to be consistent globally, resulting in varied levels of competence.[90] The STCW Code sets out the *minimum* standards of competency, and due to cost considerations most shipowners do not invest in additional training or education.[91] As illustrated in the case studies, it appears that the STCW provisions for ECDIS training may not be sufficient to ensure officers' competence in its use for safe navigation.

Although the IMO's model courses are intended to assist with the development of training programmes, they are *not* mandatory.[92] Administrations are therefore not obliged to use them in the preparation and approval of training courses to meet STCW requirements,[93] thereby further broadening the scope for varying interpretations by parties.

A recent survey conducted by the Nautical Institute found that generic training courses improved the confidence of those using ECDIS, but there are some caveats on the quality of ECDIS training received.[94] The survey identified discrepancies in the course delivery, duration, content and assessment methods.[95] Courses required for STCW certification must be approved and accredited by the state's maritime authority, and the lack of consistency indicates a worrying lack of international standards and uniformity regarding mandated training. In the case studies, the officers had completed generic ECDIS training but were not competent in the safe operation of the equipment onboard.

The STCW Code contains provisions for certification requirements and for the use of simulators for ECDIS training, but does not adequately include express provisions mandating how ECDIS must be used as an aid to navigation in maintaining a safe watch. This research suggests that ECDIS training has not been sufficiently integrated into the STCW framework.[96]

The IMO model course is generic in nature, covering the operation and limitations of ECDIS, but type-specific training in the unit used onboard is essential for competency in safe navigation with ECDIS. Bearing in mind their responsibility to provide familiarisation training as mandated by the ISM (and STCW) Code, the onus is on shipowners, operators or managers

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[90] Allianz Global Corporate & Speciality (in conjunction with the Seafarers International Research Centre of Cardiff University) 'Safety and Shipping 1912 – 2012: From Titanic to Costa Concordia' (2012) available at *http://www.agcs.allianz.com/assets/PDFs/Reports/AGCS_safety_and_shipping_report.pdf* accessed on 31/01/2018 (AGCS Report).
[91] Squire 16.
[92] IMO STCW.7/Circ.24/Rev1 'Guidance for Parties, Administrations, port State control authorities, recognized organizations and other relevant parties on the requirements of the STCW Convention, 1978, as amended' (2017).
[93] Ibid.
[94] Gale, Harry 'Confidence in ECDIS' (2017) 7 *Seaways, The International Journal of The Nautical Institute* 13-14 (Gale).
[95] Ibid.
[96] This is expanded on in Chapter 5.

to decide how the type-specific ECDIS training is delivered to their fleets' officers.[97] Companies must ensure that they meet their flag state's requirements for familiarisation training. Unfortunately, flag states have not adopted a uniform approach in addressing ECDIS familiarisation training, introducing further discrepancies in international standards.[98]

Non-standardised displays and controls increase the training required for familiarisation with – and safe, effective use of – ECDIS equipment.[99] Various options for methods of type-specific training exist, including online courses, computer based training, shore based courses (run by ECDIS manufacturers or maritime training centres using simulators) and onboard training (conducted by manufacturers or training personnel).[100] 'Trickle-down' or 'cascade' training – when an officer who has previously attended a familiarisation course gives newly-joined officers a 'crash course' once onboard – is not considered sufficient and must not be accepted as adequate familiarisation training. ECDIS manufacturers' equipment operating manuals can be difficult to follow due to their highly technical content, particularly if not written in the reader's mother tongue,[101] and are poor training tools.[102]

Vessels within a company's fleet may be equipped with different ECDIS models, and officers may thus require type-specific training from several manufacturers. The challenge faced by pilots is even greater, given the multitude of ECDIS types on the market.

There is a strong argument for standardisation of both ECDIS systems and type-specific training requirements, as considered in Chapter 5.

(d) Audits and Inspections

There is no requirement in STCW for type-specific training in ECDIS, although regulation I/14 compels companies to ensure familiarisation training with onboard equipment.[103] Officers are therefore not required to provide documentation of type-specific ECDIS training,[104] but must be able to demonstrate competence in the use of the equipment onboard during audits and inspections.

Yet detailed navigational audits and inspections have failed to identify officers' lack of competence in the use of ECDIS, as seen in the case studies. Given the significant latitude that

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97 MCA Marine Information Note MIN503(M) 'Training for ECDIS as Primary Means of Navigation' (2015).
98 Bell.
99 IMO MSC/Circ1091 'Issues to be Considered when Introducing New Technology onboard Ship' (2003).
100 The Nautical Institute 'Industry Recommendations for ECDIS Familiarisation' (2012) available at *https://www.nautinst.org/download.cfm?docid=7B6C006B-A40B-42AA-9BB8DA556CC43FDF* accessed on 31/01/2018.
101 Squire 14.
102 MSC/Circ1091.
103 STCW.7/Circ.24/Rev1.
104 Ibid.

manufacturers were allowed in interpreting the operational functions of ECDIS, there is a great disparity in methods of accessing and verifying information within the system. With almost forty makes of ECDIS on the market, inspectors and surveyors may be unsure of how to effectively assess officer competence or whether the system is being used in accordance with safe navigational practices. An SMS containing provisions for the use of ECDIS is not evidence that officers are in fact complying with the stipulated procedures.

While not practical to expect flag and port state inspectors, as well as class and independent surveyors, to have completed type-specific training for *every* model of ECDIS, action is clearly required to ensure that deficiencies in navigation with ECDIS are identified during audits and inspections. Administrations should inform their PSC Officers of ECDIS familiarisation training requirements as outlined in MSC.1/Circ.1503/Rev1. Companies must be proactive in ensuring their internal ISM auditors are familiar with the ECDIS units in use across their fleets.

V Potential Legal Implications for the Use of ECDIS

The bulk carrier *African Alke* was detained in Brisbane in 2016 following a PSC inspection by AMSA, which found that the crew was unable to properly operate the vessel's ECDIS. The crew were fully certified and the vessel's SMS had not identified the failure of onboard familiarisation training as a deficiency. The vessel's operator had to fly an ECDIS trainer in from Singapore to train the crew, and the charterer took the ship off hire while she was detained.[105]

The legal effects of the failure to meet the extensive statutory ECDIS requirements, and the effect on claims if the standards of knowledge of ECDIS and its operation are a causal factor, are beyond the scope of this dissertation. There is, however, fertile ground for interesting further research in this field, and case law will no doubt develop as ECDIS-related casualties and detentions continue to occur. The UK P&I Club anticipates significant implications for the claims sector:

> 'With the requirement for effective training, familiarisation and operation now receiving increased focus, with traditional damage defences of navigational error, heavy weather and crew negligence now being subjected to additional scrutiny, the ECDIS revolution may be

[105] Reynolds, Zoe 'Australia ship detention puts spotlight on ship safety management' *IHS Fairplay* (2016) available at *https://fairplay.ihs.com/safety-regulation/article/4269111/australia-ship-detention-puts-spotlight-on-ship-safety-management* accessed on 31/01/2018.

the catalyst which sparks a new cycle in the claims sector and one which may be even more costly than the introduction of the technology itself.'[106]

Consequences of failing to meet statutory requirements for the carriage and use of ECDIS may include vessel detention under PSC provisions, suspension of class, suspension of ISM certification and exclusion of liability for a breach related to failure to comply with H&M insurance requirements.[107]

The recording capabilities of ECDIS and VDRs[108] have seen the information from these sources become a key aspect of evidence in legal proceedings, often employed to ascertain disputed facts.[109] Amendments to the procedural rules for admiralty claims in the English courts came into force in 2017, that encourage the early exchange of electronic track data in collision claims, to simplify proceedings and expedite determination of liability.[110]

This capability to digitally reconstruct events preceding an incident has also streamlined and enhanced marine casualty investigations. However, as data recovery methods vary amongst ECDIS manufacturers, surveyors and investigators may face technically complex procedures to retrieve track recordings from some units.[111] Given the legal importance of this data, the case for the standardisation of these ECDIS operational functions is strengthened.

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[106] UK P&I Club 'ECDIS – Navigational and claims issues' (2011) available at *https://www.ukpandi.com/fileadmin/uploads/uk-pi/LP%20Documents/ECDIS%20-%20LP%20Supplement.pdf* accessed on 31/01/2018.
[107] Ibid.
[108] Voyage Data Recorder – similar to an aircraft's 'black box'.
[109] UK P&I Club op cit.
[110] The Civil Procedure (Amendment) Rules 2017 (SI 2017 No. 95 (L.1)); see *https://www.judiciary.gov.uk/announcements/electronic-track-data-in-collision-claims/* accessed on 31/01/2018.
[111] *Ovit's* track history could not be recovered from the ECDIS following the grounding, despite this being a performance standards requirement.

CHAPTER 3 POTENTIALLY UNSAFE TECHNICAL OPERATIONAL ASPECTS AND LIMITATIONS OF ECDIS

I Introduction

A fundamental difference between navigation by paper charts and electronic charts lies in how information is displayed. On paper charts, the cartographers compiling them determined how to present the information they felt that navigators required for safe navigation.[112] In contrast, when using ENCs, it is the navigator who selects the information that is displayed from a database on the ECDIS system.[113] The capability to tailor the chart to suit the particular navigational situation can enhance the safety of navigation, but only if the operator has an in-depth understanding of which charted features are appropriate to include in various circumstances. If not adequately trained, navigators may omit crucial safety-related information from the ECDIS display, or use the system at a presentation scale which does not show all features required for safe navigation.

The use of ECDIS is intended to reduce the navigational workload (compared to paper charts) as the vessel's position is continuously plotted[114] on the screen. The navigator must, however, always be cognisant of the fact that the displayed position is derived from GPS[115] data and must be verified by other means. Frequent manual positions must still be plotted on electronic charts as they are on paper charts – using visual bearings and radar ranges and bearings during coastal navigation, and celestial fixes when deep-sea. Navigators' overreliance on ECDIS significantly reduces the safety of navigation, as identified in case studies, and expressed by the International Chamber of Shipping:

> 'ECDIS is an aid to safe navigation. ECDIS does not conduct safe navigation or relieve the Master or OOW of their responsibilities for conducting safe navigation.'[116]

The objective of this chapter is to analyse the potentially unsafe technical operational aspects and limitations of ECDIS. The dangers of overreliance are illustrated by reviewing the importance of appropriate user settings, the accuracy of charts and positional information; and through the use of case studies.

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[112] Patraiko, David 'Nav Brief: ECDIS explained' (2014) Issue 5 *The Navigator* 2.
[113] Ibid.
[114] MSC.232(82).
[115] Global Positioning System.
[116] ICS BPG 72.

II A Background of Technology-Assisted Maritime Casualties

The inappropriate use of technology on ships' bridges predates electronic charts and the tendency for navigators to over-rely on automated navigational aids is by no means unique to ECDIS. The increasingly widespread use of radar commenced in the 1950s and was anticipated to reduce the number of collisions by vessels at sea. Yet the first 'radar assisted collision' occurred in 1956 between the *Andrea Doria* and the *Stockholm*, with the loss of fifty-one lives due to the improper use of radar.[117] Although radar technology is no longer new and radars have been commonplace on bridges for decades,[118] 'radar assisted collisions' continue to occur. Over-confidence in the accuracy of the information provided by ARPA[119] was identified as a causal factor in a collision between a container vessel and a yacht in 2003.[120] The report into the incident also highlighted that the fitting of radar and ARPA equipment on vessels, without officers knowing its limitations or how to use it, can contribute to accidents.[121] The term 'VHF[122] assisted collisions' has also emerged following investigation findings that in a significant number of collisions, one or both parties inappropriately used VHF radio in an attempt to avoid collision – instead of following the COLREGs.[123]

The introduction of GPS as a positional aid revolutionised marine navigation, but as with any aid to navigation, it is not infallible. A notorious case of overreliance on GPS is the cruise ship *Royal Majesty*, which ran aground in 1995.[124] Less than an hour after departure from Bermuda (bound for Boston), the vessel's GPS antenna became disconnected and the GPS defaulted to DR (dead reckoning)[125] mode. The resulting alarm was not heard on the bridge and for the next thirty-four hours none of the officers noticed that the GPS was operating in DR mode. Although (erroneous) GPS positions were being plotted on the chart, the navigators were not verifying these fixes by an independent means – a procedure required by safe bridge

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[117] Tikkanen, Amy 'Andrea Doria' *Encyclopaedia Britannica* available at *https://www.britannica.com/topic/Andrea-Doria-Italian-ship* accessed on 31/01/2018.

[118] Radar was made mandatory under the 1960 SOLAS Convention.

[119] Automatic Radar Plotting Aid. This provides a capability to track radar targets and calculate (inter alia) the CPA (closest point of approach) i.e. how close the vessel will get to yours and whether a risk of collision exists.

[120] See MAIB Rep.28/2003 *Report on the investigation of the collision between the container ship P&O Nedlloyd Vespucci and the yacht Wahkuna English Channel 28 May 2003* (2003).

[121] Ibid.

[122] Very High Frequency radio. This is used for bridge-to-bridge communication between vessels.

[123] MCA (UK) Marine Guidance Note 324(M+F) Amendment 1 'Navigation: Watchkeeping Safety – Use of VHF Radio and AIS' (2016).

[124] National Transportation Safety Board (US) Marine Accident Report NTSB/MAR-97/01 *Grounding of the Panamanian passenger ship Royal Majesty on Rose and Crown shoal near Nantucket, Massachusetts June 10, 1995* (1997).

[125] In DR mode the GPS is no longer receiving satellite-derived positional information, but is instead displaying a position calculated solely based on the vessel's course and speed – which doesn't account for leeway due to wind and currents.

watchkeeping practices and good seamanship. Due to their overreliance on GPS, by the time the *Royal Majesty* grounded she was seventeen miles from where the officers thought she was.[126]

III ECDIS Operation

(a) Electronic Chart Display Systems

Electronic chart display systems include any electronic equipment that is capable of displaying a ship's position superimposed on a chart image displayed on a computer screen.[127] ECDIS is the first class of electronic chart display systems, which meets IMO/SOLAS carriage requirements. The second class is an Electronic Chart System (ECS) which does *not* meet carriage requirements, but may be used to *assist* navigation.[128] There are a variety of privately produced ECS options, including handheld GPS units and smartphone navigation applications ('apps'). It is important to distinguish these from ECDIS, as an ECS may not legally be used as a primary means of navigation.

(b) Official and Unofficial Charts

Official (electronic and paper) charts are issued by a Government or authorised Hydrographic Office[129] and meet carriage requirements if they are kept up-to-date. All other charts are considered unofficial (private) charts and may not be used as a primary means of navigation, as they do not meet SOLAS legal requirements. Official electronic charts may be either vector charts (ENCs) or Raster Navigational Charts (RNCs).

(c) Vector Charts

When official ENCs are in use, ECDIS is operated in 'normal' ECDIS mode. ENCs conform to IHO standards[130] regarding content, structure and format.[131] ENCs are official vector charts and store hydrographic information in a database, rather than as a picture[132] like traditional charts. The navigator can select the information and features from the database to display on the ECDIS screen.[133] All information necessary for safe navigation is contained in ENCs, and

[126] NTSB/MAR-97/01.
[127] IHO S-66 'Facts About Electronic Charts and Carriage Requirements' 1.0.0ed (2010).
[128] Ibid.
[129] SOLAS V.
[130] IHO S-57.
[131] MSC.232(82).
[132] ICS BPG.
[133] ICS BPG 71.

they may contain additional data to that found on paper charts.[134] Navigators can select layers of information to be displayed, as described in Chapter 3/V below.

Charted features are attribute-encoded to IHO S-57 standards and can thus trigger alarms to draw officers' attention to navigational hazards. ENCs can be interrogated by the user to gain additional information about objects displayed on the chart. Official vector charts are considered to have an 'inherent intelligence' in that charted features can be recognised by ECDIS. Positions on ENCs are referred to the World Geodetic System 1984 Datum (WGS84),[135] making them directly compatible with GNSS[136] positions.

(d) Raster Charts

It is also possible for ECDIS to be operated in Raster Chart Display System (RCDS) mode, when RNCs (official raster charts) are used in geographical areas where ENCs are not available. Although nearly worldwide coverage of ENCs now exists, the IMO warns that sufficiently detailed ENCs may not yet have been issued for some areas.[137]

When an ECDIS is operated in RCDS mode, it must be used in conjunction with an appropriate folio of up-to-date *paper* charts, as it is not capable of performing full ECDIS functionality.[138] However, IHO standards exist for the production of RNCs,[139] and the IMO performance standards contain specifications for using ECDIS in RCDS mode.[140]

Raster charts are simply scanned digital copies of paper charts, and therefore will not trigger automatic alarms. Raster charts cannot be customised to suit user preferences or be interrogated to gain additional information about charted objects. Some raster charts may not be referenced to WGS-84 and horizontal datums and chart projections may differ between RNCs.[141]

(e) Case Studies – Unofficial Charts and/or Systems

In 2016 the ro-ro ferry *Petunia Seaways* and the historic motor launch *Peggotty* collided on the River Humber while in dense fog, resulting in *Peggotty* sinking. Although *Peggotty*'s skipper was an off-duty pilot, the voyage was not conducted in accordance with safe navigational practices. An iPad navigation app was used as the primary means of navigation, which ceased

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[134] MSC.232(82).
[135] For an explanation on chart datums, see IMO SN.1/Circ.213 'Guidance on Chart Datums and the Accuracy of Positions on Charts' (2000) and IMO SN.1/Circ.255 'Additional Guidance on Chart Datums and the Accuracy of Positions on Charts' (2006).
[136] Global Navigation Satellite System.
[137] MSC.1/Circ.1503/Rev1.
[138] Ibid.
[139] See IHO S-66.
[140] MSC.232(82) Appendix 7.
[141] MSC.1/Circ.1503/Rev1.

to function soon after departure when it lost a reliable wi-fi signal. This left *Peggotty* immersed in fog with no buoyage visible and caused the skipper to lose his situational awareness entirely. He failed to monitor the vessel's position or other traffic effectively. The apparent functionality of the iPad app gave the *Peggotty's* navigators false confidence in their ability to navigate safely in dense fog. However, they had not used the system before and no back-up arrangements, such as rigging the mast to use the radar, were considered.[142]

While competing in the 2014/5 Volvo Ocean Race, the yacht *Vestas Wind* grounded on a shoal in the Indian Ocean. The main contributing factors were the inadequate use of electronic charts and deficient cartography in presenting navigational dangers at small scales on the ECS in use. The unofficial ECS in use on the yacht was inadequate for a primary means of navigation, as described above. On paper charts of every scale that cover the area, the hazard was clear.[143]

In 2013, the general cargo vessel *Danio* ran aground off the English east coast, after the OOW fell asleep. Paper charts were the primary means of navigation onboard, but the vessel carried an ECS which did not meet SOLAS carriage requirements. The incident report found that the officers were over-reliant on the ECS for passage planning and watchkeeping.[144]

In 2010, the *Beluga Revolution* ran aground in the South Pacific. In addition to the required navigational aids, the bridge was equipped with an ECS. The navigator had pre-planned the voyage using the ECS, then transferred it to the paper charts. It was not noticed that the track nearly crossed over an island. A small scale chart was in use, which gave no warning or visual indication of the island. As raster charts were in use on the ECS, no alarms were triggered.[145]

In 2004, the bulk carrier *Rocknes* grounded in Norway with a pilot onboard. Due to a cargo shift caused by the grounding, the vessel subsequently capsized and eighteen crew members died. Paper charts were the primary means of navigation onboard, but the pilot navigated using unofficial, out-of-date electronic charts. The hazard on which the *Rocknes*

[142] MAIB Rep.4/2017 *Collision between Petunia Seaways and Peggotty on the River Humber 19 May 2016* (2017).
[143] Oxenbould, Chris, Honey, Stan & Hawley, Chuck *Volvo Ocean Race Independent Report into the Stranding of Vestas Wind* 1.2 (2015).
[144] MAIB Rep.8/2014 *Report on the investigation of the grounding of Danio off Longstone, Farne Islands, England 16 March 2013* (2014).
[145] German Federal Bureau of Maritime Casualty Investigation Rep.174/10 *Grounding of the MV Beluga Revolution off Enus (Tench) Island in the South Seas on 30 April 2010* (2011).

grounded was shown on the updated charts produced the previous year, but not on the private, out-of-date electronic chart used by the pilot.[146]

(f) ECDIS Anomalies

An ECDIS anomaly is defined as 'an unexpected or unintended behaviour of an ECDIS unit which may affect the use of the equipment or navigational decisions made by the user'.[147] Numerous ECDIS anomalies have been detected, and as the operation of the system comprises a complex combination of hardware, software and data – further anomalies may be anticipated.[148] Anomalies that have been experienced in the use of ECDIS include failure to display navigational features correctly, failure to detect objects with the automated 'route check' function during passage planning, failure to alarm correctly and failure to manage several alarms correctly.[149]

The existence of ECDIS anomalies can pose a serious threat to the safety of navigation, particularly for paperless vessels. To address this issue, the IHO created 'data presentation and performance check' datasets for ECDIS.[150] Loading these test datasets onto their ECDIS allows navigators to ascertain if anomalies exist on their system and to evaluate its operating performance.[151] The datasets also fulfil the testing requirements of the IEC 61174[152] standard, which must be complied with to meet IMO performance standards. (To further address anomalies, the IHO has updated its ECDIS-related standards – see Chapter 5/I/b.)

The test datasets should alert officers if their ECDIS software requires an update from the manufacturer.[153] It is crucial that ECDIS software is maintained and thus capable of correctly displaying up-to-date ENCs in accordance with the latest versions of the IHO's standards for chart content and display.[154]

(g) Software Maintenance

If ECDIS software is not updated to the latest version of IHO standards, the system may not meet the carriage requirements of SOLAS regulation V/19.2.1.4, which requires all vessels to have 'nautical charts … to plan and display the ship's route…'. ECDIS may not correctly

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146 Department of Marine Services and Merchant Shipping Antigua and Barbuda W.I. and German Federal Bureau of Maritime Casualty Investigation – Joint Investigation Report *Capsizing after grounding and death of 18 crew members of MV Rocknes on 19 January 2004 in Vatlestraumen sea area south of Bergen, South Norway* (2006).
147 MSC.1/Circ.1503/Rev.1.
148 Ibid.
149 Ibid.
150 IHO S-64 'IHO Test Data Sets in ECDIS'.
151 MSC.1/Circ.1503/Rev.1.
152 Testing standard for type approval of ECDIS.
153 ICS BPG 59.
154 MSC.1/Circ.1503/Rev.1.

display the latest charted features if it has not been upgraded to ensure compatibility with the newest version of the IHO's ENC Product Specification or Presentation Library,[155] and might not sound appropriate alarms.[156] It may also not be possible to install or load some ENCs if the system is not compliant with the current version of the IHO's Data Protection Standard.[157] The application software within ECDIS must therefore function entirely in accordance with IMO performance standards and be capable of correctly displaying all ENC data, to ensure the safety of navigation.[158]

The IHO has recently updated their software standards – see Chapter 5/I/b. However, some older ECDIS units[159] (the hardware component of the system) cannot be upgraded with new software, or experience difficulties when attempting to upgrade ECDIS software.[160] Some vessels may thus be required to replace their ECDIS equipment, as the IMO's performance standards state:

> 'The contents of the SENC[161] should be adequate and up-to-date for the intended voyage to comply with regulation V/27 of the 1974 SOLAS Convention as amended.'[162]

The IMO places an onus on manufacturers to 'provide a mechanism to ensure software maintenance arrangements are adequate'; and on Administrations to

> 'inform shipowners and operators that proper ECDIS software maintenance is an important issue and that adequate measures need to be implemented by masters, shipowners and operators in accordance with the International Safety Management (ISM) Code'.[163]

The procedures contained in the SMS for software updating must be adhered to by the responsible officers. ECDIS failure, non-availability of the system and subsequent delay to the vessel have resulted from failure to follow the correct procedures.[164] The IHO's test datasets should be run after each software update or ECDIS upgrade to ensure the system is functioning correctly.[165]

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155 IHO S-57 & S-52 Annex A.
156 MSC.1/Circ.1503/Rev.1.
157 IHO S-63 1.2.0ed (2015).
158 MSC.1/Circ.1503/Rev.1.
159 Installed before 01/2009 and conform to the earlier version of the IMO Performance Standard (A.817[19]) as amended.
160 AMSA 'ECDIS software' (2017) available at *https://www.amsa.gov.au/safety-navigation/navigation-systems/ecdis-software* accessed on 31/01/2018.
161 System Electronic Navigation Chart.
162 MSC.232(82).
163 MSC.1/Circ.1503/Rev.1.
164 ICS BPG 72.
165 Ibid 59.

(h) Integrated Systems

An Integrated Bridge System (IBS) is a combination of systems which are interconnected to allow centralised access to sensor information and control of navigational functions.[166] IBSs are commonplace on modern merchant vessels, with ECDIS acting as the integrating component, tying together information from numerous sensors and inputs. IBSs typically comprise sensor inputs from the following sources: ECDIS, GNSS positional information, AIS,[167] BNWAS,[168] radar and ARPA, gyro compass, heading and track control, speed log, echo sounder, GMDSS[169] communications, propulsion and steering monitoring and control, as well as cargo operations and security systems.[170]

Although the aim of an IBS is to increase safe and efficient vessel management,[171] watchkeeping officers must take account of system limitations. Navigators may become overloaded by information from so many sources and distracted from their primary duties for safe navigation. In addition, inaccurate or erroneous information from any one sensor will transmit to all parts of the system, which could affect calculations for such things as ETAs[172] and CPAs. It is essential that officers maintain an awareness of the limitations of all electronic aids to navigation that form part of an IBS, so that errors may be promptly recognised. The prudent navigator will verify all information displayed on the ECDIS screen, regardless of its sensor origin.

(i) Cyber Security

Malware is increasingly being detected onboard vessels, posing a considerable safety threat to IBSs and shipboard operations. The use of ECDIS presents significant cyber security risks, as many units are run on older, unsupported operating systems. There have been instances where ECDIS systems have been taken offline due to crew members attempting to charge cell phones on the ECDIS computers. When the ECDIS attempts to locate the drivers for the phone and cannot find them, the system crashes. As many are running XP (vulnerable as it is unsupported) with poor quality software, the systems are not easy to recover.[173]

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[166] IMO MSC64(67) Annex.1 'Recommendation on Performance Standards for Integrated Bridge Systems' (1996).
[167] Automatic Identification System.
[168] Bridge Navigational Watch Alarm System.
[169] Global Maritime Distress and Safety System.
[170] ICS BPG 73.
[171] MSC64(67).
[172] Estimated Time of Arrival – under modern international security requirements, this information must be sent to ports up to 96 hours in advance.
[173] Walters, Paul: ABS Director of Cyber Security, speaking at the Singapore Registry of Ships Forum (2017) see *http://www.seatrade-maritime.com/news/americas/27089.html?highlight=WyJlY2RpcyIsImVjZGlzJyJd* accessed on 31/01/2018.

Companies must ensure that there are clear procedures in place to prevent this type of incident, and onboard management must enforce strict compliance. (The simple act of blocking the USB ports on the ECDIS computers onboard seems a logical step.) In addition to procedures, information regarding the vulnerabilities of ECDIS systems should be incorporated into formal shore-based training and onboard safety training.

IV ECDIS Accuracy

(a) Chart Accuracy

The depth and positional information on charts is based on hydrographic surveys which were conducted employing the methods and position-fixing technology available at the time.[174] For older surveys, the positional accuracy was not as precise as modern systems allow. A vessel navigating with GNSS may thus know its position with better accuracy than that of charted features.[175] Navigators must heed the limitations of chart accuracy – guidance for best practice is available from the IMO.[176]

High-resolution electronic charts may provide a deceptive impression of increased accuracy, but are based on the same hydrographic survey data used in the compilation of paper charts. Consequently, when passage planning with ECDIS, navigators must employ the CATZOC[177] function to assess the reliability of the source data and its associated accuracy – and thus determine the level of risk for navigation in that area. The 'pick report' facility may also be used to access more detailed information about the chart in use (including the year and type of survey).

(b) Case Studies – Chart Accuracy

In 2016, the freighter *Nova Cura* was declared a total loss after running aground on a reef in the Aegean Sea whose position was incorrectly shown on the ENC in use on the ECDIS. The officers had completed generic ECDIS training but were unfamiliar with the CATZOC function, which had thus not been used during route planning. This omission resulted in the navigators being unaware of the poor reliability of the ENC's survey data.[178]

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[174] ICS BPG 65.
[175] Ibid.
[176] SN.1/Circ.213; SN.1/Circ.255.
[177] Category of Zone of Confidence.
[178] Dutch Safety Board *Digital navigation: old skills in new technology, Lessons from the grounding of the Nova Cura* (2017).

The minesweeper *USS Guardian* grounded on a reef in the Philippines in 2013. A US Navy review found that the officers over-relied on an inaccurate electronic chart that erroneously displayed the position of the reef.[179]

In 2006, the towed jack-up barge *Octopus* grounded in the Orkneys. The area had last been surveyed in the 1840s and the grounding occurred on an uncharted bank. The MAIB report included a recommendation for relevant industry bodies to emphasise to shipmasters and officers the need to carefully consider the chart source data and, in the case of electronic charts, the CATZOC when passage planning.[180]

In 2004, the tanker *British Enterprise* grounded near Istanbul. The chart indicated a sufficient depth of water for the vessel's draft – she grounded on an uncharted shoal. The incident report reminded navigators to be aware of the importance of the chart source data, its age, and likely accuracy.[181]

In 1992, the passenger vessel *Queen Elizabeth 2* grounded on uncharted rocks while bound for New York. The last hydrographic survey, conducted in 1939, had not detected the rocks on which she grounded.[182]

(c) Accuracy of Positional Information

(i) GNSS

The vessel's position as displayed on the ECDIS screen is solely based on satellite-derived information from a GNSS. A GNSS is a satellite-based system providing continuous information on position, time, course and speed.[183] The United States' GPS and Russia's Global Navigation Satellite System (GLONASS) provide near global coverage,[184] while Europe's *Galileo* and China's *Beidou* are currently developing towards full operational capacity. GPS is the most commonly used GNSS for marine navigation[185] and will be focussed on in this section, although the operating principles for all GNSSs are similar.

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[179] Royal Institute of Navigation 'Chart grounds US warship' (2013) available at *http://www.rin.org.uk/NewsItem/2705/Chart-grounds-US-warship* accessed on 31/01/2018.

[180] MAIB Rep.18/2007 *Report on the investigation of the grounding of the jack-up barge Octopus towed by the tug Harald Stronsay Firth, Orkney Islands 8 September 2006* (2007).

[181] MAIB Rep.25/2005 *Report on the investigation of the grounding of British Enterprise Ahirkapi Anchorage Area Istanbul, Turkey on 11 December 2004* (2005).

[182] MAIB *Report of the Investigation into the Grounding of Passenger Vessel Queen Elizabeth 2 on 7 August 1992* (1993).

[183] ICS BPG 65; Course and speed *over the ground* (ground stabilised).

[184] ICS BPG 65.

[185] Cox, Kieron *Electronic Navigation Systems* (2016) (Cox).

(ii) GPS

Position is determined by the intersection of distance measurements from multiple satellites within the GPS array. As the distance is calculated by the time a signal takes to travel the vast distance from the satellite to the ship-board GPS receiver, highly accurate clocks are carried on the satellites for precise timing of signal transmissions.

GPS is prone to several error sources, including ionospheric and tropospheric delays (slowing of the signal as it passes through the atmosphere), signal multipath, frequency stability, orbital errors, receiver clock errors and receiver noise.[186] Additional meteorological conditions such as solar storms or flares can degrade or disrupt satellite signals. In September 2017, radiation from the most powerful solar flare in over a decade caused high frequency (HF) radio blackouts across the daytime side of the earth (affecting communication over Africa, Europe and the Atlantic Ocean), and warnings were issued of disruptions to GPS signals.[187]

Positional accuracy may further be affected by the geometry of the satellites visible to the GPS receiver.[188] GPS is considered to have a ninety-five percent probability, meaning that only ninety-five out of one-hundred fixes will be within the stated accuracy.[189] Although new technology and system upgrades have improved the accuracy of GPS to around ten[190] to twenty-five[191] metres, it is not prudent for navigators to rely solely on satellite-derived positional information.

(iii) GPS Jamming and Spoofing

Jamming is achieved by denying GPS service in an area by transmitting a stronger signal on the same frequency.[192] As GPS signals are fairly weak, jamming may be accomplished fairly easily. For around US$50,[193] illegal jammers can be purchased online.[194] The Resilient Navigation and Timing Foundation reports that Russia has advanced capabilities to disrupt

[186] Ibid.
[187] South African National Space Agency 'Strongest solar flare in over a decade' (2017) available at *http://www.sansa.org.za/component/content/article/9-spacescience/1741-strongest-solar-flare-in-over-a-decade*; US National Aeronautics and Space Administration 'Sun Erupts with Significant Flare' (2017) available at *https://www.nasa.gov/feature/goddard/2017/active-region-on-sun-continues-to-emit-solar-flares* both accessed on 31/01/2018.
[188] Determined by the Horizontal Dilution of Position (HDOP) value.
[189] Cox.
[190] Ibid.
[191] ICS BPG 65; Accuracy is increased in areas of Differential GPS (DGPS) coverage, as corrections are applied from shore-based reference stations.
[192] Goward, Dana 'GPS Spoofing Incident Points to Fragility of Navigation Satellites' *National Defense Magazine* (2017) available at *http://www.nationaldefensemagazine.org/articles/2017/8/22/viewpoint-gps-spoofing-incident-points-to-fragility-of-navigation-satellites* accessed on 31/01/2018 (Goward).
[193] Prices increase with the size of the area to be affected.
[194] Goward.

GPS, with 250 000 cell towers equipped with GPS jamming devices as a defence against missile attacks, and there have been press reports of Russian GPS jamming in both Moscow and the Ukraine.[195]

Spoofing is achieved by sending false signals which cause GPS receivers to provide incorrect information.[196] Exploring shipping's vulnerability to deceptive GPS signals, researchers demonstrated how to 'take over' control of a vessel by GPS spoofing in 2013.[197] The false signals sent to the ship's GPS were subtle enough that they could be disguised as the effects of ocean currents and were therefore undetected by the crew and systems onboard. At a hackers' convention in 2015, a researcher provided detailed instructions for building a spoofing device and sold kits for US$300.[198]

In June 2017, more than twenty vessels were affected by a blatant GPS spoofing attack in the Black Sea.[199] All of the vessels' GPS positions showed their location to be at an inland airport in Russia. It was confirmed that there were no GPS signal anomalies, space weather or ongoing tests in the area.[200] Disturbingly, one vessel's GPS receiver indicated that the position was accurate to within one-hundred metres, yet displayed a position twenty-five nautical miles from her actual geographic location.[201] Expert analysis has concluded that this was a clear case of GPS spoofing.[202]

As GPS is part of an IBS, the false signals from jamming or spoofing will be transmitted to all components of the system, many of which rely on this information for calculations. Overreliance on satellite-derived positional information is a dangerous practice and navigators must ensure that they verify their position by an independent means such as radar or visual bearings. The marine insurance industry recognises this risk:

> 'A dependence on satellite positioning, especially GPS, is also singled-out as a threat to future shipping safety, especially in light of concerns about the reliability of available satellite-based systems and the potential threat to disruption to satellites by renegade groups or terrorists.'[203]

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[195] Royal Institute of Navigation (RIN) 'GPS Spoofing in Black Sea?' (2017) available at *http://www.rin.org.uk/newsitem/4969/GPS-Spoofing-in-Black-Sea?* accessed on 31/01/2018 (RIN).
[196] Ibid.
[197] Bhatti, Jahshan & Humphreys, Todd 'Hostile Control of Ships via False GPS Signals: Demonstration and Detection' (2017) 64(1) *NAVIGATION, Journal of The Institute of Navigation* 51-66.
[198] Goward.
[199] RIN.
[200] Ibid.
[201] Ibid.
[202] Ibid.
[203] Newton, Paul, AGCS Report.

(d) Case Study – Accuracy of Positional Information

In 2014, an 'ECDIS-assisted collision' occurred between two cargo vessels – *MV Francisca* and *RMS Bremen* – in the river port of Kiel. The incident investigation found that both vessels' ECDIS showed that they did *not* make contact and were separated by a reasonable distance. The AIS recordings from the local VTS[204] also indicated that the ships passed clear of one another. Yet, incontestably, a collision occurred, evidenced by the damage caused to the vessels by the impact.

It was found that the GPS receivers on both vessels were functioning correctly. After extensive investigation and analysis, no abnormalities in the GPS system in the area could be identified. There was no evidence of interference from jamming or spoofing. The simulated GPS satellite constellations at the time of the incident were normal. Environmental factors were found not to be a contributory factor in the collision. The investigation was unable to definitively explain the apparent separation of the vessels' true positions versus their displayed positions on ECDIS. There appeared to have been some sort of GPS anomaly or signal-shadowing. The officers on both vessels failed to verify their displayed GPS positions by an independent means and relied entirely on the positions displayed on ECDIS.

ECDIS and AIS cannot be solely relied on for positioning or collision avoidance. Maintaining a visual lookout and the use of radar and ARPA are essential for safe navigation. This incident highlights that it is precisely the growing use of ECDIS that makes it necessary for officers to continuously verify their position using all available means.[205]

V User Settings

(a) Chart Presentation

ECDIS is capable of displaying vast amounts of information, which can overload and confuse navigators if not appropriately managed.[206] A display screen that is cluttered with unnecessary information may hide or obscure essential charted features.[207] To ensure safe navigation with ECDIS, it is of paramount importance that all safety settings are appropriately configured.[208] Degraded system accuracy is often associated with user set-up errors.

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[204] Vessel Traffic Service.
[205] Federal Bureau of Maritime Casualty Investigation (Germany) Rep.276/14 *Collision in the Kiel Firth at Friedrichsort between the MV Francisca and MV RMS Bremen on 5 September 2014* (2015); Nautical Institute MARS Rep.201738 'Mystery collision reveals GPS anomaly' (2017).
[206] ICS BPG 72.
[207] Ibid.
[208] Bhuiyan, Zakirul 'ECDIS Display, Safety Settings and Alarm Management' Conference Paper, presented at the 14th International Association of Institutes of Navigation Congress (2012) 2 (Bhuiyan).

During hours of darkness, a 'night' display can be selected on ECDIS, which dims the brightness of the display and has a black background to protect watchkeepers' night vision. Concerns have been raised that the night display in some models obscures cartographic features and makes essential safety features such as depth contours and hazards less evident. This was identified as a contributory factor in the grounding of the *Costa Concordia*, as the night display on the ECS in use reduced the officers' situational awareness.[209]

The 'guard zone' is an essential feature for detecting hazards to navigation, as it creates an arc ahead of the vessel that will trigger alarms to alert of unsafe conditions in the vessel's path. The guard zone must be set to an appropriate time vector for advance notice to give the officer time to take avoiding action. If all safety settings are not correctly selected, the guard zone may not be able to recognise hazards in the vessel's path – ECDIS can only protect the navigator from the dangers he/she has asked it to look for.

The Britannia Steam Ship Insurance Association found that in all the grounding cases the club reviewed, the ECDIS safety settings were incorrectly or inappropriately configured; and in many cases the audible alarm had been disabled. The club further identified overreliance, complacency and inadequate training as risk factors for ECDIS.[210]

(b) Display Modes

ECDIS must display all chart information necessary for safe and efficient navigation, and have (at least) the same reliability and availability of presentation as paper charts.[211] The operator, however, has extensive control over the information displayed on the ECDIS screen, and inappropriate selections in this regard can significantly affect the safety of navigation. There are three options for display modes – Display Base, Standard Display and All Other Information – and the screen will look drastically different depending on the selected mode.

The mode intended to be used as a *minimum* during route planning and monitoring is Standard Display.[212] If another display mode is selected, it must be possible to 'default' back to Standard Display by a single operator action.[213] Navigators must bear in mind that Standard Display will not always include all information required for safe navigation in all

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[209] Di Lieto, Antonio 'Costa Concordia Anatomy of an organisational accident' 15 available at *https://maddenmaritime.files.wordpress.com/2012/07/costaconcordiaanatomyofanorganisationalaccident.pdf* accessed on 24/01/2018.

[210] Britannia Steam Ship Insurance Association Limited 'ECDIS – Some lessons learned' (2016) 23/1 *Risk Watch* 3-5.

[211] MSC.232(82).

[212] Ibid.

[213] Ibid.

circumstances, such as underwater obstructions and spot soundings.[214] It is however possible to select Display Base mode, which contains *less* information than Standard Display. As Display Base is not intended to be sufficient for safe navigation,[215] the advisability of it remaining a display option is questionable.

The third display mode option is All Other Information, which navigators can use to customise and enhance the display, as appropriate for the area of navigation. There are many navigational features contained in this last display mode, giving an officer many decisions to make as to which items to include in the display. This can be overwhelming if not familiar with the system and it may be convenient to simply select to display ‘all’, as this may seem to be the safest option to ensure that nothing is left out or overlooked. The danger is that the screen can then become cluttered, resulting in the officer becoming overloaded with superfluous information and losing situational awareness. The amount of information displayed must be managed to avoid obscuring charted features.[216] Navigators must ensure that their selection displays all information needed for safe navigation, but avoid displaying unnecessary data which can distract their attention from hazards or safety-related data.

Procedures for managing the display of charted information can vary extensively amongst ECDIS manufacturers – in some models the methods are simple and user-friendly, in others the functions are buried in sub-menus which are not easy to access. Given the importance of the chart display feature for safe navigation, it is essential that officers are thoroughly familiarised with these functions during type-specific training.

Certain makes of ECDIS have been found not to display some shoal soundings in Base or Standard Display Modes, due to their encoding within IHO S-57.[217] Due to an ECDIS anomaly, automatic grounding alarms have also not been triggered by these shoals in *any* display mode, even if their depth is less than the input safety depth value.[218]

(c) Display Scale

The selected display scale can have a significant effect on the safety of navigation with ECDIS. All charted information necessary for safe navigation may not be displayed if an ENC is zoomed too far in or out.[219]

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[214] Bhuiyan 4.
[215] MSC.232(82).
[216] ICS BPG.
[217] South African Navy Hydrographic Office (SANHO) ‘South African Notices to Mariners’ March 2015 Edition 18.
[218] Ibid.
[219] ICS BPG 71.

If a chart is zoomed in beyond its compilation scale (the scale at which it was created), the positional accuracy of charted features can no longer be guaranteed. ECDIS provides an indication if the selected display is at a larger scale than that contained in the ENC[220] and alerts the operator to this hazardous condition by displaying vertical grey lines ('jail grid').

Zooming the display out too far also has potentially serious consequences, due to the SCAMIN[221] feature, which reduces clutter on the screen by removing certain charted features from the display as it is zoomed out. This is much the same as paper charts, where significantly more detail is shown on larger scale than smaller scale charts. The danger is that an unexperienced or careless officer using ECDIS at a smaller scale than is appropriate for the navigational circumstances may not have all the safety-critical information required displayed on the chart. An under-scale indication[222] advises the navigator that a larger scale – and therefore more detailed – chart is available for the area of operation.

(d) Safety Contour

The correct setting of the safety contour is critical, as it marks the division between safe and unsafe water on the ECDIS display.[223] The appropriate value for the safety contour is generally determined by the following formula: vessel's draught[224] plus UKC (under keel clearance)[225] plus squat[226] minus the height of tide.[227] Once a navigator has selected a safety contour, the ECDIS emphasises it over the other contours on the display,[228] – the safety contour line is thicker, darker and more prominent – making it easy to identify. In addition, the colouring on the chart is different on either side of the safety contour, with a blue shade indicating unsafe, shallow water inside[229] the contour, and a white or grey shade indicating safe, deep water outside[230] the safety contour.

ECDIS will display a default safety contour of thirty metres if one is not selected by the user,[231] although this may obscure hazards and needs to be set appropriately for each passage.

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220 MSC.232(82).
221 Scale Minimum.
222 MSC.232(82).
223 Bhuiyan 2.
224 The vertical distance from the waterline to the keel (lowest point of the ship).
225 The vertical distance from the keel to the seabed. The required values for UKC for various stages of passage are usually defined in a vessel's SMS or company policy.
226 The bodily sinkage into the water that a vessel experiences when making headway – squat thus increases a vessel's draft when she is sailing.
227 The vertical distance from the chart datum (depth shown on chart) to the actual water level.
228 MSC.232(82).
229 To landward, generally, unless it is an isolated shoal within deeper water.
230 Generally seaward.
231 MSC.232(82).

The display of isolated danger symbols or underwater obstructions can vary depending on the value of the safety contour.[232] A prudent navigator will also consider the depth accuracy of the CATZOC area.

When the 'route check' function is employed during passage planning, the system will provide an indication if the planned route crosses the selected safety contour, to draw the navigator's attention to this hazard. While monitoring a route (sailing), ECDIS will sound an alarm if the vessel's guard zone will cross the safety contour. If this zone has not been activated, the system will not be able to alert the navigator to a potential grounding situation. If the time vector for the zone is set too low, the officer may not give him/herself sufficient time for avoiding action once the alarm sounds. The safety contour is thus a crucial feature to assist the navigator in avoiding unsafe, shallow water, but is only effective if he/she has correctly configured the parameters.

The *safety depth* is determined by the same formula as the safety contour, but applies to spot soundings[233] rather than a contour line. ECDIS will emphasize soundings equal to or less than the safety depth[234] by displaying them in a bold black rather than the light grey display for (safe) soundings of more than the safety depth. The safety depth feature does not, however, trigger an alarm.

(e) Alarm Management

ECDIS is required to provide appropriate audible alarms or visual indications relating to the navigational information displayed.[235] As the integrating component of an IBS, ECDIS will also repeat alarms from other sensors.

ECDIS alarms are intended to enhance the safety of navigation by alerting officers to imminent hazards, however in many incident investigations it is discovered that the audible alarms have been disabled as officers become frustrated by their excessive sounding. However, if the audible alarm has been disabled, the ECDIS no longer meets IMO performance standards.

Many navigators lack an understanding of alarm management and fail to appreciate that all safety settings must be appropriately configured to avoid unnecessary alarms, alarm fatigue and alarm complacency. The issue of excessive alarms has been somewhat addressed by the IHO's revised presentation library (see Chapter 5/I/b) which provides that navigational alarms

[232] Bhuiyan 1.
[233] Individual depths indicated numerically on the chart.
[234] MSC.232(82).
[235] Ibid.

should be set to a minimum at the navigator's discretion, or according to company policy. This will not, however, reduce the number of system alarms.

(f) Chart Updates and Passage Planning

As per SOLAS Regulation V/27, all charts required for the intended voyage must be adequate and up-to-date. Vessels using ECDIS must have the latest available editions of ENCs, kept up-to-date by official electronic updates (received from the chart supplier) and notices to mariners (manual updates).[236] Official updates may be either fully automatic, requiring only a satellite connection, or semi-automatic, requiring a form of hardware, usually CD-ROM.

Compared to the onerous process of updating paper charts (particularly if a world-wide folio is carried), the time commitment required of officers for official automatic updating of electronic charts is drastically reduced. This is especially beneficial given the cost-saving trend towards reducing manning levels on merchant vessels.

The efficiency of passage planning is also significantly improved when using ECDIS[237] rather than paper charts, provided that the navigator uses the system in such a way as to ensure that all hazards are identified during planning. Safety settings must be correctly configured before commencing planning, including safety contour and safety depth, taking account of the vessel's draught and the required UKC for the voyage. ECDIS has the capability to run an automated 'route check' of the planned route before saving it. However, the hazards identified by the system will depend on the user-selected safety parameters. In addition, some ECDIS have been found to only perform the route check function on larger scale ENCs, therefore alarms may not activate and this might not clearly be indicated on the display.[238] Navigators thus cannot solely rely on the automated route check function and *must* conduct a comprehensive visual inspection of the passage plan at an appropriate scale to ensure the safety of the route.[239]

If reusing a previous passage plan, the route must be rechecked to confirm that it is still safe.[240] This highlights an advantage of paper charts over ENCs – as when navigators apply updates and corrections to paper charts, they are required to physically handle and study the charts during the process, and are thus aware of each of the ports or coastlines affected by the

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[236] MSC.1/Circ.1503/Rev1.
[237] ICS BPG.
[238] UKHO NAVAREA1 Warning 317/10; SANHO 'South African Notices to Mariners' March 2015 Edition, 19.
[239] UKHO; SANHO.
[240] ICS BPG.

updates. Changes to ports frequently called at, or in a vessel's general geographic area of operation, are anticipated and passage plans amended accordingly.

When updating ENCs, however, the navigator is very much removed from the process, as all that is required is to click a button to accept the latest updates, and the system does the rest in the background. Of interest to the officer is chiefly that the updates have all been correctly installed, which the system indicates and logs. The nature of each individual update is not generally displayed beyond a technical (S-57) code, which will not indicate whether updates affect the vessel's frequently used routes. Thus, even if a route has been executed safely many times previously, it is essential to perform an automated route check on the ECDIS as well as a manual inspection of the planned passage before accepting it as safe.

Another convenience of passage planning with ECDIS is that it allows for reversal of a route, particularly useful if a vessel transits between two ports frequently. It is crucial that the route is again carefully checked as described above after reversal, as imprudent use of this function has already resulted in six vessels navigating in the incorrect lanes of the Dover Strait Traffic Separation Scheme (TSS)[241] – creating hazardous head-on situations with opposing traffic correctly following the lanes (and violating Rule 10 of the COLREGs).

(g) AIS – The Need for Caution

AIS is a maritime mobile band VHF broadcast system[242] designed to automatically provide navigational information about a vessel to other vessels and coastal authorities.[243] Displaying AIS targets on the ECDIS screen can assist a navigator's cognitive assessment of other vessels' movements and intentions. The limitations of AIS must, however, be heeded and overreliance on AIS information must be avoided.

Vessels under 300gt engaged on international voyages and under 500gt not on international voyages are not required to be equipped with AIS.[244] These smaller vessels such as yachts and fishing craft are often constructed of fibreglass or wood and may not make strong radar targets, so vigilance is required to ensure their detection. In addition, the master of any vessel may (at their professional discretion) switch their AIS off for safety or security reasons, such as in piracy areas. Navy vessels, warships and coastguard or fishery-patrol vessels generally do not transmit their AIS data either.

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[241] Wingrove, Martyn 'Does ECDIS increase the risk of ship collisions?' (2016) available at *http://www.marinemec.com/news/view,does-ecdis-increase-the-risk-of-ship-collisions_42825.htm* accessed on 31/01/2018.

[242] ICS BPG 66.

[243] See *http://www.imo.org/en/OurWork/Safety/Navigation/Pages/AIS.aspx* accessed on 31/01/2018.

[244] SOLAS V/19.

Navigators must thus be very aware that an ECDIS screen displaying AIS targets does *not* represent the complete vessel traffic situation. Radar, ARPA and a visual lookout must be used to provide full situational awareness and to ensure compliance with the COLREGs. AIS may be used to *assist* in collision avoidance decision-making, but may *not* be relied upon as the sole information system in this regard.[245]

(h) Errors of Interpretation

Errors of interpretation can degrade the safety of navigation and occur when officers misconstrue information on the ECDIS display. Common errors include confusion of display mode or display scale (sometimes ignoring the overscale indication) and uncritical acceptance of the vessel's position by neglecting the ninety-five percent probability of positional accuracy. The Japan P&I Club found that

> 'more human errors are caused by misinterpretation of information displayed on ECDIS, and this implies that the use of ECDIS leads to hazardous situations'.[246]

Navigators must bear in mind that although the ECDIS display appears modern and thus accurate, the source data used for the chart compilation is the same as paper charts. User settings and safety parameters should be checked at the start of each watch. Navigational information derived from the ECDIS must be verified by an independent means and the radar overlay feature is a convenient way of detecting any discrepancies between the two systems.

(i) Case Studies – User Settings

In 2014, the cargo vessel *Rickmers Dubai* collided with *Walcon Wizard*, an unmanned crane barge which was being towed in the Dover Strait TSS. The investigation found that *Rickmers Dubai's* OOW did not keep a proper lookout and relied solely on AIS information displayed on the ECDIS for collision avoidance. He failed to use the radar or ARPA, to maintain a visual lookout, or to take note of safety broadcasts issued advising of the tug and tow's position in the TSS. The officer's situational awareness was poor and he was not proactive in monitoring his watchkeeping duties. The investigation report suggests that a balance needs to be found between overreliance on AIS and its effective use, and that it is crucial that officers are fully aware of the system's capabilities and limitations.[247] Regarding ECDIS, the report states:

> 'ECDIS is capable of providing a wealth of information to the user, including charts, waypoints, safe water and overlaid AIS information. However, it is not a "one-stop shop"

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[245] IMO Res.A.1106(29) 'Revised Guidelines for the Onboard Operational Use of Shipborne AIS' (2015).
[246] Japan P&I Club 'ECDIS' (2017) 39 *P&I Loss Prevention Bulletin* 26.
[247] MAIB Rep.29/2014 *Report on the investigation of the collision of Rickmers Dubai with the crane barge Walcon Wizard being towed by the tug Kingston in the south-west lane of the Dover Strait Traffic Separation Scheme on 11 January 2014* (2014).

which is able to provide all of the information required by an OOW. ECDIS must be used in conjunction with other aids to navigation and collision avoidance, particularly radar and visual lookout.'

Also in 2014, the ro-ro ferry *Commodore Clipper* grounded on a charted shoal near Guernsey. ECDIS was the primary means of navigation onboard, but was not utilised effectively as key safety features were either disabled or ignored. The officers had completed generic ECDIS and type-specific familiarisation training. Passage planning was insufficient as the very low tide and effect of squat were not adequately considered, thus the bridge team did not appreciate the hazard posed by the shoal. The audible alarm had been disabled and the safety contour was inappropriately set.[248]

The bulker *CSL Thames* ran aground near Scotland in 2011. ECDIS was the primary means of navigation and no paper charts were carried. The OOW altered course for collision avoidance, without noticing that this would take the ship into shallow water. The ECDIS alarm was inoperative and the officers had not questioned the absence of an alarm, due to their insufficient ECDIS knowledge. The officers had all attended generic ECDIS training courses, but they were found to lack comprehension of the system's safety features. The OOW 'knew' that ECDIS was supposed to sound an alarm if the vessel was running into danger and thus felt no obligation to verify the vessel's position. His confidence and overreliance were clearly misplaced and reckless given that the safety contour was inappropriately set and the audible alarm not functional. The ergonomics of the bridge layout and location of the ECDIS were also considered factors in this incident.[249]

In 2009, the container vessel *Maersk Kendal* ran aground in the Singapore Strait after altering course for collision avoidance. Paper charts were the primary means of navigation and ECDIS was intended for use as an aid to navigation only. Although relevant checklists for passage planning had been completed, the plan lacked sufficient detail on both the paper charts and ECDIS. The ECDIS had not been configured to utilise built-in safety features such as safety depth, danger areas or a guard zone. As the officers had attended a generic ECDIS training course, they should have realised the advantage of employing these features. The bridge team over-relied on the inappropriately set-up ECDIS and failed to adequately monitor the ship's position.[250]

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[248] MAIB Rep.18/2015 *Report on the investigation of the grounding and flooding of the ro-ro ferry Commodore Clipper in the approaches to St Peter Port, Guernsey on 14 July 2014* (2015).
[249] MAIB Rep.2/2012 *Grounding of CSL Thames in the Sound of Mull 9 August 2011* (2012).
[250] MAIB Rep.2/2010 *Report on the investigation of the grounding of MV Maersk Kendal on Monggok Sebarok reef in the Singapore Strait on 16 September 2009* (2010).

The cargo ship *CFL Performer* ran aground off the English coast in 2008. The grounding occurred twenty-nine minutes after the OOW had altered course to follow the passage plan shown on the ECDIS. The planned route took the vessel across an area where the charted depth of water was less than the vessel's draught – the route was obviously not adequately checked for navigational hazards during planning or monitoring. ECDIS was the primary means of navigation onboard, but none of the vessel's officers had been trained in its use and thus many of the system's features which could have prevented the grounding were not utilised. The officers were not aware of the significance of the safety contour and safety depth, or how to set up a guard zone.[251]

The container vessel *LT Cortesia* ran aground on the Varne Bank in 2008. The OOW over-relied on an unofficial ECS and his situational awareness was reduced due to poorly configured user settings. The safety contour and alarms were inappropriately set. The night display on the ECS was identified as a causal factor in the grounding, due to the colour contrast not clearly differentiating shallow water depths, and chart symbols being difficult to detect on the darkened display. If the officer had fixed the vessel's position on the paper chart – which was *legally* the *primary* means of navigation – the hazard would have been clearly evident. The incident report found:

> 'Too often, the distinction between the various operating modes of an electronic chart display system are not clear enough, and the resulting legal consequences are extremely far-reaching.'[252]

[251] MAIB Rep.21/2008 *Report on the investigation of the grounding of CFL Performer Haisborough Sand North Sea 12 May 2008* (2008).

[252] German Federal Bureau of Maritime Casualty Investigation Rep.01/08 *Grounding of the LT Cortesia on 2 January 2008 on the Varne Bank in the English Channel* (2009).

CHAPTER 4 THE HUMAN FACTOR AND HUMAN ERROR IN THE USE OF ECDIS

I Introduction

From 2011 to 2015, the number of marine casualties and incidents reported to the European Maritime Safety Agency (EMSA) steadily increased.[253] Half of the casualties were of a navigational nature, such as groundings and collisions.[254] The International Union of Marine Insurance (IUMI) reported an increase in major vessel casualties in 2016, the second year in a row after more than a decade of decline, with the frequency of total loss caused by groundings having increased more quickly than other categories of casualty.[255] Given that the primary function of ECDIS is to contribute to safe navigation,[256] should technological advancements in bridge equipment not have led to a decrease in the occurrence of marine casualties since the carriage of ECDIS became mandatory?

Instead, recent years have seen several ECDIS-assisted navigational accidents, incidents and near misses.[257] Although ECDIS design issues have been identified, analysis of these accidents indicates that the causes are predominantly not system design failures, but are more commonly due to operational failures by deck officers in their use of ECDIS.[258] The objective of this chapter is thus to critically evaluate the human factor and human error in the use of ECDIS.

II The Human Factor and Human Error in the Maritime Domain

(a) Overview

Human error has long been regarded as a major causal factor in maritime incidents, with between seventy-five and ninety-six percent of marine casualties being attributable to human

[253] EMSA 'Annual Overview of Marine Casualties and Incidents 2016' 15-16.
[254] Ibid 8.
[255] IUMI *2017 Shipping Statistics – Analysis, Casualty and World Fleet Statistics as at January 2017: Key Observations* (2017) 2-3; see also *http://maritime-executive.com/article/insurers-report-rising-frequency-of-major-casualties* accessed on 31/01/2018.
[256] MSC.232(82).
[257] Chhabra, Yashwant 'A little learning: examining ECDIS education' (2014) Issue 5 *The Navigator* 4.
[258] Ibid.

error.[259] In recent years, analysis of shipping casualties has generated a growing awareness of the central importance of the human element.[260]

The UK Maritime and Coastguard Agency (MCA) recently identified a lack of situational awareness as the most significant of 'the deadly dozen' human factors in maritime safety,[261] a finding supported by an extensive American Bureau of Shipping (ABS) study.[262] Case studies in this paper have illustrated how the use of ECDIS may lead to a lack of situational awareness by watchkeepers. A study by the US Coast Guard identified fatigue, inadequate communication and inadequate technical knowledge (chiefly the improper use of technology) as the three greatest human factor problems[263] at sea. The poor design of automation, decisions based on inadequate information, and faulty standards, policies or practices were also found to be issues.[264]

The IMO adopted a resolution outlining its vision, principles and goals for the human element in 1997, which was updated in 2003.[265] Through this resolution, the IMO acknowledged the need for more focus on human-related activities in the safe operation of vessels and assigned the human element issue high priority due to its prominent role in the prevention of maritime casualties:

> 'Effective remedial action following maritime casualties requires a sound understanding of human element involvement in accident causation. This is gained by thorough investigation and systematic analysis of casualties for the contributory factors and the causal chain of events.'[266]

The ISM Code addresses the human element by establishing a standard for the safe management and operation of vessels and the implementation of safety management systems.[267]

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[259] AGCS Report 3; Baker, Clifford & Seah, Ah 'Maritime Accidents and Human Performance: the Statistical Trail' ABS Technical Paper presented at MARTECH Singapore (2004) (Baker); Rothblum, Anita 'Human error and marine safety' Conference Paper, presented at the US National Safety Council Congress and Expo, Orlando (2000) (Rothblum); Transportation Safety Board of Canada 'Working Paper on Tankers Involved in Shipping Accidents 1975-1992' (1994); Cormier, P.J. *Towing Vessel Safety: Analysis of Congressional and Coast Guard Investigative Response to Operator Involvement in Casualties Where a Presumption of Negligence Exists* (unpublished Masters Thesis, University of Rhode Island 1994); Bryant, D.T. 'The Human Element in Shipping Casualties' Report prepared for the Department of Transport Marine Directorate, UK (1991); UK P&I Club 'Analysis of Major Claims 1992'; Wagenaar W.A. & Groeneweg, J. 'Accidents at sea: Multiple causes and impossible consequences' (1987) 27 *Int. J. Man-Machine Studies* 587-598.
[260] Gregory, Dik & Shanahan, Paul *The Human Element – a guide to human behaviour in the shipping industry* (2010), i (Gregory).
[261] UK MCA Marine Guidance Note MGN520(M) 'Human Element Guidance Part 2, The Deadly Dozen – 12 Significant People Factors in Maritime Safety' (2016).
[262] Baker.
[263] US Coast Guard 'Prevention Through People: Quality Action Team Report' Washington (1995).
[264] Ibid.
[265] IMO Resolution A.947(23) 'Human Element Vision, Principles and Goals for the Organisation' (2003).
[266] Ibid 3.
[267] See *http://www.imo.org/en/OurWork/HumanElement/Pages/Default.aspx* accessed on 31/01/2018.

The IMO has thus initiated measures to address the human factor as a component of vessel casualties and to mitigate associated environmental damage.[268]

In addition to safety considerations, maritime casualties give rise to significant financial implications for shipowners, charterers and insurers. Over a recent ten-year period, the Standard P&I Club estimated that insurance claims cost the P&I industry US$15 billion, with sixty-five percent of pay-outs (US$10 billion) being for incidents in which humans played the principal part.[269] 'The types of claim we see … keep recurring, and inevitably these are rooted in the more unfortunate consequences of human behaviour.'[270]

(b) Error Management

Since the majority of shipping casualties are caused by human error, considering the human factor in shipboard operations is of paramount importance to improve safety.[271] Risk reduction and error management are essential in the safety-critical, high-risk maritime industry, however '[t]o err is human…'[272] and the complete elimination of human error is an impossibility. However, if people's understanding, actions and behaviour change – many maritime accidents, incidents and errors could be avoided.[273] Error management is the responsibility of the wider maritime industry, not only seafarers:

> 'The human element is a complex multi-dimensional issue that affects maritime safety, security and marine environmental protection. It involves the entire spectrum of human activities performed by ships' crews, shore-based management, regulatory bodies, recognized organizations, shipyards, legislators, and other relevant parties, all of whom need to co-operate to address human element issues effectively.'[274]

Human error has been controlled in other industries through use of a human-centred approach; and increased human-centred design, that takes account of people's abilities and limitations.[275]

In developing regulations and policies, sufficient safeguards should be included therein to ensure that a single human or organisational error does not result in an accident through their application.[276] Effective maritime resource management has been proven to prevent shipping

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[268] One of the objectives of the ISM Code is pollution prevention.
[269] Gregory v.
[270] Spencer, Chris (Director of Loss Prevention, Standard P&I Club) foreword in Gregory.
[271] Rothblum.
[272] Pope, Alexander *An Essay on Criticism, Part II* (1711).
[273] MCA MGN520(M).
[274] IMO Resolution A.947(23).
[275] Rothblum.
[276] IMO Resolution A.947(23).

accidents caused by human and organisational errors[277] and the requirements for bridge resource management training for deck officers are discussed in Chapter 4/IV/e.

Conditions experienced in a shipboard environment can have a detrimental effect on human performance, including rough weather, ship motion, temperature, noise and vibration.[278] Error management requires an understanding of the nature of the errors experienced and the context in which they occur.

(c) Types of Human Error

Human error may be described as being an incorrect decision, an improperly performed action or an inappropriate lack of action (inaction).[279] Depending on the nature of the task and their experience with the given situation, people operate at one of three levels of performance – skill-based, rule-based or knowledge-based[280] – and there are error types associated with each level.

Skill-based errors are errors of execution that occur when an individual is very experienced and familiar with the task at hand.[281] Reactions are automatic or reflexive and the cognitive processing of information occurs sub-consciously, so minimal mental resources are required and attention may be diverted to other activities. These error types include unintentional actions that occur due to a failure of attention (slips) or a failure of memory (lapses).[282] In the context of bridge watchkeeping at sea, these error types are more common amongst senior officers whose vast experience may lead to complacency in the execution of routine navigational tasks.

When an individual is only somewhat familiar with a task but lacks the experience to perform it at a sub-conscious level, rule-based performance errors occur due to their inability to recognise or comprehend a situation.[283] Information is misinterpreted and the incorrect rule is applied, selected from a choice of memorised rules. These errors are classed as mistakes – the action is intentional, however the individual did not mean to take an incorrect course of action or violate a rule.[284] Rule-based errors are more commonly made by junior officers who do not yet have extensive bridge watchkeeping experience and are following rules learned

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[277] The Swedish Club 'Maritime Resource Management' available at *https://www.swedishclub.com/media_upload/files/Publications/TSC_MRM_140616_ORIGINAL.pdf* accessed on 31/01/2018.

[278] Squire 9.

[279] Rothblum.

[280] Rasmussen, Jens 'Skills, rules, and knowledge: signals, signs and symbols, and other distinctions in human performance models' (1983) SMC-13 *IEEE Transactions on Systems, Man & Cybernetics* 257-267 (Rasmussen).

[281] Ibid.

[282] Reason, James *Human Error* (1990) (Reason).

[283] Rasmussen.

[284] Reason.

during their training – their situational awareness and assessment capabilities still require further development.

Shortcomings in an individual's knowledge can result in knowledge-based performance errors.[285] This error type may also occur due to a limited ability to apply existing knowledge to new situations.[286] Although these errors are more common for junior officers, even seasoned navigators may make knowledge-based errors when faced with a situation of which they have no experience.

All of the above error types are found in the use of ECDIS, as illustrated in the case studies in this dissertation. In addition, officers commit violations, which differ from mistakes in that violations are intentional actions that deliberately contravene known rules, policies or procedures. Overreliance on ECDIS may be considered a breach of SOLAS and STCW requirements,[287] as well as a violation of the COLREGs if officers fail to use all available means to maintain a proper lookout. The standard operating procedures for the use of ECDIS should be clearly defined in the SMS, although officers are seen not adhering to these company-specific rules, thus breaching ISM Code requirements.

III Automation and Human Performance

(a) Overview

Human performance can be significantly affected by the design of the technology that people have to work with.[288] If automation is designed without sufficient consideration of the information that the operator needs to access, critical data may be displayed in a manner that is difficult to interpret, causing confusion.[289] Automation changes the task it is meant to support and creates new error pathways and knowledge demands.[290] The efficiency of operations can be increased by investment in automation, but without a parallel investment in training, risk-taking can also increase – particularly given the recent trend towards reduced manning levels on merchant vessels.[291] Automation can generate more distance between people and the world

[285] Rasmussen.
[286] Ibid.
[287] Nichol, David 'Technology alone will not ensure safety at sea' (2017) 1 *Lookout* (UK P&I Club publication) 13.
[288] Rothblum.
[289] Ibid.
[290] MSC/Circ1091.
[291] Gregory vi.

around them, isolating them from their environment and making them less likely to notice changes in operating conditions or to take effective correcting action.[292]

In modern IBSs, ECDIS acts as the integrating component, tying together information from numerous sensors and inputs. In these systems, the bridge equipment essentially also forms part of the bridge team.[293] The way in which users interact with equipment is referred to as the human machine interface (HMI) and relates to things like displays, menus, controls and alarms.[294] Despite the advantages of automation, system designers often neglect to consider end users. Navigators are thus required to monitor and integrate complex data from numerous inputs. Current initiatives to develop a human-centred design approach for navigation systems are explored in Chapter 5/I.

(b) The Effects of Automation on Decision-Making

Officers serving onboard merchant vessels are embedded in organisational cultures that are dominated by time and cost,[295] commercial pressure being an ever-present reality. Decisions made in this context tend to favour efficiency over thoroughness, guided by the experience of the individual and the training they have received.[296] If officers are insufficiently trained or if they perceive organisational expectations as too demanding, the risks taken in their decision-making processes will increase.[297] People generally prefer the path of least resistance – in both cognitive and physical work – thus decision-makers often adopt strategies intended to reduce cognitive effort and minimise the likelihood of information overload.[298]

The introduction of automation can change decision-making patterns and alter how situations are assessed and handled.[299] It has been seen in a number of the case studies in this dissertation that ECDIS has the potential to reduce watchkeepers' situational awareness, principally due to overreliance on automation. We have seen that officers adopt a passive role in watchkeeping, relying on automated system alarms to alert them to potentially unsafe situations, rather than proactively monitoring their surroundings on the bridge and the dynamic operating environment at sea. This role as a system monitor breeds complacency and boredom, and fosters fundamentally unsafe navigational practices.

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292 Ibid 11.
293 Norris, Andy 'Making equipment part of the team' (2014) Issue 7 *The Navigator* 10.
294 Ibid.
295 Gregory 27.
296 Ibid 27, 30.
297 Ibid 24.
298 Mosier, Kathleen & Skitka, Linda 'Human Decision Makers and Automated Decision Aids: Made for Each Other?' in Parasuraman, R & Mouloua, M (eds) *Automation and Human Performance: Theory and Applications* (1996) 203.
299 Ibid 216.

Research has found that over-automated systems can encourage 'automation-induced complacency' and that delegation to automated systems makes human decision-makers less attentive and less likely to notice unusual occurrences that are not brought to their explicit attention by the system.[300] The failure of decision-makers to notice problems because an automated aid fails to detect them, or when they take inappropriate action based on automated information, is known as 'automation bias'.[301] In the aviation industry, automation bias has been identified as a contributory factor in a high percentage of incidents attributable to pilot error.[302] Automated systems do not indicate their limitations to the user,[303] encouraging a misplaced perception of the systems' infallibility and exacerbating the tendency of overreliance.[304]

The use of ECDIS is intended to improve the safety of navigation and many of the system's automated features are aimed at reducing maritime incidents caused by human error. ECDIS carriage is mandatory on merchant vessels and officers may therefore feel justified basing their navigational decisions on information automatically generated by the ECDIS, notwithstanding that the system may not be correctly configured to provide the navigator with all the salient facts they should be considering. There may be a sense of abdication of decision-making responsibility when relying on automated systems[305] such as ECDIS, partly due to automation bias.

Given the common factor of overreliance in many of the ECDIS-assisted incidents studied, officers' navigational decision-making processes while using ECDIS require evaluation:

> 'The psychology of the decision-making environment needs to be examined closely to ensure that automated feedback is in fact used only as part of a more thorough decision-making process. … To build a strong relationship between human decision-makers and automated decision aids, attention needs to be given to design issues on the one hand, and human psychology on the other.'[306]

Design issues identified within ECDIS are proactively being addressed by the maritime industry (see Chapter 5/I), leaving the more complex human factor to consider. Navigators need to be mindful that merely because the ECDIS display appears believable and trustworthy – and

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[300] Ibid 206.
[301] Ibid.
[302] Ibid 207.
[303] Ibid 210.
[304] Ibid 213.
[305] Ibid 218.
[306] Ibid 220.

that the path of least resistance is to make decisions based on the displayed data – more cognitive effort is required to maintain situational awareness and ensure safe navigational decision-making.

(c) Complacency

The UK MCA recently identified complacency (defined as 'a misplaced feeling of confidence that everything is OK') as one of the significant human factors that can influence human error and lead to maritime accidents.[307] Complacency occurs as a result of an individual's poorly calibrated sense of risk.[308] A perceived familiarity with one's operating environment can breed complacency and make familiar actions seem less risky.[309] Common reasons for complacency include inadequate monitoring of a situation, insufficient knowledge or experience to recognise that a situation has changed, fatigue, and the same task having been repeated satisfactorily on many previous occasions without incident.[310]

The Swedish Club has identified officers' complacency in not verifying information and making assumptions about displayed information as immediate causes of incidents leading to navigational claims, and highlights the importance of officers being aware of the errors and limits of navigational equipment.[311] As described in the previous section, passive watchkeeping practices of monitoring automated systems like ECDIS can breed complacency and lead to a lack of situational awareness, posing a clear hazard to the safety of navigation.

(d) Overreliance

Overreliance on ECDIS has resulted in some officers becoming reluctant to look out of the bridge windows. In a recent study, officers participating in exercises on a navigational simulator were monitored using eye-tracking software, to assess what sources of information they were using for decision-making.[312] It was found that officers spent a significant amount of time watching the ECDIS screen, resulting in *only eleven percent* of their time being spent looking out of the bridge windows.[313] Besides being manifestly bad seamanship, these practices can reduce situational awareness and may contravene Rule 5 of the COLREGs which requires officers to use all available means to maintain a proper lookout.

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307 MCA MGN520(M).
308 Gregory 20.
309 Ibid 16.
310 MCA MGN520(M).
311 The Swedish Club 'Claims at a Glance' (2016) 44 available at *https://www.swedishclub.com/media_upload/files/Publications/Loss%20Prevention/TSC%20claims%20at%20a%20glance%20Web%2030%20June%202016.pdf* accessed on 31/01/2018.
312 Window, Steve 'The normalisation of deviation' Presentation, delivered at the 19th International Navigation Simulator Lecturers' Conference, Cape Town (2016).
313 Ibid.

Overreliance on automated systems and ECDIS was discussed extensively in Chapter 4/III/b above. Situational awareness and the application of basic seamanship skills seem to be fading with the increase of automation and electronic decision-support systems.[314] There is an increasing tendency for officers to become over-reliant on electronic aids to navigation without an appreciation of the systems' vulnerability in terms of accuracy, reliability, availability and integrity.[315]

(e) Generational Considerations

Many younger officers have now grown up with technology at their fingertips and are comfortable with its use. Due to immersion in this culture of information technology, they tend to revert to electronic displays for their primary decision-support systems during times of stress.[316]

> 'It is probable that technology is having an adverse effect on the way in which some seafarers conduct their business. There are various reasons for this, not least the universal problem of a generation that is being brought up to rely on technology to solve problems without having to process information for themselves.'[317]

Although a universal phenomenon, this reliance on technology is particularly dangerous in the maritime domain and highlights the importance of younger officers understanding the fallibilities of automated systems. Some junior officers become so absorbed in technology, particularly ECDIS, that their situational awareness is confined to the displayed screen – rather than looking out of the windows.[318]

There is a further complication with the use of ECDIS that can affect the bridge dynamics and confuse the norm of the most experienced officers having the most knowledge. As many junior officers are familiar with the digital world, they acquire the basic technical competencies to operate ECDIS quickly, while there is sometimes a reluctance from older masters and senior officers to learn new computer-based skills[319] which take them away from their comfort zone of traditional methods of navigation. Many senior navigators who learned their trade on trusted paper charts are unwilling to place the same trust in ECDIS as their juniors do, and are less inclined or interested in learning the intricacies of the systems' technical operation.

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[314] Squire 17.
[315] Ibid 18.
[316] MSC/Circ1091.
[317] Squire 18.
[318] Ibid.
[319] Gale 14.

Safety issues can arise if senior officers feel that junior officers better understand ECDIS than they do – and allow their professional pride to hold them back from learning – particularly as much of the merchant fleet is now paperless. A case in point is the *Ovit* grounding, where the master was not familiar with the ECDIS in use, despite having attended the required training courses. This is illustrated in the MAIB report, which states:

> 'Attendees at the [type-specific] training courses were a mix of senior and junior officers with varying degrees of experience at sea and with ECDIS. Ovit's master was uncomfortable completing the course with junior officers. In particular, he found it embarrassing to ask questions.'[320]

Navigational safety may also be compromised if masters delegate their navigational responsibilities to junior officers who are more adept at the use of ECDIS. The master remains ultimately responsible for the safe navigation of the vessel, but how can he/she check the safety of a passage plan on the ECDIS if not proficient in the use of the system? When asked by surveyors to demonstrate an operation on the ECDIS during audits or inspections, many masters' first response is to call one of the junior officers to do it for them.[321] This is particularly concerning given that the master should be ensuring that all officers use ECDIS in accordance with SMS procedures.

IV Safety Management

(a) Overview

Effective implementation of the ISM Code and a genuine organisational commitment to a culture of safety can reduce occurrences of human error. Shipowners and managers are responsible for the development of a company organisational culture which educates and motivates seafarers towards compliance, and not only through the application of the ISM Code.[322]

Unfortunately, increasing evidence is emerging during PSC inspections of a lack of attention to the application of regulations and procedures, including non-compliance with the ISM Code.[323] The Swedish Club has found that many collisions occur due to the company's SMS and navigation procedures being ignored by officers[324] and concludes that no matter how

[320] MAIB Rep.24/2014.
[321] Walsh, Gary 'ECDIS' Presentation, delivered at the Nautical Institute Command Seminar, Cape Town (2017).
[322] Squire 16.
[323] Ibid 15.
[324] The Swedish Club 'Collisions and Groundings' (2011) 6 available at *https://www.swedishclub.com/upload/loss_prev_docs/collisions-and-groundings-2011-high-res.pdf* accessed on 31/01/2018.

good the technology onboard is, vessels still collide – mainly due to a lack of safety culture and inexperienced crew.[325]

(b) Manning

Regulation 2.7 of the Maritime Labour Convention[326] requires member states to ensure that their vessels have a sufficient number of seafarers employed onboard for safe operation, taking account of fatigue. Economic considerations have, however, resulted in a trend towards reduced crew sizes and minimum manning. This increases the workload of those onboard,[327] particularly for officers who must carry the extra paperwork burden required under the ISM Code. Pressure and stress due to tight operational schedules and deadlines; as well as the lack of an adequate safety culture onboard have been identified as potential pre-cursors to human error and risk tolerance.[328]

(c) Fatigue

Fatigue has been identified as a contributory factor in many maritime accidents.[329] The IMO developed guidelines on fatigue mitigation and management[330] which describe fatigue as:

> 'A reduction in physical and/or mental capability as the result of physical, mental or emotional exertion which may impair nearly all physical abilities including: strength; speed; reaction time; coordination; decision-making; or balance.'

Fatigue is particularly dangerous in shipping operations as it results in impaired performance and diminished alertness:

> 'The technical and specialized nature of this industry requires constant alertness and intense concentration from its workers. Fatigue is also dangerous because it affects everyone regardless of skill, knowledge and training.'[331]

The intention of the IMO's guidelines was to provide information on seafarer fatigue, solutions to combat it and to help prevent future fatigue-related accidents from occurring.[332] However, compliance with the IMO guidelines is voluntary, even though fatigue now poses such a risk for the safety of life at sea.[333]

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325 Ibid 13.
326 International Labour Organisation Convention, MLC 2006, as amended (entered into force in 2013) – considered the fourth pillar of international maritime safety law, along with SOLAS, STCW and MARPOL.
327 AGCS Report.
328 MCA MGN520(M).
329 IMO; MAIB; US Coast Guard; Squire; US Marine Transportation Research Board 'Human Error in Merchant Marine Safety' Washington (1976); US National Research Council 'Crew Size and Maritime Safety' Washington (1990).
330 IMO MSC/Circ.1014 (2001).
331 Ibid.
332 Ibid.
333 Squire 12.

The Manila Amendments to the STCW Code increased the mandatory minimum hours-of-rest requirement for seafarers and compelled Administrations to take account of the danger posed by seafarer fatigue, particularly if their duties involve the safe operation of the vessel.[334] Even with this updated legislation in place, commercial pressure, reduced manning levels and the operational requirements of many working merchant vessels create a shipboard environment in which fatigue is still a reality.

Fatigued officers experience a reduced decision-making ability, slower response times, lapses in memory and an inability to concentrate,[335] potentially contributing to unsafe practices and affecting how information is processed while using ECDIS. The ability to perceive, understand and respond to stimuli is affected by fatigue[336] and chronically fatigued individuals tend to have a higher risk tolerance, selecting easier, riskier options. The passive watchkeeping role that some officers adopt in the use of ECDIS may increase the effects of fatigue, due to the monotonous nature of monitoring an automated system. Some ECDIS models have been found not to adequately draw attention to hazards in the night display mode – a fatigued officer may also be less likely to recognise these hazards.

(d) Local Practices

In safety-critical environments like the maritime industry, it is important to understand how people learn.[337] If officers have not received effective formal training for their navigational duties, on-the-job informal learning from other officers onboard will naturally occur. The danger is that the existing officers may not themselves be adequately trained and thus transfer unsafe, risky practices and short-cuts in the operation of equipment.[338]

Correcting these 'local practices' or procedural violations can reduce accidents and improve maritime safety, but if this behaviour is not addressed it can become the new norm, lowering safety standards and increasing risk tolerance.[339] Reasons for this unsafe behaviour include ineffective training, insufficient supervision and monitoring, an ineffective onboard safety culture, the convenience of shortcuts, and not comprehending the risks involved.[340]

Shortcuts in the use of ECDIS are common, particularly since there were no mandated training requirements when the equipment was first installed onboard many vessels. Officers

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[334] STCW Code Section A-VIII/1.
[335] MSC/Circ.1014.
[336] Ibid.
[337] Gregory 61.
[338] Ibid 62.
[339] MCA MGN520(M).
[340] Ibid.

thus intuitively figured out how to make ECDIS work for them in the easiest way possible, without comprehending the system's operation or limitations. Even if officers have subsequently received the training required by the Manila Amendments, these convenient old habits may be hard to break. ISM audits should be thorough enough to identify unsafe local practices in the use of ECDIS, and rectify them by ensuring the navigational procedures contained in the SMS are followed in practice.

(e) Bridge Resource Management

Bridge Resource Management **(**BRM)[341] is the effective management and utilisation of all resources – human and technical – available to a bridge team, to ensure the safe completion of their vessel's voyage.[342] The Manila Amendments included requirements for BRM training for deck officers.[343] Effective BRM allows the bridge team to anticipate and correctly respond to the ship's changing situation, while poor BRM may lead to a loss of situational awareness.[344]

BRM training equips officers with skills to recognise developing error-chains and act to break the chain of accident causation. The concept for this training originates in the aviation industry, where it was developed to address the human element in pilot error.

(f) Resilience Engineering

Despite humans' many flaws, the human factor in the *prevention* of maritime casualties in a high-risk domain should not be underestimated. This sentiment is expressed in the opening dedication in Gregory:

> 'The global shipping industry is a dangerous place. Every day, it loses two ships, pays out US$4 million in claims and radically changes the lives of hundreds of people forever. Human behaviour is the source of virtually all such loss. *It is also the reason why the loss is not greater*.' (author's emphasis)

The growing complexity of systems introduces escalating challenges for safety and risk management.[345] Resilience engineering recognises that due to their ability to continually adjust, adapt and compensate, humans are vital in complex, integrated systems.[346] Resilience engineering is concerned with constructing 'systems that are able to circumvent accidents through anticipation, survive disruptions through recovery, and grow through adaptation'.[347]

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[341] Also known as Human Element, Leadership and Management (HELM) training.
[342] Patraiko, David 'Nav Brief: Managing expectations' (2014) Issue 7 *The Navigator* 2.
[343] STCW Tables AII/1; AII/2.
[344] Manjeshwar, Srirang 'Building bridges for best practice' (2014) Issue 7 *The Navigator* 6.
[345] Madni, A.M. & Jackson, S. 'Towards a Conceptual Framework for Resilience Engineering' (2009) 3(2) *IEEE Systems Journal* 181-191 (Madni).
[346] Gregory 88.
[347] Madni.

People are able to cognitively assess situations and exercise judgement, allowing them to identify and remedy disruptions more adeptly than automated systems can. Human agents thus introduce resiliency into automated systems and are considered a net asset, despite human deficiencies.[348]

The recognition of the human role in the safe operation of complex systems is pertinent given the increase in the automation of shipboard systems, as well as advances in the automation of vessels themselves.[349] The application of resilience engineering principles to improve safety in the maritime domain requires development and is a field for further research.

[348] Ibid.
[349] The IMO is currently conducting a scoping exercise to determine how the safe operation of autonomous ships may be introduced in IMO instruments.

CHAPTER 5 INDUSTRY INITIATIVES TO IMPROVE THE SAFETY OF NAVIGATION WITH ECDIS AND ADDITIONAL CONSIDERATIONS TO MITIGATE UNSAFE PRACTICES

I Industry Initiatives to Improve the Safety of Navigation with ECDIS

(a) MAIB Safety Study

The manner in which officers use ECDIS was identified as a contributory factor in numerous vessel grounding investigations conducted by the MAIB. It was found that ECDIS was not being used as it was designed to be, with officers employing inappropriate chart scales and safety contours, disabling alarms and guard zones, and not using the automatic route check function to ensure the safety of planned passages.[350]

Following the groundings of *CMA CGM Vasco da Gama* and *Muros*, the MAIB commenced a safety study[351] in late 2017 to assess why officers are not using ECDIS as envisaged by regulators and system manufacturers.[352]

> 'The overarching objective is to provide comprehensive data that can be used to improve the functionality of future ECDIS systems by encouraging the greater use of operator experience and human-centred design principles.'[353]

This study was launched in the very latter stages of research for this dissertation, and the findings will be of great interest to the author.

(b) Updated IHO Standards

In a review of their standards conducted due to ECDIS anomalies, the IHO found that their standards had been interpreted differently by manufacturers. IHO standards S-52, S-63 and S-64 have thus recently been updated to mitigate future implementation irregularities, address anomalies and improve ECDIS usability.[354] Changes include the reduction of excessive alarms and standardisation of chart symbology.

The new standards entered into force in 2017 and vessels must update their systems to ensure compliance with SOLAS carriage requirements, although there is some debate as to whether ECDIS *software* updates are mandatory under the current legal framework.[355] The complications with updating software on older ECDIS units was described in Chapter 3/III/g.

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[350] MAIB Rep.22/2017.
[351] In collaboration with the Danish Maritime Accident Investigation Board.
[352] MAIB Rep.22/2017.
[353] Ibid.
[354] IHO 'Information on IHO Standards related to ENC and ECDIS' Rev1.1 (2017).
[355] See Indries, Lucien *Updating the ECDIS data rendering software – A mandatory requirement under the lex lata?* (unpublished LLM in Maritime Law dissertation, University of Oslo 2016) available at *https://www.duo.uio.no/handle/10852/54111* accessed on 31/01/2018.

(c) Port State Control CICs

Recommendations in the MAIB report into the grounding of the *Ovit* included a proposal to the Paris MOU to conduct a Concentrated Inspection Campaign (CIC) of ECDIS-fitted vessels to establish the standards of officers' knowledge. Seven of the nine PSC MOUs conducted CICs from September to November 2017 focussing on the safety of navigation, including ECDIS use.

The CIC included the requirement for the provisions of SOLAS and STCW relating to ECDIS to be met, and for officers to demonstrate familiarisation with ECDIS. The results of the campaigns are currently being analysed.

(d) S-Mode

The Nautical Institute (NI), International Association of Institutes of Navigation and other bodies have proposed that the IMO should agree to a single set of guidelines for manufacturers to use when designing navigation systems.[356] Their proposal is for a standard mode (S-Mode) that is identical by all manufacturers at a basic level, however more specialist modes would also be available.[357] Officers would thus require less time to become familiar with the basic operation of the system, which should improve competence and safety.

There is not, however, blanket agreement within the maritime industry of this approach to S-Mode, with some parties[358] cautious about standardisation of a separate, independent mode only. Interestingly, recent research aimed at informing future ECDIS design by investigating officers' experiences therewith, found that operators would prefer ECDIS to be highly customizable.[359]

S-Mode is specifically directed at how the equipment is controlled and how data is accessed and displayed. The NI conducted an online survey to collect user input on S-Mode's proposed design. S-Mode would be of particular benefit to newly-joined officers who have not completed type-specific training on the ECDIS in use onboard, as well as pilots and surveyors. Standardisation of features also makes sense as officers are increasingly multilingual. The development of an S-Mode has been identified by the IMO as one of its priorities for E-navigation.

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[356] Patraiko, David 'Nav Brief: Maintaining standards' (2017) Issue 14 *The Navigator* 2.
[357] Ibid.
[358] Including ICS and CIRM.
[359] Nielsen 63.

(e) E-Navigation

The IMO's E-Navigation initiative is expected to have a significant effect on the future of navigation. E-navigation is defined as,

> 'the harmonized collection, integration, exchange, presentation and analysis of marine information onboard and ashore by electronic means to enhance berth to berth navigation and related services for safety and security at sea and protection of the marine environment'.[360]

The goal is to improve the safety of navigation and reduce errors, by meeting present and future user needs through harmonisation of navigation systems and supporting shore services.[361] The core elements of the onboard application of E-navigation include actively engaging officers in the navigation process to carry out their duties as efficiently as possible, while preventing distraction and overburdening.[362]

The IMO approved the Guideline on Software Quality Assurance and Human-Centred Design for E-navigation (MSC.1/Circ.1512) in 2015. The focus on user needs and human-centred design will hopefully address many of the human factors identified as problematic in the use of ECDIS.

(f) Software Maintenance Standard

As there is currently no industry-standard for software maintenance of onboard equipment, BIMCO[363] was concerned by the associated increasing risk of incidents on ships, delays and costs to shipowners and cyber security concerns.[364] BIMCO has seen incidents of malfunctions in navigation equipment and ships suffering blackouts due to unexpected complications with software updates.[365] BIMCO and CIRM (Comité International Radio-Maritime – the international association for the marine electronics industry) have thus submitted the maritime industry's first proposal for an industry-wide standard for software maintenance to the IMO for consideration.[366]

The goal of the standard is to ensure that software updates occur in a secure and systematic way. The scope of the standard extends to shipboard equipment and associated

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[360] IMO MSC.85/26/Add.1/Annex.20 'Strategy for the Development and Implementation of E-navigation' (2008).
[361] Ibid.
[362] Ibid.
[363] Baltic and International Maritime Council.
[364] BIMCO 'BIMCO and CIRM Propose Software Maintenance Standard for Shipping' (2017) available at *https://www.bimco.org/news/press-releases/20171214_software-maintenance* accessed on 31/01/2018.
[365] Ibid.
[366] Ibid.

integrated systems, including navigation systems.[367] Various stakeholders involved in the software maintenance of shipboard equipment are identified, including shipowners, masters and crews.[368] Requirements for shipowners include that maintenance-related operations be carried out in accordance with the ISM Code, procedures are in place to ensure that software is up-to-date in accordance with the latest regulatory requirements, and possible risks to the ship are identified and assessed.[369] The IMO will consider the proposed standard at the Sub-Committee on Navigation, Communications, Search & Rescue meeting in February 2018.

(g) Cyber Security

The IMO has issued guidelines on maritime cyber risk management[370] and has adopted a resolution requiring shipowners and managers to incorporate cyber risk management and security into ISM SMSs by 2021.[371] Amendments to the ISM Code should be considered[372] to ensure that the threat is addressed in a comprehensive manner and applied consistently across the world's fleet.

The international shipping industry has proactively responded to the threat by producing its own guidelines[373] (aligned with the IMO's) to provide practical recommendations on maritime cyber risk management.

II Additional Considerations to Mitigate Unsafe Practices in the Use of ECDIS by Deck Officers

Shortcomings in the design and technical operational aspects of ECDIS have been identified and are being addressed through initiatives by parties in the maritime industry, as described in the previous section. This research has found that the other primary factor inhibiting ECDIS from effectually achieving its intended function of contributing to safe navigation is inadequate officer training, as illustrated by the case studies. This section thus considers ways to improve ECDIS training and mitigate unsafe practices by deck officers in the use of ECDIS.

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[367] CIRM/BIMCO Joint Working Group 'Industry Standard on Software Maintenance of Shipboard Equipment' V.1.0 (2017).
[368] Ibid.
[369] Ibid.
[370] MSC-FAL.1/Circ.3 'Guidelines on Maritime Cyber Risk Management' (2017).
[371] Resolution MSC.428(98*)* 'Maritime Cyber Risk Management in Safety Management Systems' (2017).
[372] Wingrove, Martyn 'IMO imposes cyber security on ship ISM' (2017) available at *http://www.marinemec.com/news/view,imo-imposes-cyber-security-on-ship-ism_48159.htm* accessed on 31/01/2018.
[373] 'The Guidelines on Cyber Security Onboard Ships' V2.0 (2017) Produced and supported by BIMCO, CLIA, ICS, INTERCARGO, INTERTANKO, OCIMF and IUMI available at *http://www.ics-shipping.org/docs/default-source/resources/safety-security-and-operations/guidelines-on-cyber-security-onboard-ships.pdf?sfvrsn=16* accessed on 31/01/2018.

This research has identified the lack of global consistency in the application of STCW training standards as a contributory factor in the unsafe use of ECDIS. Recruitment of officers from developing nations due to lower wage expectations may make commercial sense for shipowners, but introduces risks due to the possibility of inferior navigational competence. The discrepancies in training standards need to be addressed and it may also be time to re-evaluate the effectiveness of current STCW provisions.

The MCA recently recognised that competence entails more than holding an appropriate training certificate, and identified capability – defined as 'the blend of knowledge, skills and attitude to enable effective, safe performance' – as one of the significant human factors that can influence human error and cause accidents.[374] As part of their Continuing Professional Development programme, the NI has launched a Command Diploma Scheme. Guidance for candidates states:

> 'Industry players, including employers, are becoming aware that STCW should be regarded as a minimum standard. There is significant variation between flag states and individual training institutions in the way that this standard is delivered and the degree to which it is met'.

The North P&I Club suggests that a component in most major claims is the issue of officer quality, and as part of a loss prevention effort they are subsidising the cost of an online seafarer evaluation programme. Their determination that it is more cost effective to subsidise *additional* training than to pay the costs involved in claims caused by (sub-standard, STCW-certificated) officers is evidence of opinion in industry that the provisions of the STCW Code for officer competency are not sufficient to prevent casualties.[375] The investigation report into the grounding of the chemical tanker *Sichem Osprey* in 2010 included a recommendation to the IMO: 'To raise the minimum training level required to deliver STCW titles'.[376]

Although the STCW Code contains provisions for certification requirements and for the use of simulators for ECDIS training, it does not adequately include express provisions mandating how ECDIS must be used as an aid to navigation in maintaining a safe watch. This research suggests that ECDIS training has not been sufficiently integrated into the STCW framework. A challenge faced by stakeholders in the maritime industry is to ensure that legislation can keep up with technological developments in navigation systems. At the 2010

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[374] MCA MGN520(M).

[375] North P&I Club 'The Right Crew – Recruit' (2017) *Loss Prevention Briefing;* also see *http://maritime-executive.com/article/to-reduce-losses-north-pi-suggests-testing-seafarers* accessed on 31/01/2018.

[376] Bureau d'enquetes sur les evenements de mer (France) *Report of safety investigation: Stranding of the chemical tanker vessel Sichem Osprey on 10 February 2010 on Clipperton Island* (2010) 17.

Manila Conference of Parties to the STCW Convention, Resolution 15 was adopted – concerning future amendments and review of the STCW Convention and Code. Encouragingly, this resolution notes,

> 'that rapidly evolving technology and training methodologies require a consistent approach towards reviewing, amending and updating the STCW Convention and Code…'.[377]

However, the resolution then states that frequent amendments should be avoided as they may be problematic to Maritime Administrations, shipowners, training institutions and seafarers. The text thus recommends that significant amendments be developed and adopted on a five-yearly cycle basis, with a comprehensive review of the Convention and Code carried out every ten years, to ensure they remain up-to-date with emerging technologies.[378] If one considers the rapid advancements in the technological operations of electronic aids to navigation (particularly ECDIS and integrated systems) that have occurred over the last decade, this approach – while practical from an administrative perspective – hardly seems adequate.

Part 4.1 of Chapter VIII (Part A) of the STCW Code regarding principles to be observed in keeping a navigational watch only contains two provisions relating specifically to ECDIS, as outlined in Chapter 2/II/b. While performing the watch, the code requires the OOW to make regular checks of the course steered, compasses, autopilot, navigational lights, radio equipment and UMS[379] controls.[380] Given that ECDIS is now the primary means of navigation on an increasing number of vessels, it would surely have been prudent to include a check of the essential safety settings and parameters of ECDIS in this provision, to draw attention to their importance for safe navigation. This section contains no provision warning of the dangers of overreliance on ECDIS or guiding officers as to how ECDIS should be used as an *aid* to navigation in maintaining a safe watch. Making both the IMO Model Course 1.27 and the provisions in Part B of the STCW Code regarding simulation training for ECDIS mandatory would help in addressing the global discrepancies encountered in ECDIS training. The COLREGs contain provisions for the use of radar – the time has surely come to include an amendment for the use of ECDIS, given the evidence of overreliance on ECDIS and AIS for collision avoidance.

Recent guidance from the IMO confirms that mandatory type-specific ECDIS familiarisation training is *not* required by the STCW Code.[381] The ISM and STCW Codes

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[377] CONF.2.32 Final Act of the Conference of Parties to STCW, Resolution 15.
[378] Ibid.
[379] Unmanned Machinery Spaces.
[380] Chapter VIII, Part 4.34.
[381] STCW.7/Circ.24/Rev1.

contain provisions for familiarisation training, but in very general terms. Given that officers' lack of familiarity with ECDIS has been identified as a causal factor in accidents and vessel detentions, there is evidently a need for (legally enforceable) international standards to clarify the required technical proficiencies. Both the NI and ICS have drafted comprehensive checklists that could be employed as templates for mandatory ECDIS familiarisation training. A practical assessment to demonstrate particularised competencies should be included, before an officer may use the ECDIS for navigation. Type-specific training should address actions to take in the case of failure of any integrated system components. ECDIS and GNSS-input failures should be drilled for regularly onboard to familiarise officers with the procedures to follow, and these should be included in every ECDIS-equipped vessel's SMS.

Resolution 7 of the STCW Manila Amendments recommends that Administrations ensure that shipping companies provide refresher training at suitable intervals. A requirement for refresher training in ECDIS (generic and type-specific) should be specified, as no such provision currently exists. The UK P&I Club has highlighted the loss of situational awareness that ECDIS can cause and has stressed the need for assessments and training renewal on ECDIS, as software and operating functions change with system updates.[382] Refresher training would also help to break bad habits in the use of ECDIS, as well as address skills regression.

Amending legislation to improve the standard and consistency of ECDIS training could reduce incidents of ECDIS-assisted casualties and improve navigational safety. But to be effective, measures to address the human factor must be deeply embedded into ECDIS pedagogy. Training interventions must be developed to change the attitude of navigators in their approach to the use of ECDIS, which is harder to achieve than teaching technical skills.

Personal observations made while teaching generic ECDIS training courses[383] – while of course by no means empirical research – have revealed the depth of overreliance that students place on ECDIS, and were part of the motivation for this dissertation topic. Students complete a written assessment in which they are required to articulate the hazards associated with the use of ECDIS, including system limitations, the dangers of overreliance, potential errors in the accuracy of GPS, and the need to fix position manually by an independent means. These students thus demonstrate theoretical knowledge of the limitations of ECDIS, but – due to automation bias – a percentage of them initially seem unable to apply these cautions in practice. When intentional errors are introduced during practical simulator exercises, some students still

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[382] Devereese, George 'Shortages in crew navigation skills cause ship accidents' *The Complete Guide to ECDIS 2017*, 9.

[383] Based on IMO Model Course 1.27.

demonstrate blind faith in flawed GPS positions and trust the ECDIS even when the radar is giving conflicting positional information. While additional corrective guidance is of course given to these candidates, the five-day generic ECDIS course as required by STCW may not be sufficient to address the underlying gaps in knowledge and experience of these students.

When ECDIS training became mandatory by an STCW amendment, this training was in many ways ‘tacked on’ to the existing syllabus, rather than integrated into it. Traditional position fixing skills are still being taught in relation to paper charts – and then there is a separate ECDIS learning component. This may feed the impression some junior officers have developed that they are not required to manually fix positions on ECDIS, as they learned to fix on paper charts. Not integrating ECDIS into traditional navigation training also tells students that ECDIS operation is quick and easy to learn, indicating that the system largely thinks for itself with minimum input or effort required from operators.

ECDIS must be integrated into the chartwork classes that cadets attend – when traditional position fixing skills are taught, these must be demonstrated on paper *and* electronic charts. The impression must not be fostered that paper and electronic charts are complete separate entities in terms of manual position fixing practices and requirements. Students must understand that anything that can be done on a paper chart can *and should* be done on ECDIS. Given the transition of the world’s fleet to paperless navigation, many students will now never use paper charts once working at sea. However, the principles of traditional navigation remain unchanged and must be instilled during ECDIS training.

The same is true of passage planning – once students have been taught the principles, they should practice and demonstrate these skills on both paper charts and on ECDIS, rather than these being separate training activities. Case studies can be employed to illustrate the dangers of overreliance and emphasise the importance of correctly configuring safety parameters to ensure the system is supporting safe navigation as it was intended to.

ECDIS is the integrating component of complex modern bridge systems, and the complexities of the use of ECDIS need to be integrated into training practices. Navigators must be taught *how* to manage the extensive information the IBS – through the ECDIS – provides them with. Students should be given the tools to equip them to prioritise data correctly and avoid information overload. The management and processing of data and information must be trained for, and decisions must be made using knowledge, not only information from a display screen.[384]

[384] Squire 18.

There is a strong case for additional simulator training in navigational syllabi, which allows instructors to assess whether students can maintain situational awareness in a modern bridge environment, rather than just assess their theoretical knowledge of bridge watchkeeping. Research has shown that well-structured simulator training can improve safety by reducing the occurrence of maritime casualties caused by human error, and thus reduce accident-related costs for shipowners and insurers.[385]

The use of navigation simulators has developed to meet the training needs of the safety-critical, high-risk operations experienced in the maritime domain.[386] Recent research found that simulator-based training goes beyond teaching the technical proficiencies and cognitive skills required by STCW.[387] Appropriate interventions by instructors during simulator exercises result in crucial corrective actions to discourage students from adopting incorrect, unsafe practices.[388] This is vital given that junior officers often acquire 'bad habits' learned from officers onboard, including short cuts, risk tolerance, overreliance and complacency in the use of electronic aids to navigation. Debriefing upon completion of simulation exercises is key to the learning process, allowing instructors the opportunity to provide detailed feedback on students' performance while employing exercise replays as an effective training resource from which students can recognise, be held accountable for, and learn from their errors.[389] Simulation training must include intentional errors of displayed information and failure of GNSS inputs, to force students to recognise errors and become proficient in plotting manual fixes on ECDIS.

Finally, a particular challenge faced in South Africa is that due to the shortage of available cadet berths and junior officer employment opportunities, months or even years may elapse between shore-based training and shipboard employment. Inevitably, 'skill fade' occurs during this time and much of the theoretical knowledge of navigational systems is diminished. Once a cadet or junior officer finally finds themselves standing bridge watches, the ECDIS is 'easier' to use than the radar, and reliance is placed on ECDIS for navigational decisions without fully

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385 Cross, Stephen *The Application of High Quality Maritime Simulator Training to Improve Safety and Economy in Shipping Operations* (unpublished PhD thesis, Southampton Solent University 2009) available at *http://ethos.bl.uk/OrderDetails.do?uin=uk.bl.ethos.565955* accessed on 31/01/2018.
386 Sellberg, Charlott *Training to become a master mariner in a simulator-based environment: The instructors' contributions to professional learning* (unpublished Doctoral thesis in Education, University of Gothenburg 2017) 23 available at *https://gupea.ub.gu.se/bitstream/2077/54327/1/gupea_2077_54327_1.pdf* accessed on 31/01/2018.
387 Ibid 97; Ms Sellberg did, however, also note: 'Although the STCW convention strives to maintain international standards for training and assessment, one reason previous studies have found problems in the training system is likely that simulators are implemented in various ways in different settings'.
388 Ibid 92-3.
389 Ibid 93, 96.

comprehending its operation or limitations. The safety of navigation is clearly compromised in these circumstances and refresher training should be considered.

CHAPTER 6 CONCLUSION

Despite an apparently robust legal framework regulating the use of ECDIS, the current legislative provisions do not appear to be effective in preventing ECDIS-assisted accidents, particularly vessel groundings. This assertion is supported by the case studies reviewed in this research. These case studies also provide evidence of the unintended consequences of the introduction of legislation mandating the carriage of ECDIS by merchant vessels, which has in these cases threatened the safety of navigation.

The significant latitude that manufacturers were allowed in interpreting the technical operation of ECDIS required by IMO performance standards resulted in a wide disparity in functionality within systems. Given the importance of manual position fixing, this function in particular should be consistent amongst ECDIS manufacturers. Shortcomings in the design and technical operational aspects of ECDIS have been identified and are being addressed through initiatives by parties in the maritime industry. The standardisation of systems and a focus on human-centred design will hopefully assist in addressing many of the challenges faced by officers in the use of ECDIS. Standardisation of ECDIS operational features will be advantageous to officers, pilots, surveyors, inspectors and accident investigators.

Insufficient ECDIS operator knowledge and training has been identified as a causal factor in numerous vessel groundings.[390] Current training in ECDIS as mandated by the STCW Code does not appear to be adequate to ensure officers' competence in its use for safe navigation, as seen in the case studies. ECDIS training has not been sufficiently integrated into the STCW framework and express provisions mandating how ECDIS must be used as an aid to navigation in maintaining a safe watch should be included. Given that most maritime casualties are caused by human error, measures to address the human factor should be embedded into ECDIS pedagogy. Navigators must be taught how to manage and prioritise the extensive data the IBS – through the ECDIS – provides them with, to avoid information overload.

Navigation by ECDIS is fundamentally *different* to paper charts due to how charted information is displayed. With ECDIS, the navigator controls the display by selecting which charted features and information are visible on the screen. Tailoring the chart display to suit the particular navigational situation has benefits and can enhance safety, but only if the navigator comprehends which charted features are appropriate to include in various circumstances. If navigators are inadequately trained in the use of ECDIS, they may omit safety-critical information from the display, or use the system at a display scale which does not show all

[390] MAIB Rep.22/2017.

charted features required for safe navigation. It is of paramount importance that all user settings are appropriately configured to support navigational safety, including the display mode, display scale, safety contour, safety depth and guard zone. Officers disabling or ignoring automated ECDIS functions designed to alert them to hazards may result in the use of ECDIS decreasing rather than improving the safety of navigation.[391]

Navigation by ECDIS and paper charts is fundamentally the *same* regarding the requirements for manual position fixing. Manual positions must be frequently plotted on ECDIS, as they are on paper charts. Navigators must understand the vulnerabilities of satellite-derived GPS positional information and verify these positions by an independent means – using visual bearings and radar ranges and bearings during coastal navigation, and celestial fixes when deep-sea. The radar overlay function can be used to verify GPS information and mitigate overreliance on ECDIS and AIS. Although the ECDIS display may appear modern and therefore accurate, navigators must bear in mind that charted information may be based on older hydrographic survey data and should employ the CATZOC function to assess the accuracy of ENC data.

Overreliance has been identified as a primary risk in the use of ECDIS, as it significantly reduces navigational safety. ECDIS is an *aid* to navigation and must be used in conjunction with traditional watchkeeping skills and the practices of good seamanship to ensure the safety of navigation. An awareness of the human factor issues associated with the human machine interface is required by all stakeholders in the safe navigation of merchant vessels.[392] Automation creates new error pathways and automation bias can significantly affect decision-making. Passive watchkeeping practices of monitoring automated systems like ECDIS can breed complacency and pose a hazard to the safety of navigation. Instead of fulfilling its primary function of improving the safety of navigation, the use of ECDIS can in fact reduce situational awareness by distracting navigators from looking out of the bridge windows or paying attention to information clearly displayed on their radar screen.

The culmination of endeavours to eradicate human error in shipping has resulted in autonomous vessels now looming on the navigational horizon. Despite human shortcomings, human agents introduce resiliency into complex automated systems and are considered an asset due to their ability to cognitively assess situations, exercise judgement, adapt and compensate. This research has found that in the case of ECDIS, the introduction of technology intended to

[391] MAIB Rep.22/2017.
[392] Squire 17.

reduce human error in shipboard operations has inadvertently created new error sources. The advent of these types of technologically-generated error pathways may have broader implications for the safe operation of autonomous vessels.

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