EXPLORING THE IMO'S E-NAVIGATION AND EU'S E-MARITIME CONCEPTS AND DEVELOPING STRATEGIES TO IMPLEMENT MARITIME ITS IN TURKEY

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ABSTRACT

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International Maritime Organization's (IMO) e-Navigation concept aims to utilize advanced communication and decision support technologies to increase the overall safety of navigation and prevent maritime accidents while reducing ship emissions, operational costs and workload on the maritime sector; globally. The e-Maritime concept is an e-Navigation vision that is adopted by the European Union (EU) which shares the same aims with the IMO's e-Navigation concept. However, the EU e-Maritime concept also aims to develop European policies, strategies and capabilities needed to adopt a union-wide, effective and efficient maritime Single Window system that shall increase the profitability and competitiveness by reducing the administrative burden on the European maritime industry.

The primary aim of this thesis is to explore the harmonized international co-operation on the development of technologies, standards, strategies and legal frameworks on the road to the actualization of the e-Navigation and e-Maritime concepts. The secondary aim of this thesis is to explore the strategy, technological advancements, infrastructure investments and legal developments regarding e-

Navigation and e-Maritime concepts in Turkey. These aims are adopted to provide comprehensive information which can contribute to future research, and up-to-date status of the development and intended future uses of these concepts in order to emphasize their expected benefits and effects on the maritime industry. The methodology of this thesis mainly consists of a multi-disciplinary evaluation of information and knowledge gained from the primary and secondary sources on IMO's e-Navigation and EU's e-Maritime concepts, and related developments in Turkey.

Keywords: E-navigation, E-maritime, Maritime intelligent transportation systems

ÖZ

IMO’NUN E-SEYİR VE AB’NİN E-DENİZCİLİK KONSEPTLERİNİN ARAŞTIRILMASI VE TÜRKİYE’DE DENİZCİLİKTE AUS’U UYGULAMAK İÇİN STRATEJİLER GELİŞTİRİLMESİ

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Uluslararası Denizcilik Örgütü’nün (IMO) e-Seyir konsepti gelişmiş iletişim ve karar destek teknolojilerinden yararlanarak küresel çapta seyir güvenliğini arttırmayı ve deniz kazalarını önlemeyi hedeflemektedir. Böylece aynı zamanda gemilerden kaynaklı kirlilik, işletme maliyetleri ve denizcilik sektörü üzerindeki iş yükü azaltılabilecektir. Avrupa Birliği’nin (AB) bir e-Seyir vizyonu olan e-Denizcilik konsepti, IMO’nun e-Seyir konsepti kapsamındaki hedefleriyle aynı hedefleri taşımaktadır. Bununla birlikte, AB’nin e-Denizcilik konsepti, AB çapında karlılığı ve rekabetçiliği artıracak ve Avrupa denizcilik endüstrisi üzerindeki idari yükü azaltacak, etkili ve verimli bir denizcilik “Tek Pencere” sistemi kurabilmek için gereken Avrupa politikaları, stratejileri ve yeteneklerini geliştirmeyi de amaçlamaktadır.

Bu tezin temel amacı, e-Seyir ve e-Denizcilik konseptlerinin hayata geçirilmesine giden yolda teknolojilerin, standartların, stratejilerin ve yasal çerçevelerin geliştirilmesi konusundaki uyumlaştırılmış uluslararası işbirliğini incelemektir. Bu tezin ikinci amacı, Türkiye'de e-Seyir ve e-Denizcilik konseptleri ile ilişkili ilan edilmiş stratejiler, teknolojik gelişmeler, altyapı yatırımları ve yasal gelişmeleri araştırmaktır. Bu amaçlar, e-Seyir ve e-Denizcilik konseptlerinin küresel denizcilik endüstrisi üzerindeki beklenen faydalarını ve etkilerini vurgulamak, gelecekteki araştırmalara katkıda bulunabilecek geniş kapsamlı bilgi sağlamak, bu konseptlerin gelişiminin güncel durumunu ve bu konseptlerin gelecekte niyet edilen kullanım amaçlarını ortaya koymak için benimsenmiştir. Bu tezin metodolojisi temel olarak IMO'nun e-Seyir ve AB'nin e-Denizcilik konseptleri, ve bu konseptlerle kapsamında Türkiye'de meydana gelen gelişmeler ile ilgili ile birincil ve ikincil kaynaklardan edinilen bilgilerin multidisipliner bir yaklaşımla değerlendirilmesidir.

Anahtar Kelimeler: E-navigation, E-maritime, E-seyir, E-denizcilik, Denizcilikte akıllı ulaşım sistemleri

To my dear wife Betül and son Poyraz.

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LIST OF ABBREVIATIONS

ABBREVIATIONS

AI	Artificial Intelligence
AIS	Automatic Identification System
ARPA	Automatic Radar Plotting Aid
AtoN	Aids to Navigation
BAM	Bridge Alert Management
BAM	Bridge Alert Management
BIIT	Built-In Integrity Test
BIMCO	Baltic and International Maritime Council
BOT	Build, Operate, Transfer
CCRS	Consistent Common Reference System
CDMA	Code Division Multiple Access
CMDS	Common Maritime Data Structure
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COLREG	Convention on the International Regulations for Preventing the Collisions at Sea
COMSAR	Committee on Radiocommunications and Search and Rescue
COSPAS	Space System for the Search of Distressed Vessels
CPA	Closest Point of Approach

D8	Developing Eight
DGCS	Directorate General of Coastal Safety
D-GNSS	Differential GNSS
DoC	Domain of Co-operation
DoI	Domain of Interest
DSC	Digital Selective Call
DWT	Deadweight Tonnage
EC	European Commission
ECDIS	Electronic Chart Display and Information System
EGNOS	European Geostationary Navigation Overlay Service
EMSF	The e-Maritime Strategic Framework
ENC	Electronic Navigational Chart
EP	European Parliament
ESB	Enterprise Service Bus
ETA	Estimated Time of Arrival
EU	European Union
FAL	Convention on Facilitation of International Maritime Traffic
FSA	Formal Safety Assessment
GAGAN	GPS Aided Geo Augmented Navigation
GATBP	Geoscience Australia (SBAS) Test-Bed Project
GHG	Greenhouse Gas
GISIS	Global Integrated Shipping Information System

GLONASS	Global Navigation Satellite System
GMDSS	Global Maritime Distress and Safety System
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning System
GSM	Global System for Mobile
HCD	Human Centered Design
HEAP	Human Element Analyzing Process
HF	High Frequency
HLUG	High-Level User Group
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities
ICT	Information and Communication technologies
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IHO	International Hydrographic Organization
IMCO	Inter-Governmental Maritime Consultative Organization
IMDG	International Maritime Dangerous Goods
IMO	International Maritime Organization
INMARSAT	International Maritime Satellite Organization
INS	Integrated Bridge Display System
INS	Integrated Navigation Systems
IP	Internet Protocol

IR	Infrared
ISO	International Organization for Standardization
IT	Information Technologies
ITS	Intelligent Transportation Systems
IVE	Inter VTS Exchange Format
kHz	Kilohertz
LAN	Local Area Network
LL	International Convention on Load Lines
LNG	Liquified Natural Gas
LORAN-C	Long Range Radionavigation C
LPG	Liquified Petroleum Gas
LRIT	Long-Range Identification and Tracking of Ships
LTE	Long Term Evolution
LTE-M	Long Term Evolution for Maritime
MarNIS	Maritime Navigation Information Services
MARPOL	International Convention for the Prevention of Pollution from Ships
MCC	Maritime Connectivity Platform Consortium
MCDF	Maritime Connectivity Development Forum
MCP	Maritime Connectivity Platform
MEPC	Marine Environment Protection Committee
METU	Middle East Technical University

MF	Medium Frequency
MHz	Megahertz
MIR	Maritime Identity Registry
MOBESE	Mobil Elektronik Sistem Entegrasyonu (*Eng: Mobile Electronic System Integration*)
MoU	Memorandum of Understanding
MSAS	Multi-functional Satellite Augmentation System
MSc	Master of Science
MSC	Maritime Safety Committee
MSI	Maritime Safety Information
MSR	Maritime Service Registry
NASA	National Aeronautics and Space Administration
NAV	Sub-committee on Safety of Navigation
NAVTEX	Navigational Telex
NCSR	Sub-Committee on Navigation, Communications, Search & Rescue
NO_x	Nitrogen Oxides
NSAS	Nigerian Satellite Augmentation System
Ph.D.	Doctor of Philosophy
PKI	Public Key Infrastructure
PM	Particulate Matter
PNT	Positioning, Navigation and Timing

PSC	Port State Control
PSW	Port Single Window
QZSS	Quasi-Zenith Satellite System
RCO	Risk Control Option
R-Mode	Ranging Mode
RSA	Rivest–Shamir–Adleman
RSRP	Reference Signals Received Power
S-AIS	Satellite AIS
SARSAT	Search & Rescue Satellite Aided Tracking System
SBAS	Satellite-Based Augmentation System
SCT	Special Consumption Tax
SDCM	System for Differential Correction and Monitoring
SIP	Strategy Implementation Plan
SKEMA	Sustainable Knowledge Platform for the European Maritime and Logistics Industry
S-Mode	Standardized Modes of Operation
SOLAS	International Convention for the Safety of Life at Sea
SO_x	Sulphur Oxide
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers
STM	Sea Traffic Management
STW	Standards for Watchkeeping and Training

SWOT	Strengths, Weaknesses, Opportunities, and Threats
TEU	Twenty-foot Equivalent Unit
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
USB	Universal Serial Bus
USD	United States Dollar
UV	Ultraviolet
VDES	VHF Data Exchange System
VDL	VHF Data Link
VHF	Very High Frequency
VIMSAS	Voluntary IMO Member State Audit Scheme
VLCC	Very Large Crude Carrier
VTMC	Vessel Traffic Management Center
VTS	Vessel Traffic Service
WAAS	Wide Area Augmentation System
WiMAX	Worldwide Interoperability for Microwave Access
W-LAN	Wireless Local Area Network
WWRNS	World Wide Radio Navigation System

CHAPTER 1

INTRODUCTION

Maritime transportation is one of the most cost-effective and efficient means of transportation especially for large volumes and quantities of cargo that needs to be carried across long distances, making it the main driving force of the global economy.

Since the industrial revolution, technology has been advancing at an unprecedented rate. Ships and ports, the backbones of the maritime industry, rapidly evolved with each new technology that became available. The high pace of technological advancement led to the creation of many concepts and innovations that the maritime sector did vastly benefit in the form of increased safety, security and efficiency, over the years. Increasing awareness on matters of sustainability, safety and security issues created demand for new information and communication technologies as well as the adoption of new international treaties and regulatory frameworks.

New information and communication technologies changed the way businesses and governments run in a globalized world. Communication technologies enabled global access to information exchange. As accessing information become available easier and cheaper, the demand for even more efficient, more versatile and more reliable technologies increased. As a result, every capable nation came up with its own set of technological solutions to meet such demands. Soon, it was realized to overcome the compatibility and efficiency issues of various solutions provided by nations, an international co-operation on standardization was inevitable.

Today, the effects of digital information technology on the maritime industry can be seen across the entire maritime industry. Innovative concepts utilizing integrated Information and Communication technologies (ICT) promise more efficient and sustainable solutions to the modern problems of the industry, compared to solutions of the past [1].

Since 2005, International Maritime Organization (IMO) and International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) have been leading and harmonizing the international effort on standardization and modernization of maritime information and communication technologies as known as the e-Navigation[1], for the needs of present day and the future. The e-Navigation is, in essence, a human-centered concept that focuses on defining and harmonizing the international standards on modern technology on ships and shore stations. With e-Navigation, IMO aims to increase navigational safety of navigation to prevent maritime accidents while reducing ship emissions, operational costs and workload on the maritime sector, globally. Existing navigational systems and services will evolve as more user needs driven technologies, services and products become available within e-Navigation concept [2].

The IMO's e-Navigation concept plays a crucial role in the emergence of the European Union's (EU) e-Maritime concept. While e-Navigation primarily aims to reduce maritime accidents by advancing maritime information and communication sharing and processing capabilities globally, the main aim of the e-Maritime is to reduce the administrative burden on all maritime stakeholders in European Union by optimizing maritime information reporting requirements and take advantage of the

[1] Although the name of the concept is written as e-navigation in IMO publications, there are several different uses in the literature such as enavigation, eNavigation, e-Navigation. Latter is chosen to be used in this thesis.

advanced information and communication capabilities provided within the e-Navigation concept [3].

Turkey is located on a unique geographical location as Turkey is surrounded by three seas where several important international maritime trade routes meet. There are 162 freight and ten passenger harbors, 461 fishing ports, 84 marinas in Turkey [4] Turkish maritime industry manages operates a 29.1 Million DWT fleet, making it the 14th largest merchant fleet in the world [4]. Turkey also houses the Istanbul Strait which is deemed as the most critical natural narrow waterway in the world [5]. As a result, Turkey has been utilizing the best available technology, infrastructure, and trained personnel to regulate and manage the maritime affairs in the region and keep the maritime traffic flowing. Recently, Turkey has been developing policies and building the necessary infrastructure to prepare for the implementation of suitable aspects of IMO's e-Navigation concept and EU's e-Maritime concepts to further increase navigational safety in the region and therefore prevent maritime accidents and environmental pollution [6]–[8].

1.1. Aims of the Thesis

The primary aim of this thesis is to explore the harmonized international co-operation on the development of technologies, standards, strategies and legal frameworks on the road to the actualization of the IMO's e-Navigation and EU's e-Maritime concepts. Additionally, the relationship between these highly related concepts is explored to show the distinctions in the driving forces and aims of the concepts.

The secondary aim of this thesis is to explore the strategies, technological advancements, infrastructure investments and legal developments regarding IMO's e-Navigation and EU's e-Maritime concepts at the global scale and in the Republic of Turkey in particular.

These aims are adopted to provide comprehensive information on the IMO's e-Navigation and EU's e-Maritime concepts -including the historical developments, expected benefits, possible effects, and future directions- in order to create an up-to-date big picture on the concepts that are expected to shape the future of the maritime transportation industry.

1.2. Methodology, Scope and Structure of the Thesis

The methodology of this thesis mainly consists of the multi-disciplinary evaluation of information and knowledge gained from the primary and secondary sources related to the IMO's e-Navigation and EU's e-Maritime concepts. Primary sources referred to in this thesis include publications of the IMO (MSC and MEPC committee, and NAV and NCSR sub-committee meeting reports and publications), the IALA (reports on studies and publications), the European Parliament and the European Commission (directives, project and study reports) and the Republic of Turkey (national law, regulations, strategy plans and development reports), the international law on maritime and environment (international treaties, IMO regulations, EU legal framework, etc.) and official reports on projects related with the IMO's e-Navigation and EU's e-Maritime concepts. Secondary sources referred in this thesis consist of scientific and academic publications (Turkish and English dissertations, theses, papers, conference proceedings, presentations and journal articles) related with the IMO's e-Navigation and EU's e-Maritime concepts.

The limitation that was faced while writing this thesis was the requirement of gaining knowledge on the broad spectrum of subjects that the IMO's e-Navigation and EU's e-Maritime concepts involve in. After the literature review process, it was revealed that these subjects were belonging to several different disciplines including Information and Communication Technologies, Intelligent Transportation Systems, International Maritime Law and Maritime Transportation Engineering. Therefore, a multi-disciplinary approach was adopted in order to understand, examine and evaluate all aspects of the IMO's e-Navigation and EU's e-Maritime concepts as correctly as possible.

The first chapter of this thesis briefly introduces the IMO's e-Navigation and EU's e-Maritime concepts.

The second chapter of this thesis introduces the IMO's e-Navigation concept. Historical evolution, driving forces, aims and evolution of the IMO's e-Navigation concept are explored in this chapter.

The third chapter of this thesis introduces the EU's e-Maritime concept. Historical evolution, aims and development of the e-Maritime concept and its relationship with the IMO's e-Navigation are explored in this chapter.

The fourth and fifth chapters of this thesis explore the expected benefits of the IMO's e-Navigation and EU's e-Maritime concepts. These expected benefits are examined from a multi-disciplinary approach in order to reflect their effects on several aspects of the maritime industry: The human element, the navigational technology, the information exchange and the environment.

The sixth chapter of this thesis explores the developments regarding the IMO's e-Navigation and EU's e-Maritime concepts in Turkey.

The seventh chapter concludes the findings of this thesis and refers to future studies.

CHAPTER 2

THE E-NAVIGATION CONCEPT

The e-Navigation is an International Maritime Organization (IMO) led concept based on the harmonization of marine navigation systems and supporting shore services driven by user needs [2].

The e-Navigation is currently defined by IMO as [2]:

> *"e-Navigation is the harmonized collection, integration, exchange, presentation and analysis of maritime 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."*

From the definition above; it is clear that the broad scope of the e-Navigation encompasses advancing legal, environmental, technological and technical aspects of the maritime navigation in order to increase the overall safety of navigation and thus to reduce the number and severity of maritime accidents.

The 85th Session of IMO Maritime Safety Committee agreed on the core objectives related to the e-Navigation concept [3], [9]. The core objectives of e-Navigation include;

i. Improving safety and security navigation by utilizing shore-based vessel traffic observation and management facilities,
ii. Preventing maritime accidents and reducing human errors by developing and utilizing advanced navigational aids and support systems onboard ships,
iii. Harmonizing global standards to achieve consistency and interoperability between maritime information exchange networks and platforms, while improving onboard and shore-based communication and data exchange technologies for robustness and speed,
iv. Reduce the amount of administrative and reporting tasks and workload on ship personnel and elimination of wasted resources (primarily paperwork and time) due to redundant procedures, and
v. Promoting efficiency and sustainability in maritime transportation.

One of the objectives of the e-Navigation is to modernize the ship and shore-based technologies by defining and implementing harmonized international standards. Existing and new technologies shall be combined into one standardized overarching structure that aims to enhance navigational safety and security while reducing the workload and increasing efficiency [3].

The simplified drawing of the e-Navigation structure is shown in Figure 1. Figure 1 shows the connections between the users of the e-Navigation and introduces two important structures that e-Navigation structure shall depend on [10]:

i. The Common Maritime Data Structure (CMDS) spans on data domains of both shipboard and shore environments. CMDS serves an essential function as it is a key to harmonization between the technical systems of both shipboard and shore-based stakeholders; and

ii. A World Wide Radio Navigation System (WWRNS), which delivers, in particular, the position and time data to virtually all technical systems in e-Navigation. WWRNS currently consists of Global Navigational Satellite Systems (GNSS) such as Global Positioning System (GPS) and Global Navigation Satellite System (GLONASS), Galileo and Beidou and terrestrial positioning systems such as Long-Range Radionavigation C (LORAN-C) and DECCA.

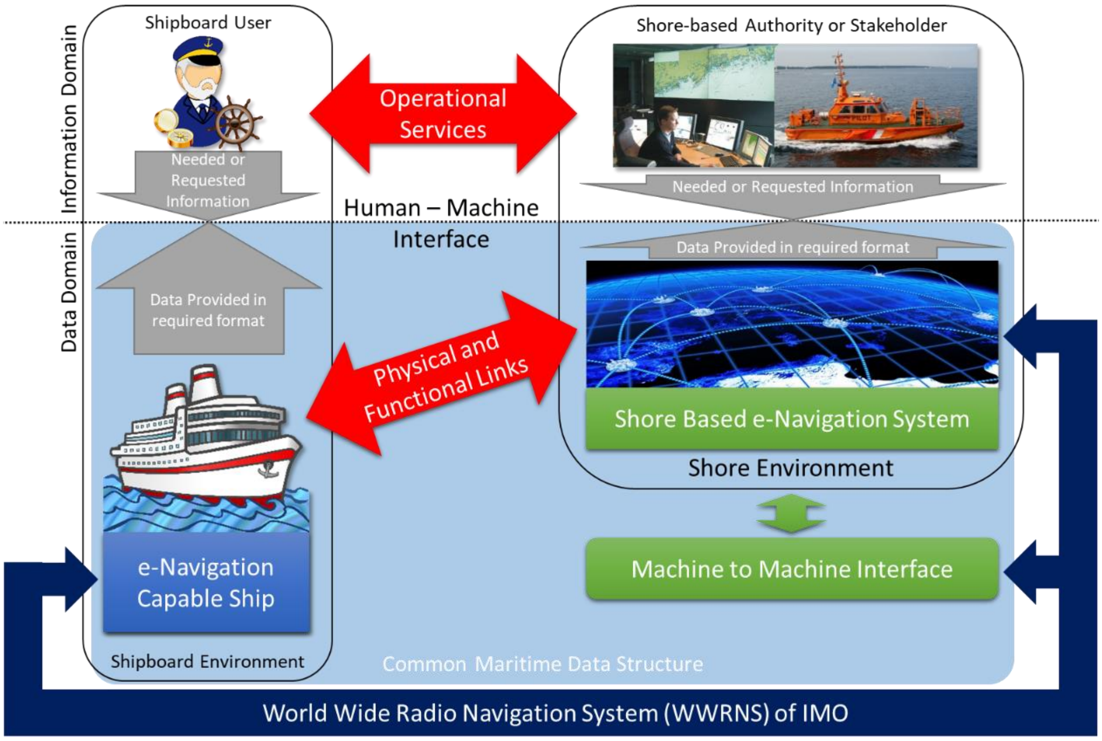

Figure 1. A simplified drawing of the e-Navigation structure. Adapted from [11].

For simplicity of representation, the ship-to-ship communications are not shown in Figure 1, although they are an essential part of the e-Navigation. The e-Navigation structure depicted in Figure 1 clearly shows four segregated parts for data and information gathering, exchange and processing:

1. Shipboard environment,
2. Shore environment,
3. Data domain, and
4. Information domain.

To explain how the e-Navigation structure depicted in Figure 1, let us assume that a shore-based user requests information about a ship. First, data generated by onboard navigation and communication systems in the shipboard environment need to be collected and transferred to systems in the shore environment, using communication networks consisting of different technologies. Then systems located ashore process this data into a standard format to be stored in databases. Then the requested data can be pulled from the databases and transferred to the shore-based user's system. Then this data is processed into presentable information so that a human operator can understand it.

The e-Navigation is a broad and long-term concept, involving many maritime actors and have the potential to impact on the entire maritime community. The ultimate goal of the e-Navigation concept is to integrate all navigational and communicational systems into a single comprehensive system. Such a globally integrated system will evolve the entire maritime industry as e-Navigation will fundamentally change the way actors of the industry have been interacting with each other [3]. Table 1 shows the examples of e-Navigation stakeholders classified into four main categories [9], [11].

Table 1. Examples of the stakeholders of the e-Navigation. Retrieved from [9], [11].

Stakeholder Group	Examples of Stakeholders
1. International Organizations	• Multinational organizations such as IMO, other UN bodies, EU and other similar organizations
2. States	• Flag States, Coastal States, Port States
3. Business Sector	• Branch organizations such as shipowner associations and branch organizations for equipment manufacturers • Equipment manufacturers, service providers and shipbuilders • Maritime advisory firms and superintendents
4. Users	• Shipborne: All different types of ships, both commercial and non-commercial. • Shore-based users such as Vessel Traffic Service (VTS), Pilots, Meteorological, hydrographic institutions/service providers, ship handling agencies, and other ports

While there are existing technologies available that are suitable to meet the goals of e-Navigation, the major problem that IMO is facing is the lack of global acceptance and compatibility of such technologies. Many nations have been developing, adopting and enforcing various solutions based on different technologies, systems and data exchange methods to regulate the maritime affairs within their waters. Various national legislations have been enforced that require reporting of the same information using different forms, delivered through different mediums and agents. Various methods of data exchange and reporting styles (via web pages, e-mail, electronic forms, paper forms, hand-written documents, etc.) have been used for exchanging information between ships and shore. Even different formats (digital format of files, arrangement inside documents, etc.) are used to exchange same information depending on the source and destination of the data; as communications between ships and land stations are made via different systems and technologies. Various Global Navigation Satellite Systems (GNSS) have been introduced to be used for navigation on different parts of the world [12].

These differences between technologies, systems and formats already create unnecessarily redundant work, compatibility and interoperability issues [9], [13]. On top of this, equipment manufacturers offer a vast array of options for equipment that have been produced for decades. For example, Electronic Chart Display and Information System (ECDIS) has been around for well over a decade and manufacturers have been offering a vast range of different models of ECDIS systems to select from. Not only ECDIS user-interfaces vary between different manufacturer; they can differ from year-to-year even within the same model or series. Some ECDIS equipment has advanced capabilities that go well beyond a standard ECDIS, while some barely meet the international performance standards. It is already envisioned that ECDIS to play a more significant role in the future as it shall be utilized within the e-Navigation concept for communicating navigational information between ships and land authorities [9], [13].

Without a global standardization effort; nations, administrations, manufacturers and users may opt-in different technologies, systems, software, data formats and user-interfaces which will at some point lead to compatibility and interoperability problems, extended training periods, decreased efficiency and most importantly, decreased the safety of navigation. In order to identify and solve these critical issues, international harmonization and standardization approach on navigational and communicational issues is adopted within the e-Navigation concept [9], [13].

While the business and economic concerns are not the primary driving forces behind the e-Navigation concept, this does not necessarily mean that increased time and cost efficiency is impossible or not aimed within the e-Navigation concept. On the contrary, the usage of highly advanced and comprehensive navigational technologies combined with high-speed and reliable communication systems could bring enormous advantages to shipboard and shore-based users. For example; ports, ships and businesses could adjust their schedules and allocate their resources a lot more efficiently with the availability of precise information provided by automated reporting systems. Every individual ship could receive a Suggested Time of Arrival from a port's management over a high-speed digital communications network, enabling ships to adjust speed or "slow-steam" along the route to increase fuel economy and decrease emissions [9].

With the increased global awareness on sustainable development and environmental sustainability; the maritime sector adopted more environmentally conscious, more efficient and safer practices and management systems that are governed by international regulations [12]. In the last century, IMO has led international co-operation and harmonization of international regulations and successfully reduced the air pollution from ships by controlling the levels of Sulphur in marine fuels, increased the energy efficiency of ships by requiring installation of energy management systems, promoted the use of alternative fuels such as LNG and LPG onboard ships and most importantly reduced the rates of maritime accidents to a level that now human error is the main reason behind the majority of maritime accidents [14]–[18]. The e-Navigation concept will further reduce the rate of maritime accidents by aiding the user in the decision-making process and increasing the users' situational awareness, through the overarching e-Navigation structure that will be built on advanced technology, human-centered design and intelligent systems [9], [12].

The e-Navigation concept is still currently at its planning and early implementation phase. Status, focus and priorities of the concept are largely debated by all stakeholders of the maritime sector and will continue to evolve with the changing trends in user needs, advances in ICT, and scientific community's input [19]. Weintrit (2016) states that a grassroots movement of adopting e-Navigation services will be the indicator of the actual acceptance and understanding of the e-Navigation by the maritime industry [3].

2.1. Historical Evolution of e-Navigation

In 2005, a call for co-operation within the electronic maritime navigation regulatory development field made to the IMO's Maritime Safety Committee by the United Kingdom and this call was supported by Japan, The Marshall Islands, The Netherlands, Norway, Singapore and United States of America [20], [21].

In 2006, at the 81st session of the IMO Maritime Safety Committee, development of an e-Navigation Strategy Plan was proposed, with a target completion date of 2008 [22].

In 2008, the 54th session of sub-committee on Safety of Navigation (NAV) finalized the e-Navigation Strategy Plan and requested the Maritime Safety Committee to allocate four sessions to complete the work between 2009 and 2012 [22]. In December 2008, Maritime Safety Committee approved the e-Navigation Strategy Plan and set out the four-year work schedule [21].

In 2009, IMO requested Norway to lead Standards for Watchkeeping and Training (STW), Communication and Search and Rescue (COMSAR) and NAV sub-committees to work on the e-Navigation concept and coordinate the e-Navigation effort while 43 other Member States and 18 international organizations were to prepare reports [20], [21].

In 2011, the 57th session of sub-committee on NAV agreed on the e-Navigation structure and on the work to replace the International Hydrographic Organization's older S-57 digital data transfer standard with advanced S-100 standard as the baseline for creating a framework to access all data under the scope of International Convention for the Safety of Life at Sea (SOLAS) Convention and development of a CMDS. It was also agreed to postpone the target completion date of e-Navigation Strategy Plan from 2012 to 2014 [22], [23].

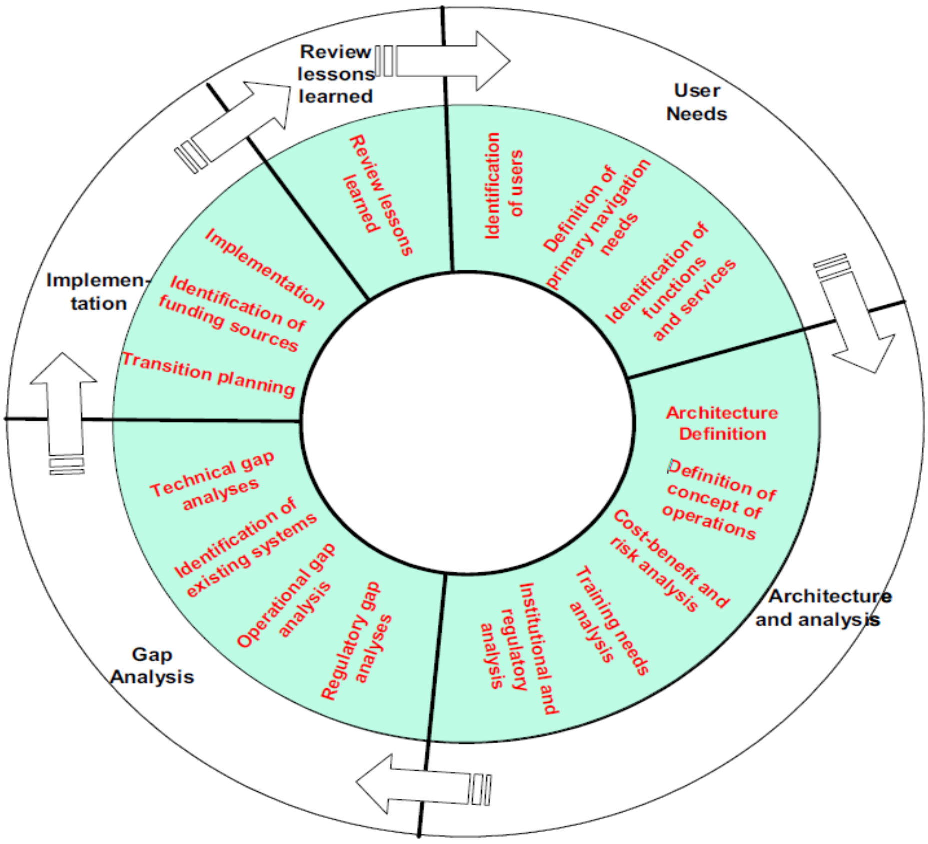

Figure 2. Process showing the phases of the development of e-Navigation. Retrieved from [9].

Between 2009 and 2013, as a result of the Member States' efforts within the IMO's e-Navigation Work Program, the following tasks were completed [20], [21]:

i. Survey and prioritizing of User Needs in 2009,
ii. Description of functions and services, selection of system structure in 2010,
iii. Gap analysis in 2011,
iv. Risk and cost/benefit analysis in 2012,
v. Proposal for a final Strategy Implementation Plan for e-navigation (operational, technical, regulatory, training), including promotion and funding in 2013.

Gap analysis, risk and cost/benefit analysis work that took place between 2011 and 2012 were uniquely crucial as a tool called "Human Element Analyzing Process" (HEAP) was used to identify the particular issues related with the human element in the e-Navigation concept [24]. IMO MSC/Circ.878 circular defines HEAP as a practical tool that is designed to address the human element, to be used for consideration of maritime safety and environmental issues.

As a result of the HEAP process, the following aspects were identified as essential for the success of e-Navigation [9]: Training, Competency, Language Skills, Workload, and Motivation.

The HEAP also revealed that the Alert Management, Information Overload, and Ergonomics were the prominent concerns for the proper implementation of the e-Navigation [9].

In January 2013, IMO Correspondence Group on e-Navigation recommended that the three tasks below should be fast-tracked [19]:

i. Updating, by adding new modules, the existing performance standards for integrated navigation systems relating to the harmonization of bridge design and display of information;
ii. Revising the existing guidelines and criteria for ship reporting systems relating to standardized and harmonized electronic ship reporting and automated collection of onboard data; and
iii. Developing new guidelines on the harmonized display of navigation information received via communications equipment.

In 2013, the Chairman of the IMO Correspondence Group on e-Navigation (Mr. John Erik Hagen) invited the Member States to provide five main practical solutions to problems related with the implementation of e-Navigation, in order to finalize the work of the group [25]. In September 2013, the 59th session of sub-committee on NAV endorsed five prioritized solutions on the seamless transfer of data and information between various equipment onboard, ship and shore stations [22]:

i. S1: Improved, harmonized and user-friendly bridge design,
ii. S2: Means for standardized and automated reporting,
iii. S3: Improved reliability, resilience and integrity of bridge equipment and navigation information,
iv. S4: Integration and presentation of the available information in graphical displays received via communication equipment and,
v. S9: Improved communication of VTS service portfolio.

As can be seen from the list above, S1 and S3 solutions are closely related with the IMO's Human-Centered Approach with the intention of reducing the workload, increasing the efficiency of Bridge Resource Management and preventing accidents due to the human error while S2, S4 and S9 solutions are within the fields of advanced communication and navigation systems.

These five solutions aim to solve problems regarding information over-burdening by providing a standardized human-machine interface, harmonized data collection and seamless communication by increasing the interoperability of different communication systems and increase the safety of navigation by providing advanced information, management and coordination capabilities to Masters and authorities [26].

In 2014, IMO decided to merge the Sub-Committee on Safety of Navigation with the Sub-Committee on Radio Communications and Search and Rescue in an effort to increase efficiency. In July 2014, 1st meeting of the IMO's now *Sub-Committee on Navigation, Communications, Search & Rescue* (NCSR) dealt with some of the most critical international topics of last decade, such as Polar Code, the modernization of the Global Maritime Distress and Safety System (GMDSS), enhancement of the Long-Range Identification and Tracking of Ships (LRIT) system within European Union for Search & Rescue purposes, and the e-Navigation Strategy Implementation Plan [27].

2.1.1. The e-Navigation Strategy Implementation Plan

At the IMO's 1st NCSR meeting in 2014, the 28th agenda on Norway's proposed draft on e-Navigation Strategy Implementation Plan (SIP) approved [27]. The main objective of draft e-Navigation SIP was to harmonize the maritime sector to implement the five prioritized solutions between 2015 and 2019, as endorsed at the 59th session of sub-committee on NAV while taking into account the findings of the IMO Formal Safety Assessment (FSA) [26]. The five prioritized solutions (with their sub-elements) delivered in the draft e-Navigation SIP are given in detail below [26], [27]:

i. S1: Improved, harmonized and user-friendly bridge design,
    a. Standardized dialogs and manuals;
    b. All bridge equipment to follow IMO BAM (Bridge Alert Management) performance standard;
    c. Information accuracy/reliability indication functionality for relevant equipment;
ii. S2: Means for standardized and automated reporting,
    a. Automated collection of internal ship data for reporting;
    b. Documents representation using single window mode;
    c. All national reporting requirements to apply standardized digital reporting formats based on a recognized and internationally harmonized standard developed by IMO
iii. S3: Improved reliability, resilience and integrity of bridge equipment and navigation information,
    a. Built-in integrity test;
    b. Standard endurance, quality and integrity verification testing;
    c. Improved reliability and resilience of onboard positioning, navigation and timing (PNT) information by integration with and backup of by integration with external and internal systems;
iv. S4: Integration and presentation of the available information in graphical displays received via communication equipment and,

a. Presentation of available information on Integrated Navigation Systems (INS) multifunctional graphical displays (including Maritime Safety Information [MSI], AIS, charts, radar, etc.);
b. Implementation of a CMDS using a universal International Hydrographic Organization (IHO) S100 data model;
c. Standardized interfaces for data exchange should be developed to support the transfer of information from communication equipment to navigational systems.
d. Most communication equipment uses one of the International Electrotechnical Committee (IEC) 61162 series interface standards. However, IEC should make sure that the interfaces meet the S100 principle;
e. Provision of correct data for the area of operation by the shore side;
f. Automatic selection of most appropriate communication means according to bandwidth, content, integrity, costs;

v. S9: Improved communication of VTS service portfolio.
   a. This task needs to identify the possible communications methods that might be used and whose relevancy can be demonstrated by tests for different areas of operation.

As a result of the HEAP and FSA processes used in the solution establishment phase of the draft e-Navigation SIP [24], the Risk Control Options (RCOs) related with the development of e-Navigation were identified. RCOs used for the assessment of the prioritized e-Navigation solutions and some of the sub-solutions are as follows [26]:

i. RCO 1: Integration of navigation information and equipment including improved software quality assurance (related to sub-solutions S1.6, S1.7, S3.1, S3.2, S3.3, S4.1.2, and S4.1.6);
ii. RCO 2: Bridge alert management (related to sub-solution S1.5);
iii. RCO 3: Standardized mode(s) for navigation equipment (related to sub-solution S1.4);
iv. RCO 4: Automated and standardized ship-shore reporting (related to sub-solutions S2.1, S2.2, S2.3 and S2.4);
v. RCO 5: Improved reliability and resilience of onboard PNT systems (related to sub-solution S3.4);
vi. RCO 6: Improved shore-based services (related to sub-solution S4.1.3 and solution S9); and
vii. RCO 7: Bridge and workstation layout standardization (related to sub-solution S1.1).

In 2018, the 99th session of the IMO MSC approved and adopted the updated e-Navigation SIP proposed by the 5th meeting of the NCSR (Agenda item no. 22) [28].

Sub-solutions and tasks that are related to RCOs 1 to 7 (as how they are established within the updated e-Navigation SIP) are matched in Appendix A[28]. Appendix A is adapted to include RCO related sub-solutions and tasks only. RCOs and their corresponding solutions are matched and listed on the left side of the table in Appendix A. Tasks related to the development and implementation of these solutions and matched on the right side of the table in Appendix A. The full sub-solutions list can be found in the updated e-Navigation SIP (NCSR 5/22/1 and MSC1/Circ. 1595) [28].

2.1.2. The Implementation Schedule of e-Navigation Concept

In the draft e-Navigation SIP, it was expected that the tasks -when completed during the period between 2015 and 2020- should provide the sector with harmonized information in order to start designing products and services to meet the e-Navigation solutions [29]. The draft e-Navigation SIP envisioned that the 22 scheduled e-Navigation tasks to be completed by 2020 [9]. Initial schedule envisioned for all individual tasks in the draft e-Navigation SIP is given in Table 2 [26].

Table 2. Initial envisioned schedule of the tasks required for the implementation of e-Navigation. Retrieved from [26].

	2014	2015	2016	2017	2018	2019	2020
T1	■	■					
T2	■	■					
T3		■	■	■	■	■	
T4		■	■	■			
T5(a)		■	■				
T5(b)			■	■	■	■	
T6		■	■	■			
T7(a)		■	■				
T7(b)			■	■	■	■	
T8		■	■	■	■	■	
T9		■	■				
T10(a)		■	■	■			
T10(b)					■	■	
T11	■	■					
T12		■	■	■	■		
T13		■	■	■	■	■	
T14(a)		■	■	■			
T14(b)		■	■	■	■	■	
T15		■	■	■	■	■	
T16		■	■	■			
T17		■	■	■	■	■	
T18	■	■					

The updated e-Navigation SIP indicates that the work related to the Tasks No. 1, 2, 7a, 7b, 11,12 and 18 has been already completed as of 2018 [28]. The updated e-Navigation SIP states that the implementation of Tasks No. 4, 13 and 17 now have high priority and estimated to be completed until 2021 [28]. These tasks are given in Figure 3.

No	Task	Remark	Prioriti-zation	2017 NCSR 4	2018 NCSR 5	2019 NCSR 6	2020 NCSR 7	2021 NCSR 8
13	Develop Guidelines on the harmonized display of navigation information received from communications equipment showing how navigation information received by communications equipment can be displayed in a harmonized way and what equipment functionality is necessary	Interim Guidelines To be finalized after completion of T4 and T17	HIGH					
4	Formulate the concept of standardized modes of operation, including store and recall for various situations, as well as **S-mode** functionality on relevant equipment	Guidelines under development (2019)						
17	Further develop the MSPs to refine services and responsibilities ahead of implementing transition arrangements. Resolution on Maritime Service Portfolios.	Guidelines under development (2019)						

Figure 3. The latest schedule for the implementation of high priority e-Navigation tasks. Retrieved from [28].

Implementation of tasks no. 8, 14 and 15 now have medium priority while the rest of the tasks (3, 5a, 5b, 6, 9, 10a, 10b and 16) now have low priority. The implementation schedules of medium and low priority tasks are undefined at the time of writing [28].

Assuming all goes well, the implementation phase of e-Navigation tasks can complete in the third decade of the century, as the implementation period is expected to continue through 2020s [21]. Though, the timeframe for full e-Navigation implementation could stretch to 2040s [30], [31].

Although this timeframe is still subject to change according to the degree of international co-operation, shifts in needs of e-Navigation users and pace of technological advancement; one of the businesses that are working on maritime research and development sector already foresights fully autonomous ocean-going ships to set sail as early as 2035 [32]. The realization of unmanned, fully autonomous ocean-going ships can fundamentally affect the development of the e-Navigation concept.

2.2. The need for the e-Navigation Concept

Due to low number of ships and the slower pace of business practices of the past, high-speed digital communication was not a priority when it came to ship-to-ship and ship-to-shore communications until recently. Today, business practices of the globally connected world and large amounts of valuable data generated onboard ships and shore stations call for faster, more reliable, efficient and cost-effective means of communication [12].

IALA described critical issues related to present problems and future needs of the global maritime sector that led to the call for the e-Navigation concept. According to the IALA [12];

i. Maritime traffic volume is increasing. Authorities need modern tools to manage the maritime traffic in their jurisdiction and coordinate their efforts to prevent congestion, delays and accidents,
ii. The volume of information exchange between the actors of the maritime industry is increasing as a result of increasing demand and competition in the maritime industry,

iii. The need for precise, rapid and efficiently displayed information is growing as coordination between different actors of the maritime industry gains importance,
iv. There are security concerns over cyber-attacks and vulnerabilities of communication and navigational systems as these systems are becoming more and more interconnected, and
v. Environmental protection and pollution prevention are gaining importance in the maritime industry due to increasing global awareness.

Following sub-chapters will focus on above issues.

2.2.1. IMO's Role on Maritime Accident Prevention

Today, modern ships still have many personnel onboard. While the number of the crew varies by types and sizes of ships, the number of the crew onboard during a voyage could grow up to dozens. All of the personnel have to carry out their pre-designated duties as well as adapting to last minute changes and even responding to emergencies in the highest sea and weather conditions, while still going on with their lives. Working onboard a ship could be challenging due to various different reasons that affect personnel's ability to carry out their duties. The harsh working conditions could come in the form of natural forces, workplace and -sometimes oppressive or the lack of- social interactions, prolonged isolation from society, personal decisions or orders, fatigue, inadequate communications between both crew and other ships, poor or not up-to-date general technical knowledge, decisions based on inadequate information, psychological and physical factors [16], [33], [34].

When these operational conditions and associated risks are managed poorly, even the best trained and most experienced personnel could make mistakes. Mistakes of a single or few of the personnel could accumulate over time and trigger chains of events that could go unnoticed or noticed too late, increasing the change and/or severity of once-dormant risks, which can result in an accident which could have been avoided; an accident that could end up with loss of time, loss of money or, most importantly, loss of life [16], [33], [34].

The fact that an accident could result with loss of life is the main reason IMO primarily focuses on preventing (as well as reducing the severity and total number of) maritime accidents by using all legislation tools and resources at IMO's disposal [35].

IMO is an intergovernmental organization, founded in 1958. It received its current name in 1982. Prior to 1982, it was called the Inter-Governmental Maritime Consultative Organization (IMCO). As its previous name suggests, IMO does not have any instrument to enforce or implement international conventions, legislation, regulations, agreements or codes, etc. into any Member States legal framework, as IMO's primary purpose is to adopt international treaties. In another word, the IMO's aim to prevent maritime accidents is achieved through the will and efforts of the IMO Member States. It is necessary to mention that the IMO Member States solely volunteer to accept international treaties on maritime matters and implement these treaties into their as national law. Member States can and sometimes do choose not to become a signatory of such treaties (or even specific parts of them unless they are enforced in a *"take all or nothing"* manner) for various reasons; again, IMO has no jurisdiction over any sovereign nation's decision. Upon agreement to an international treaty, Member States shall direct the resources and means available to their government to implement the accepted international treaty as domestic law [35], [36].

In 2016, IMO established the Member State Audit Scheme & Implementation Support to make the implementation process easier to asses, monitor, regulate and enforce for the Member States. This gives Member States the ability to review their current status to identify their weak points and strengths to better conform to the IMO's standards on maritime safety and security and the protection of the marine environment, and to maintain an updated and harmonized guidance on survey and certification related requirements regarding to their flag or coastal state capacity and responsibilities [36].

Through the IMO's Member State Audit Scheme & Implementation Support, Member States are encouraged to;

i. Collect and assess data on maritime incidents,
ii. Prepare and analyze investigation reports on maritime accidents and casualties,
iii. Conduct research to identify the causes and effects of such events, and
iv. Publish related statistics and findings,

in order to contribute to IMO rulemaking effort related to the prevention of maritime accidents and protection of nature, and to further increase the effectiveness of the existing treaties [18], [36].

Nations have been conducting research to identify the root causes of maritime accidents and publishing their findings in order to prevent maritime accidents, related risks and losses long before the IMO's Member State Audit Scheme & Implementation Support is established (the Member States; under their capacity as Flag State, are required to investigate any casualties occurred, as per SOLAS Convention regulation I/21, International Convention for the Prevention of Pollution from Ships (MARPOL 73/78) articles 8 and 12, Load Lines Convention Article 23 and the United Nations Convention on the Law of the Sea (UNCLOS) article 94 on Duties of the flag State, paragraph 7) [37]. There are tens of thousands of accident reports provided by the Member States to IMO, today.

IMO's Global Integrated Shipping Information System (GISIS) houses one of the largest maritime databases ever created. Although GISIS database is not limited only to maritime accidents; the database includes tens of thousands of maritime accident reports provided by the Member States, since the 1970s. At the time of writing, a total of 3858 very serious type maritime accidents are listed in the GISIS database while only 1594 (about 41%) of the very serious accidents have one (or more) investigation report(s) [38].

It is necessary to mention that the numbers above are obtained via a free public membership to the GISIS website. Authors of this thesis cannot confirm whether other memberships have more access than a free public membership or not.

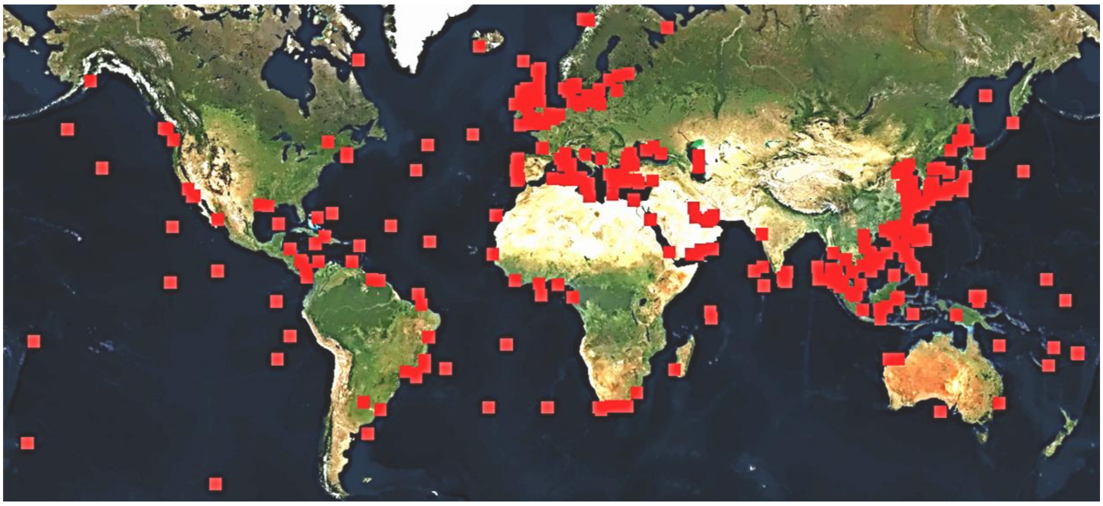

Figure 4. Map of 480 maritime accidents happened between 2015 and 2019 that are categorized as "very serious", as listed in IMO's GISIS database. Generated via [38].

While accident reports give the regulators valuable information about the contributing factors and progression of an accident, accident reports alone might not be enough to mitigate the causes and to prevent accidents from repeating. Asyalı and Erkapan (2014), in their study *"Analysis of maritime accidents involving ships engaged in international voyages within Turkish waters, between 2004 and 2008",* state that the accident reports that were investigated in the paper show a very low rate (about 40%) of human error. Authors suggest that the actual human error contribution rate could be a lot higher as the parts of the accident reports may not be correctly filled in the intended way, for various reasons [39].

This raises the issue of the authenticity of the maritime accident reports, which could mean that the evaluation of accident reports alone could be misleading in the search for finding the real root causes behind maritime accidents. Therefore, it could be argued that both comprehensive scientific research and maritime accident analyses needed to identify and mitigate all of the root factors that are causing accidents, especially for the creation of well-defined legislations by IMO [18].

Luo and Shin's (2016) comprehensive literature review of the research on maritime accidents, which comprises 572 papers published in 125 journals over the 50 years from 1965 to 2014, shows a clear trend that the human factor has progressively become the main reason behind maritime accidents [14].

Pazara et al. (2008), in their research, explain the reason why human factor progressively increased its share in maritime accidents. Similar to the technological leap in every sector throughout the last half of the century, the ship design also dramatically changed. Navigation, propulsion and stability systems' core technologies continuously advanced and increased their reliability. As a result, all these systems and structures had gradually decreasing contributions to the causes of maritime accidents. Pazara et al. (2008) also state that the "maritime system is a people system" and the role of the shipborne systems is relatively small compared to the human factor [17].

Uğurlu et al. (2015), in their research investigating grounding accidents and contribution of the human error in maritime accidents using the information provided by IMO GISIS database, state that the ship collisions and groundings make up nearly 70% of all maritime accidents that have happened in European seas while grounding type being the most prominent. In their research, Uğurlu et al. (2015) also mention that the human factor is the most significant cause of all maritime accidents [18].

In light of the findings from many maritime accident researches; it could be stated that the human factor is the main cause behind maritime accidents today, despite all dedicated technology and systems used onboard ships to aid the crew [14], [16]–[18], [39].

2.2.1.1. Reducing Human Error

In the last century, ships and their design has seen a tremendous change. As mariners need immediately available reliable information to avert from accidents or near-miss situations; onboard systems becoming more robust, faster and smarter over the years. Once time-consuming, complex and skill requiring work became the mundane tasks of automation systems, even done several hundred times in seconds [17].

Radar exceeded the capabilities of even the best lookouts, then ARPA Radar provided alarms and tools to increase the navigational awareness on the bridge. Global Positioning Systems increased position fixing accuracy to the point of a couple of meters, at refresh rates up to 50 position fixes in a single second. GMDSS equipment gave ships and shore stations the ability to use bidirectional digital communication. When AIS came into reality, ships and shore stations started to exchange navigation related data digitally without the need for satellite-based communication. Navigational data of dozens of ships can be exchanged via the AIS system in a matter of seconds, while such large amounts of data cannot be easily digested by a human operator, especially on the separate and tiny screens of the AIS receivers. This problem was solved by ECDIS systems. ECDIS systems on the bridges of the ships are essentially specialized computers which process all navigational data (including navigational maps, navigational data generated onboard and gathered from other ships and shore stations, etc.) into information that is presented in an easily understandable interface on large screens.

Simply put; in time, systems used on ships became more interconnected and advanced as technology progressed, constantly evolving to be better and better at performing their duties: Increasing the situational awareness of the operator and the overall safety of navigation.

On the contrary, possibly the most critical part of the ship stood mostly unaltered: The Master.

Master of a ship is still a human who has biological and physiological limitations, albeit the technology and world surrounding him or her have been evolving rapidly since the industrial revolution.

However, this does not mean that the Masters do not ever improve themselves. Masters usually start as young cadets and get promoted to Master status after working for many years on board ships and completing dozens of contracts. Masters learn how to gain professional knowledge and professional skills since they were students and cadets. Students and cadets go through an extensive education period as stated by the SOLAS and International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) Conventions and keep on learning through their carriers while gaining experience from working on ships and facing all kinds of natural and man-made problems over years, even after they become Masters. Continuous assessments of the knowledge and skills (such as periodic exams, audits, performance evaluations, etc.) aim to keep the Masters at their peak levels while risks, dangerous events, near-misses and accidents regularly test their abilities to prepare and actually deal with such situations.

Therefore; the Master is the most knowledgeable, skilled and experienced professional working onboard a ship and has the ultimate authority and responsibility on the safe management of the ship, her crew and all operations; according to Annex I of the STCW 78 Convention.

In other words; the Master is the final decision-maker on a ship.

Masters reach their decisions through a series of thought and risk evaluation processes; using skill, knowledge, experience and all situational information that are available to them.

A century ago, most of the situational information was provided by the competent crew onboard, and now it is provided by advanced technology. This reliance on advanced technology creates a synergy between the human and machine to work together, even throughout the decision-making process. If one side fails to work in harmony with the other half -such as delayed presentation of a Closest Point of Approach (CPA) warning of a cross passing vessel due to reception of unreliable AIS data in heavy weather conditions, or inadequate digestion of mass information provided on the ECDIS displays by a not-so-well-rested watchkeeping officer at 4 o'clock in the morning- the decision maker may trigger a series of unnoticed mistakes [17].

Increasing the safety and security of maritime practices, especially navigation, requires proven tools that are optimized for good decision-making [9]. IMO's Strategy for the Development and Implementation Report (MSC 85/26/Add.1 Annex 20) states that the presence of a double-checking mechanism improves the reliability of the decision making process by 1000 percent [9]. Navigational systems designed in compliance with the e-Navigation concept could support the mariners by providing unparalleled information presentation and communication tools [3]. Intelligent systems could improve the decision-making process by double-checking the decisions of the users [9], preventing miss understandings, mistakes and accidents.

There are many causes rooting the human error in maritime accidents. Biological needs and limitations, such as sleep and fatigue, are also important factors, as they need to be properly mitigated in order to increase navigational safety.

The EU's *Project Horizon*, conducted between 2009 and 2011, aimed to measure the difference in perception and tiredness levels of watch-keeping officers due to the effects of fatigue, during different times of the day and various lengths of shifts. Project Horizon is then superseded by MARTHA project, which was conducted between 2013 and 2016. Project Horizon and MARTHA scientifically proved that sleep deprivation and continuous tiredness for extended periods (such as six months, which is not unusual for contract times of sea-fearers) had quantifiable effects on the whole crew, both the deck and engine teams. These effects include -but not limited to- increased stress levels, slower reaction times, decreased work efficiency, lowered motivation and impaired perception. It is also stated that any of these negative effects can result in near-misses or even accidents [16], [40].

Final report of the project MARTHA concludes with suggesting solutions such as implementing transparent Fatigue Risk Management Systems to mitigate the fatigue problem. The last item in the conclusion part of the report is quite different from the others and directly quoted below without any alteration [40]:

“In the longer term, improved vessel design will make a significant impact in reducing the effects of sleepiness and fatigue.”

Therefore, in order to achieve and maintain the harmony between the human and machine, the interface design and ergonomics of the navigational aids and equipment onboard shall be shaped according to the mariners’ needs and limitations [26], [40]–[42].

The e-Navigation concept aims to deal with the efficiency, reliability, safety and environmental issues caused by non-standardization of the navigational equipment on the bridges of the ships by incorporating an internationally harmonized human-centered approach on present and future bridge equipment design standards [43]. With the aid of e-Navigation systems that utilize a broad range of shipboard sensors and high-speed digital communication technologies, highly reliable information can be provided and presented clearly even under harshest navigational conditions. Standardized interface formats such as S-Mode could prevent distraction and information overburden on the Masters and officers, while also shortening the training and familiarization period required for different ECDIS interfaces. Standardized data communication formats such as IHO’s S100 standard could be used for digital information exchange between ships and land stations that could provide new communication abilities between ships and shore. Authorities could digitally download voyage plans of all ships in their jurisdiction and request all ships to make a necessary change on their voyage plan in an instant with a *single click* or could broadcast a time-critical information without the need of time-consuming voice communication and better utilize the limited time and channels available, especially in the state of an emergency.

Overall, the e-Navigation aims to make use of advanced standardized technology related to navigation and communication to aid humans in the decision making process in order to further increase navigational safety, to prevent maritime accidents, to achieve better efficiency and to prevent damage to the environment [9].

Therefore, it could be argued that both technology and systems used on board and the crew interacting with them needs to co-operate and compensate for each other's weaknesses in order to further prevent maritime accidents and loss of lives.

2.2.2. Unfulfilled Potential of the GMDSS

GMDSS was introduced by IMO to set the internationally agreed standards on safety communication equipment and procedures in order to provide unprecedented communication capabilities and increase overall safety in distress situations [44]:

> *"GMDSS is designed to ensure that any emergency at sea will result in a distress call and the response to that call will be immediate and effective. The days when a ship could vanish without trace should then be ended."*

IMO started developing the technological aspects and legal framework of the GMDSS in the 1980s. GMDSS was introduced as part of the 1988 Amendments to the SOLAS 74/78 Convention's Chapter IV. GMDSS entered into force in 1992 while the full enforcement process of the system was gradually spread over from 1992 to 1999 (newly building passenger ships had the first priority while old cargo ships had the last priority), in order to give the shipowners and authorities time to adapt. As of 1999, SOLAS Convention Chapter IV requires GMDSS equipment to be fitted onboard of ships over 300 Gross Tons that are involving in international voyages and all passenger ships regardless of size [44].

GMDSS was first designed to utilize the terrestrial radio and satellite-based communication systems developed in the 20th century. The non-profit International Maritime Satellite Organization (INMARSAT) was founded by IMO in 1979 to introduce a global two-way digital communication network that works on nearly every part of the world, solely designed for maritime-related communication and search and rescue services. For robustness, cost-efficiency and efficient use of limited satellite bandwidth, it was decided that terrestrial communication systems and satellite systems be used in conjunction within the GMDSS. By design, the short-range communication was intended to be done via VHF radios while long-range communication was done via the usage of HF and MF radios and satellite systems based on INMARSAT and COSPAS-SARSAT satellite networks. Even today, some of the communication technologies reminiscent from Second World War (such as VHF and MF/HF radio) are still operational and actively used by ships and shore stations globally within the GMDSS system.

Since the 2000s, IMO implemented new systems that enhanced the capabilities of the existing GMDSS communication solutions. For example; The IMO's 2002 amendments to the SOLAS Convention Chapter V requires AIS to be fitted onboard all SOLAS ships[2]. It is estimated that there are currently more than 50,000 merchant ships fitting to this classification [45].

[2] All passenger ships that engage in international voyages, or any ship larger than 500 gross tons that is engaging in international voyages. The term "SOLAS ship" has the meaning of "Ships that the SOLAS convention applies to" in the maritime industry.

The AIS system is intended to provide navigational information of ships in vicinity to and allows Masters, officers and maritime authorities to track and monitor vessel movements in an easier fashion thus increasing overall navigational safety. AIS system uses two-way short-range digital data communication over VHF frequency to share navigation related data, similar to the logic behind VHF radio. AIS system provides ships a free-to-use way to electronically exchange ship data including identification, position, course, and speed, with other nearby ships and VTS stations. AIS transponders also could be interconnected to other systems such as VHF DSC radios for establishing voice communication with a particular ship without the need of calling them via a publicly available voice communication channel (where anyone and everyone could listen publicly) first and ECDIS systems to process the navigational data gathered from ships in vicinity [46].

Another addition to onboard GMDSS is the LRIT System. Since 2009, the LRIT system makes use of the already existing satellite-based communication system for the routine gathering of positional data of all ships. This positional data is then shared with the IMO Member States for security, threat evaluation and accident response [46]. This being said, the LRIT system is not a navigational aid or communications solution; unlike AIS or Satellite AIS (S-AIS). It instead serves as the remote observation and validation system that is mostly utilized for the security-related issues that ships and their crew can face (piracy, attacks and other illegal activities to take control of a ship, her crew or cargo) [46].

In 2017, IMO's NCSR sub-committee issued the NCSR 4/29 report which includes Draft Modernization Plan of the GMDSS. In the report, IMO stated that GMDSS has been serving the maritime sector well for many years, yet the full potential of the system has never been used [47]. Draft Modernization Plan of the GMDSS introduced the coordinated plan of work for IMO to modernize the GMDSS. Final draft on the Modernization Plan of the GMDSS is expected to be completed in 2020 while the approval and adoption phase is expected to complete in 2022 [47]. The plan states that the revised GMDSS -including new technologies such as VHF Data Exchange System (VDES), NAVDAT (a modernized NAVTEX approach), MF/HF radio equipment that is capable of digital communications and multiple satellite service providers within the GMDSS network- is planned to be entered into force by 2024 [47]. At the 98th session of IMO's Maritime Safety Committee, the Draft Modernization Plan of the GMDSS (that was proposed in the NCSR 4/29 report) was adopted and included in post-biannual agenda of MSC [48].

VDES is a broadband digital communications solution that uses terrestrial VHF radio band, similar to the AIS. Additionally, the VDES can also utilize satellite-based communication when needed. It is proposed that VDES transceivers can sustain two-way data transfer rates up to 300kbps [46], [49]. As the proposed VDES will be partly utilizing communication technologies based on the free-to-use AIS, it has the potential to provide mariners a practical, worldwide, low-cost digital communication ability [46].

VDES could be an essential part of the e-Navigation concept as it shall provide cost-effective digital communication abilities between ships and shore stations. Though technical details are not yet clearly defined yet; VDES could make use of the existing equipment and systems onboard which would lower the initial costs required to install VDES on ships and shore stations and possibly shorten the facilitation period required. It could be argued that the transition from AIS to VDES could have a similar effect as the transition from dial-up modems to the first generation broadband modems, in terms of speed and application versatility [49].

If and when fully adopted; versatile communication systems such as VDES could become a crucial part of e-Navigation capable systems and could increase the safety of navigation while increasing efficiency; without creating any substantial additional operational costs [50].

With the aid of VDES; ships could share not only momentary navigational data but full voyage plans or intended routes, send and receive digital files without solely depending on satellite or GSM based pay-to-use systems. ECDIS onboard ships could receive Electronic Navigational Chart (ENC) updates and Notices to Mariners (NTM) digitally over VDES network and apply these updates automatically, without the need of any user interaction. In case of unsafe navigational conditions occurring in a busy area, authorities could merely request a change on voyage plans of all of the ships in their jurisdiction area by simply broadcasting related messages directly into ECDIS via utilizing the VDES network. Virtual Aids to Navigation (AtoNs) can be created to simulate a real one temporarily, like an out-of-order buoy until a new one is installed. Estimated Time of Berthing to a port could be calculated for each ship that is expected to visit that port and shared with all shareholders instantly and in real-time, without the need of any user interaction, even before the ship's departure from the Port of Arrival. These abilities are unprecedented and could fundamentally change how the maritime sector operates [50].

IMO's Draft Modernization Plan of the GMDSS mentions the legal and technical preparations required for the forthcoming of a new satellite-based Maritime Safety Information service provider market. The terminology "recognized mobile satellite communication service" appears in the report many times and it ought to replace the word "Inmarsat" throughout the SOLAS Convention [47].

With the critical reduction in the cost of launching satellites thanks to re-useable rockets and availability of delivering multiple small satellites in a single launch, the private sector is gaining interest to have a share in the satellite communication market [51]. IMO is working on updating the current regulatory framework to enable the recognition and operation of new mobile satellite communication service providers in the GMDSS. NCSR committee established a Communications Working Group to finalize the draft performance standards for shipborne GMDSS equipment to accommodate additional providers of GMDSS satellite services [47].

2.2.3. Obsolete ECDIS Data Model Standard

In 1992, IHO adopted the S-57 Transfer Standard for Digital Hydrographic Data. The S-57 intended to support all types of hydrographic data, the associated technology and different user groups, but adoption has been relatively limited. Today, the usage of the S-57 standard in the maritime domain is almost limited to the data formatting of ENCs that are used by ECDIS systems [52]. Due to the technical limitations and non-flexible nature of the S-57 standard, IMO started to work on revising the S-57 standard, in 2000 [53].

IMO adopted IHO's Universal Hydrographic Data Model (S-100) as the basis of the CMDS of e-Navigation, in 2014 [54]. Currently, the IHO has approved the S-100 based product specifications for high-resolution bathymetry and nautical publications [53].

Research shows that the ECDIS is already capable of handling simultaneous multiple S-100 standard-based services and products (such as real-time tidal information, weather forecast and sailing directions) which can offer valuable information for better decision-making and thus could increase the safety of navigation [53].

There are many benefits of adopting the S-100 standard for the e-Navigation concept. S-100 standard is open to web-based applications and therefore future-proof; as there would be no need to launch new sets of standards are needed for updating the S-100 standard. Its applications can simply be updated to the newest edition via delivery of the newer software and data packages [55].

The S-100 standard is also compatible with many different data encoding formats which increases the flexibility of its applications. Also, new capabilities can be added to S-100 enabled devices via the installation of extensions or add-ons, as demands and needs of the maritime industry evolve in time [56].

The future use cases of navigational equipment, aids, services and products that would be developed within the e-Navigation concept shall also utilize digital communications between ships and shore stations using the IHO's S-100 data transfer standard [1].

2.2.4. Growing Cybersecurity Threats

E-Navigation systems shall take advantage of existing navigational and communicational systems onboard ships as well as intelligent navigational systems and high-speed terrestrial and satellite-based digital communication technologies that are going introduced in the future. The introduction of a high-speed wireless connection to highly integrated systems on a ship might render cybersecurity threats more crucial than ever before. In order to mitigate future threats, current issues with existing technologies should be ironed out first.

IMO requires all SOLAS ships to carry AIS equipment since 2005 and AIS transponders shall be kept operational at all times (excluding when Masters' deem unfit to do so). A "Class A" AIS equipment installed on a ship periodically (varying from every few seconds to every 6 minutes depending on the navigational status of the ship) broadcasts information regarding the name, call sign, IMO number, position, heading, speed, type of ship, type of cargo, destination port and the estimated time of arrival to the destination port and more information regarding navigational status of the ship.

To mitigate malicious intentions to some degree, there is an exception for the usage of AIS transponders. IMO Resolution A29/Res.1106 states that the AIS transponders onboard ships can be turned off in case the Master deems that usage of AIS creates vulnerability to the ship [57]. This can effectively prevent real-time navigational information gathering from a ship. Although such precaution will have zero effect if the ship broadcasts the arrival port, destination port and ETA information even once. Upon the reception of such information, it will be saved to the databases of online ship tracking service providers and will be publicly available online.

It is already proven that the navigational systems of ships are vulnerable to malicious attacks, such as the spoofing of GPS signals. As AIS and satellite positioning signals are not encrypted or authenticated, they can be overridden by a stronger broadcast. Such broadcast could be done via a source that is closer to the target, like a small boat or drone carrying spoofing equipment close to a ship. In 2013, researchers proved the technical possibility of such a cyber-attack and successfully diverted the autopilot system off-course without bringing any alarms on the bridge of a ship. The total cost of the devices used for such an attack was around 2.000 USD [45].

If and when the number of crew needed to operate ships decreases or if the fully automated ships start to sail through oceans in the future, ships may become easier targets. New ways to mitigate the cyber-security threats might be needed as the publicly available and un-encrypted nature of the AIS and global positioning system may also create piracy threats in the future as well. These future piracy threats for highly autonomous and unmanned ships may not need to use force or firearms to gain control of a ship. Attackers could utilize high-tech warfare methods (such as hacking, spoofing, hijacking, availability disruption, indiscriminate jamming, etc.) These methods could also cause difficulties in correctly determining the location of ships and reduce the effectiveness of the intervention efforts [45].

Another potential source of threat is the ECDIS system used onboard ships. Due to the highly interconnected structure of the ECDIS system, most ECDIS systems have direct access to AIS, GPS and radar systems while some ECDIS systems also have access to the internet through the ships the Local Area Network (LAN). Also, even today, most of the ECDIS equipment share a significant amount of hardware and software with everyday computers. They often run on a commonly used operating system (such as Microsoft Windows) and house portable mass storage cards or USB connection ports for service purposes. While highly unlikely, it is possible that computer-based ECDIS systems could get infected via the internet, LAN, mass storage cards or even USB sticks that are solely designed to be used for installing ENC updates, as maritime accident investigations show abused use of these connections and drives have already happened in the recent past. Isolating the ECDIS and navigational systems from the rest of a ship’s systems with a firewall is one of the recommended precautions against cybersecurity threats [45].

Effectively managing cybersecurity risks may become more important as the ship design and technology advances towards intelligent and autonomous systems in the immediate future. In order to mitigate potential cybersecurity threats; universal design and performance standards on the equipment and systems to be used within the e-Navigation concept -such as AIS, VDES and ECDIS- should address existing and probable future privacy and cyber-security issues [45].

2.2.5. Pollution Prevention and Environmental Protection

IMO's slogan "*Safe, secure and efficient shipping on clean oceans*" [58] could be the best summary of the intentions of the IMO on its responsibilities over environmental concerns. Since its founding in 1959, the IMO and the IMO Member States adopted many regulations and preventive measures to prevent (or at least minimize) the maritime accidents, prepare for the pollution emanating from maritime operations and maritime accidents, and to protect the environment [59].

In 1973, the Sub-committee on Marine Pollution (which would become the MEPC in 1985) was established in IMO as a result of the increasing international awareness and co-operation on environmental matters and the increasing scale of pollution emanating from serious maritime accidents and oil spills [59]. Over time, MEPC introduced several amendments and protocols to the MARPOL 73/78 convention in order to keep it updated with the latest developments in the maritime industry and mitigating associated environmental risks and issues [60].

Again in 1973, the MARPOL convention was adopted. The MARPOL convention is still the main international convention on the protection of the marine environment by prevention of pollution from shipping operations or accidents. The ratification process of the 1973 MARPOL convention took a few years as the many IMO Member States did not ratify the convention due to various technical problems in the convention [60]. However, serious maritime accidents involving large tankers and major oil spills happened in 1976 and 1977 which resulted in the adoption of the MARPOL convention and the 1978 protocol. The MARPOL 73/78 convention finally entered into force in 1983. MARPOL 73/78 convention Annex I on Oil Pollution Prevention and Annex II on Control of Pollution from Noxious Substances Carried in Bulk are mandatory for all IMO Member States, while the rest of the annexes are open for voluntary adoption [60].

MARPOL convention's Annex I on Prevention of Pollution by Oil and Annex II on Control of Pollution by Noxious Liquid Substances in Bulk regulate the ship design and certification, carriage requirements and cargo operations related with carriage of oil and dangerous chemicals in bulk [60]. These liquids can spill into sea as a result of maritime accidents (as a result of operational errors, navigational errors, poor decision-making, poor execution of regulations, etc.) and they can severely damage the environment and the ecosystem in an area for prolonged periods of time. In the past, such accidents happened in large scales and lead to vast quantities of pollution. In order to mitigate the massively deteriorating environmental impacts of such events, strict regulations are developed, implemented and enforced via inspections.

MARPOL convention's Annex III on Prevention of Pollution by Harmful Substances Carried by Sea in Packaged Form entered into force in 1992. Together with the SOLAS Chapter VII on International Maritime Dangerous Goods (IMDG) Code, MARPOL Annex III regulates the carriage of the harmful substances that are mostly carried by container ships [60].

MARPOL Convention's Annex V on Prevention of Pollution by Garbage from Ships entered into force in 1988. Annex V was developed to particularly regulate and control the plastic and other garbage output from ships. Plastic is deadly for marine species. Once plastic enters the food web of any marine species, as it cannot be digested, it accumulates. This accumulation is not limited to the body of an individual specie; the accumulated plastic is transferred to other individuals and species as a result of trophic levels and processes. Therefore, plastic output from ships is entirely prohibited. Output of other garbage from ships is systematically regulated by a sea area, garbage type and distance-based method [61].

IMO and the IMO Member States already achieved a dramatic reduction in maritime pollution by adopting effective regulations and implementing successful comprehensive control mechanisms [59]. As the result of strict enforcement of regulations and developments in ship design and maritime technology, the environmental pollution emanating from maritime industry have been successfully reduced. However, with the ever-increasing importance of environmental matters and the fragile state of the global environmental balance, the pressure on every polluter is increasing.

Today, Global Warming and Climate Change are two of the most prominent on-going environmental issues in the world and the IMO's e-Navigation concept can provide beneficial tools for both authorities to effectively monitor and further reduce the air pollution from the maritime industry while businesses can enjoy increased fuel, cost and time efficiency provided by tools and services brought with the IMO's e-Navigation concept. Therefore, the following part of this sub-chapter will focus on air pollution from ships.

In 1997, an additional protocol was adopted to amend the MARPOL Convention with the Annex VI on Air Pollution from Ships, which entered into force in 2005. Annex VI deals explicitly with limitation of the Sulphur Oxide (SO_x), Nitrogen Oxide (NO_x), Ozone depleting substances and Greenhouse Gas (GHG) emissions from ships, and shipboard energy efficiency [60].

Annex VI of the MARPOL convention is particularly important for keeping the balance and continuum of the atmospheric processes, reducing the adverse effects of the GHG emissions from maritime industry and reaching the goals of United Nations Framework Convention on Climate Change (UNFCCC) 1997 Kyoto Protocol and 2015 Paris Agreement on Climate Change [61].

Although shipping activities were not included in the 2015 Paris Agreement, in parallel with the steps that IMO has been taking to prevent maritime pollution for the last 50 years, IMO set a goal to eliminate half of the GHG emissions from shipping until 2050 to fight against the climate change [62].

There are three key reports published by the IMO's MEPC on the studies conducted on the GHG emissions from the maritime industry so far (with a fourth study being carried out at the time of writing). All three reports show that direct and indirect impacts of the GHG emissions from ships were evaluated in these studies. The direct impact of the GHG emissions comes from CO_2 and Black Carbon (which is a component of Particulate Matter). CO_2 gas absorbs the light in the infrared spectrum very efficiently and therefore has a direct warming effect in the atmosphere. CO_2 gas also is the major contributor of the Anthropogenic Global Warming and Climate Change effects. Black Carbon particles, on the other hand, absorb all (UV, IR and visible) wavelengths of light and therefore has a direct warming effect in the atmosphere as well, which in total is estimated to be between 25 and 60 percent of the amount of warming caused by CO_2 [63].

The indirect impact of the GHG emissions comes from the SO_x, NO_x and CO gases. NO_x acts as an indirect GHG by contributing to the photochemical processes and creation of O_3 in the tropospheric layer. CO has the same tropospheric O_3 creation effect, but also it reduces the availability of OH radicals in the troposphere. OH radicals would have otherwise interacted and neutralized other GHGs in the atmosphere, and therefore CO has an indirect GHG effect [63]. O_3 in the tropospheric layer not only has a warming effect but also changes evaporation, rain and snow regimes, cloudiness, and effects the atmospheric circulation [64].

In 2000, at the 45th session of the IMO MEPC, the first report on the GHG emissions from ships was published. Japan (MEPC 45/INF.27) and Norway (MEPC 45/INF.7) conducted scientific studies -which were limited in geographical size- on several GHG emissions. As a result of the first report on GHG emissions from shipping; the importance of developing policies on reducing GHG emissions from ships were strongly expressed and Member States were invited to participate in the policymaking effort to reduce the GHG emissions from shipping, at the 45th session of the IMO MEPC. Also, the importance of commitment to the 1997 Kyoto protocol was reminded several times in this session [65].

In 2009, at the 58th session of the IMO MEPC, the second report on the GHG emissions named “Opportunities for Reducing GHG Emissions from Ships” was published. The second report on the GHG states that, if implemented, policies on technical and operational measures could increase the fuel efficiency of ships and at the same time reduce the GHG emissions from ships by 25 to 75 percent (from the levels in 2007). Revision of the MARPOL Annex VI It has also been stated that there were several non-financial barriers that could discourage the adoption and implementation of such policies [63], [66].

In 2014, at the 67th session of the IMO MEPC, the third report on the GHG emissions was published. It is stated that the precision of the estimates in this report have dramatically higher accuracy and resolution compared to previous reports as a different approach (instead of using fuel consumption and GHG emission averages per categories of ship types and sizes, calculations were carried out for each individual ship that was active in service) was preferred and data gathered from AIS and LRIT has been incorporated into the estimation process. Also, the report predicts GHG emission growth rates between 2012 and 2050 to be between 50 and 250 percent, depending on different fleet growth and regulatory action scenarios. Only one scenario predicts lower GHG emissions in 2050 than 2012 levels [67].

The reports show that estimates on the total annual global CO_2 emissions from shipping have been increasing steadily between 1990 and 2007, from 560 million tons to over 1.050 million tons. After 2007 however, this increasing trend is replaced with a stagnation trend. The estimated total annual global CO_2 emissions from shipping between 2007 and 2012 were around 1.000 million metric tons [61], [63], [65]–[67]. It could be argued that the end of the increasing trend as of 2007 could be a result of the international efforts led by IMO to regulate and reduce the GHG emissions from shipping.

In 2017, IMO MEPC approved the roadmap for developing a “Comprehensive IMO Strategy on Reduction of GHG Emissions from Ships”. As a result, in 2018, at the 72nd session of the IMO MEPC the “Initial IMO Strategy on Reduction of GHG

Emissions from Ships" was adopted, recalling the United Nations 2030 Agenda for Sustainable Development [62].

In this aim, IMO is already working on establishing a set of rules for new building ships today. Regulations are shaped limit fuel consumption according to ship's cargo capacities. It is also planned that the limits will get stricter over time. The GHG emissions from ships are therefore is expected to reduce dramatically in the near future [62].

CHAPTER 3

THE E-MARITIME CONCEPT

The maritime industry is a crucial part of the European transport network. Over 1.200 commercial seaports and 70.000 km coastlines, the European Union is one of the densest port regions in the world. Today, over 70% of all international and over 35% of all intra-European trade is made via maritime transportation while 385 million passengers are carried across European seas, annually [68].

Nature of shipping has been changing as the demand for maritime transportation has been increasing steadily. Businesses have been investing in human resources and technology to improve their services to meet the demand. In order to cope with ever-increasing amounts of cargo more and larger ships (for example; Ultra Large Container Ships that can carry more than 20.000 TEU containers are being deployed on main container shipping routes, even today) are being launched. As a result; ports and all maritime actors connected with ports and ships (such as administrations, VTS, agents etc.) are also evolving to handle such large amounts of cargo. The problem is that there are already very busy ports which meet a large portion of the current maritime transportation demand (the three busiest ports carry more than 20% of all cargo handled across all EU ports) in the European Union. The demand growth on maritime transportation is estimated to continue as a 50% increase is expected by 2030. As the demand grows, more and larger ships could be launched which might lead to increased waterway congestion, increased emissions and larger associated risks. Administrations have been embracing new initiatives in order to manage such risks and reduce their effects pro-actively, and have been adopting new regulations to ensure a continuum of safe, secure and sustainable maritime transportation [68].

The e-Maritime concept focuses on the needs of administrative and business domains of the maritime industry for improving their applications to meet such future needs [3].

The e-Maritime concept aims to create a harmonized Single Window[3] solution that streamlines the interactions between all actors of the maritime industry in a cost-effective manner, utilizing the benefits of the internet and advanced communication technologies onboard and ashore [1], [3], [69].

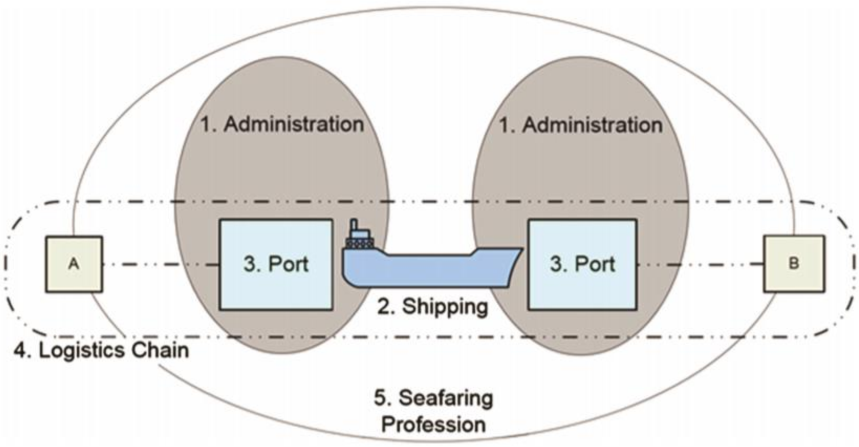

Figure 5. An integrated view of the e-Maritime domains. Retrieved from [3].

Currently, the "e-Maritime" terminology is commonly associated with the European Union's (EU) e-Maritime initiative throughout the literature and within the maritime industry [3]. Such usage could have been adopted due to the fact that the e-Maritime concept was started to be developed within the European Commission 6th Framework Programme in 2004 [69] though there are similar projects that also have

[3] An integrated maritime reporting and information exchange network

been developed by countries outside of Europe; such as the USA and South Korea, as well [70], [71].

EU e-Maritime initiative aims to develop European policies, strategies and capabilities needed to adopt a union-wide, effective and efficient maritime single window system that reduces the administrative burden on the maritime industry. It is expected that the EU e-Maritime initiative shall provide interoperability between all maritime administrative functions and essential applications in business activities across Europe. EU's e-Maritime structure shall be integrated into all maritime transport chains and encompasses all administrative and business actors of the maritime industry throughout the EU [3], [69].

There are other aims of the EU e-Maritime initiative as well. One of them is to improve safety and security throughout the European maritime industry by harmonizing different national legislation, procedures and practices of different Member States, which can lead to inefficient use of human resources and unnecessary duplicate work. Such harmonization would enable the maritime business to save time and resources that would otherwise be used for complying different administrative requirements [3], [72]. Fast and reliable digital communication systems, ability to exchange of massive amounts of maritime related information could also reduce the burden on the administrations as the Member States would be able to manage the maritime affairs benefiting from real-time compressive information gathered from many different actors of the industry [3]. The administrative and business actors of the European maritime industry would have access to an open, harmonized and comprehensive information exchange between European and international maritime actors [72].

Another important aim of the EU e-Maritime initiative is to enable sustainable waterborne transport across the EU by integrating services that offer increased efficiency and environmental protection [3], [72]. There are already environmental monitoring services available to remotely track fuel consumption, engine efficiency, GHG and particulate matter emissions of ships. These services are used to optimize the fuel consumption of ships and minimize pollution emanating from ships. There are other services that provide tools to overview discharges to sea, ballast water, chemicals and wastes of ships as well. Information gathered from these services could also be used to create risk profiles of fleets or individual ships, regarding their possible environmental effects in case of maritime accidents. Such services could be advanced and harmonized within the EU's e-Maritime initiative [73].

The main challenge is to get the continuous support of the maritime industry as the EU e-Maritime concept is a long-term concept. Sustainable solutions that address future user needs and developments, especially in the communication and information exchange technologies, are crucial for achieving the goals of the EU e-Maritime initiative [74].

3.1. Historical Evolution of the e-Maritime Concept

European Union's concerns over the IMO's pace on regulatory processes and implementation of measures (emanating from the slow and insufficient response to major maritime accidents) led the EU to introduce their own set of regulations. These regulations would become a part of the EU law which EU could enforce on the Member States unlike the "voluntary" acceptance of IMO treaties. Initiatives regarding safety and environmental protection were the driving force behind the efforts to eliminate sub-standard and incompliant shipping. EU improved its legal and regulatory system to enforce shipping standards that were beyond IMO requirements throughout the EU. While the move to enforce shipping standards that are beyond IMO requirements was successful, this move created an unforeseen side effect. Some set of regulations that were enforced within the EU was not required in other nation's seas or international seas. Maritime businesses in EU voiced their concerns over the fact that stricken standards might hurt their competitiveness. In order to keep enforcing their own requirements and complying IMO standards at the same time, EU actively supported (and in various cases led) the rule-making and implementation processes of the IMO [75].

To effectively support IMO rulemaking and implementation process, it is essential that Member States of the EU (and (Norway and Iceland) acted as one voice in the IMO meetings, especially to avoid misdirection and out of purpose statements. In order to ensure that, the European Commission (EC) was tasked to coordinate other Member States on the issues regarding the EU and EU's position on these issues. Also, EC played a key role in this coordination effort; as it acted as an umbrella over the Member States in order to guide them in the IMO rule-making and implementation process [75].

Improving competitiveness, safety, and security of the European shipping industry are primary objectives of the EC Maritime Transport Strategy. In order to achieve these objectives, EC has been supporting maritime related technological innovations and developments via Framework Programmes since 1994 [3], [76].

The Maritime Navigation Information Services (MarNIS) project started as a parallel project of IMO's e-Navigation concept within the EU's 6^{th} Framework Programme, in 2004. The MarNIS project was launched to develop an e-Navigation vision for the

EU. The project resulted in aims similar to the e-Navigation concept's aims, e.g., minimizing navigational accidents, protecting the maritime environment, improving navigational safety [1]. The main difference of MarNIS project's result that it also stated that EU's e-Navigation vision should also directly aim to reduce costs related with the administrative burdens and increase the profitability of the maritime industry [73]. The project aimed that thru use of advanced technology: All maritime related information shall be gathered from ships, processed, stored and distributed via a standardized shore-based network system [1], [73], [74].

Providing the cost-effective availability and promoting the use of maritime related information was the main aim of the MarNIS project; in lieu with Lisbon Agenda, the mid-term review of the Transport White Paper and the Blue Book on an Integrated Maritime Policy [1], [74]. This objective became more relevant in time as the usage of faster and more reliable maritime communication technologies become more common in Europe and was also strongly supported by the Maritime Transport Strategy for 2008-2018 [74].

The 2009 Communication from the EC named "Strategic Goals and Recommendations for the EU's Maritime Transport Policy Until 2018" states that communication technologies that are available and being developed shall be facilitated for a true "European maritime transport space without barriers". The proposed action plan was to define the e-Maritime framework that shall enable the introduction of automated electronic identification, monitoring, tracking and reporting systems which can decrease administrative burdens [74], [77].

The 2010 "Summary report of the contributions received to the e-Maritime public online consultation" published by EC showed the results of the e-Maritime public online consultation that aimed to collect and assess the views of the maritime stakeholders on e-Maritime initiative's proposed measures, applications and their outcomes. The report shows that the measure to "Define e-Maritime Standards" should be the first priority according to the vast majority of the maritime stakeholders that joined to the survey, as over 95% of all respondents identified this measure as rather "important" or "very important" [72].

The 2010 "e-Maritime Standardization Requirements and Strategies" report published by the Sustainable Knowledge Platform for the European Maritime and Logistics Industry[4] (SKEMA) provided in-depth knowledge on how a framework on e-Maritime concept should be conceptualized. The report suggested a Norwegian multi-modal Intelligent Transport System structure called ARKTRANS as a reference for the development of an e-Maritime framework [78].

The 65th EP Directive in 2010[5] on "Reporting formalities for ships arriving in and/or departing from ports of the Member States" required EU Member States to introduce an harmonized (electronic) National Single Window which is capable of exchanging standardized reporting information to be requested only once from ships, which also abides the requirements of IMO Convention on Facilitation of International Maritime Traffic (FAL) Convention, with a deadline of 1 June 2015 [79].

In 2012, the eMAR project was launched within the EU's 7th Framework Programme to define the e-Maritime framework for the successful implementation of standardized National Single Windows throughout the EU. The eMAR project's main aim was to develop the e-Maritime Strategic Framework through the

[4] Funded within the EU's 7th Framework Programme.
[5] The EP Directive 2010/65/EU.

participation of research, business and public communities of the maritime industry [80]. In December 2014 the eMAR project finalized with following outputs [81]:

i. Two fully interoperable platforms (The Danaos Collaboration platform and InleMar Ecosystem) that significantly reduce Information Technologies (IT) complexities and costs,
ii. The Intelligent Ship reporting application (i-Ship), which offered the first Directive 2010/65/EU compliant solution to the maritime industry, and
iii. The e-Maritime Strategic Framework (EMSF).

The Danaos Collaboration platform and InleMar Ecosystems mainly involves integrating existing IT structures of maritime business to the e-Maritime ecosystems in order to utilize various e-Maritime services, excluding ship reporting. InleMar Ecosystem enables maritime businesses to upgrade their IT structure to be compatible with the EMSF. The Danaos Collaboration platform mainly involves in inter-connecting maritime businesses. It enables maritime businesses to offer their services on an e-Maritime ecosystem, manage their personnel's interactions with other and other businesses within the e-Maritime ecosystem [82].

The i-Ship and EMSF subjects are covered in "Benefits of the e-Maritime Concept" chapter.

3.2. Relationships Between the e-Navigation and e-Maritime Concepts

The IMO membership consists of 174 Member States, 81 international non-governmental organizations in consultative status and 64 intergovernmental organizations which have signed agreements of cooperation with IMO [83]. Among other Member States of the IMO, EU's Member States also had a critical contribution to the development and realization of IMO's e-Navigation concept as several major e-Navigation projects (e.g., ACCSEAS, Efficiensea and MONALISA projects) were initiated and completed directly by the EU Member States coordination [3], [74].

Due to the concerns over IMO's slow pace of adopting new concepts, the EU decided to develop its own e-Navigation vision and named it as the e-Maritime [75]. Although the development of both concepts continued separately, EU's e-Maritime concept is deemed to encompass the IMO's e-Navigation concept [3].

Figure 6. It is deemed that the EU's e-Maritime concept encompasses the IMO's e-Navigation concept. Retrieved from [3].

The concern over separate but simultaneous development of IMO’s e-Navigation and EU’s e-Maritime concepts were also voiced by the EC in the 56th session of the IMO’s Sub-Committee on Safety of Navigation, in 2010. The difference between the two concepts (at that time) was explained [42, Para. 8.10]:

> *“In essence, IMO's e-navigation focused primarily on the shipborne navigation and on the development of electronic technology, processes and services to get a ship quickly and safely from berth to berth. Europe's e-Maritime focused primarily on the shore-based facilitation and on the development of electronic technology, processes and services to facilitate the flow of goods over sea – and consequently the ships that carry these goods – to, from and around Europe.”*

From the explanation above; it is clear that the IMO’s e-Navigation and EU’s e-Maritime concept are focusing on the same actors of the maritime industry, there are distinct differences in the aims and geographical scopes of these concepts.

The IMO’s e-Navigation concept mainly aims to advance maritime navigation and communication technologies to be used onboard and ashore, and harmonizing global standards to increase the overall safety of navigation, globally. The e-Navigation concept shall provide proper utilization of all existing shipboard systems such as AIS and GMDSS and shore-based management systems (such as VTS), and also shall lead the harmonized development of new global communication systems such as VDES and MCP [74].

On top of having the same aims with the IMO's e-Navigation (but to be exclusively applied within the EU borders), the EU's e-Maritime concept also aims increasing efficiency of the entire European maritime industry by creating unified means to seamlessly exchange all maritime-related data and information that European maritime businesses and administrations need [1], [42].

Although the main aim of the IMO's e-Navigation concept does not directly include maritime businesses' or administrations' needs, it is envisioned to provide services that will be to the benefit of them by increasing efficiency, reducing overall fuel consumption and preventing accidents [74].

The difference in driving forces between the IMO's e-Navigation and EU's e-Maritime concepts was also clear from the beginning of both concepts' developments. As previously mentioned, the MarNIS project was launched in 2006 within the EU FP6 in order to develop the e-Navigation vision of the EU. Apart from increasing safety of navigation, preventing accidents, increasing efficiency and protecting environment, the MarNIS project identified two more key issues related to economic concerns of the maritime businesses and administrations. The clear incentive to take the economic aspects of the maritime industry distinctly outlines the main difference in driving forces between IMO's e-Navigation and EU's e-Maritime concepts [1], [3].

Today, work on strategy, development and implementation plans IMO's e-Navigation and EU's e-Maritime concepts are already completed (and even partially realized as real-world applications to some extent). There are relations between the SIP of e-Navigation concept and EMSF of e-Maritime concept, reflecting the distinctions between these concepts. The e-Navigation SIP takes serious consideration on harmonizing and developing international law, standards and regulations for the more effective and more sustainable management of the human factor in maritime with the aid of advanced standardized technology, in order to prevent maritime accidents and protect the environment. However; the EMSF is deemed to have a broader scope than the IMO’s e-Navigation SIP. On top of the issues taken into consideration within the e-Navigation SIP, EMSF also considers the issues coupled with the rapid access demand to large amounts of maritime related information. Satisfying the rapid information demand of the maritime businesses (such as port operators, ship operators, bunker suppliers, ship chandlers, agents etc.), increasing the efficiency and reducing the costs related with gathering, harmonizing and re-distributing large amounts of data that is created and demanded is critical to improve competitiveness of the European maritime industry and was the primary concern while developing the EMSF [1], [3], [70], [74], [76].

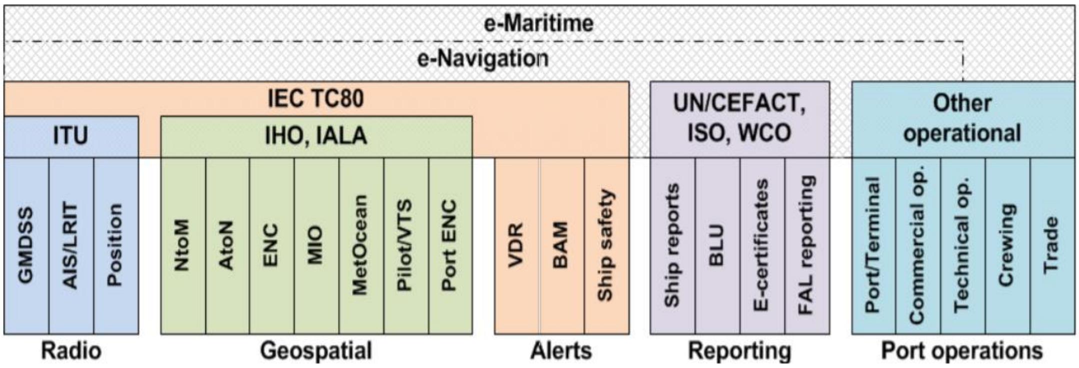

Figure 7. Maritime-related data used within e-Navigation and e-Maritime concepts. Retrieved from [84].

IMO’s e-Navigation and EU’s e-Maritime concept is planned to utilize the same (or mostly similar) maritime communication technologies and systems, as they both identified the rapid digital communication ability between ships and shore to be critical. Automation of mundane tasks once done with the supervision or direct input of the human operators (such as reporting and data exchange) tasks play an essential role in both concepts [3].

Possibly not to create unnecessary complexity by introducing different standards or technologies for the systems that would have mostly same capabilities; EU plans to utilize the navigation and communication technologies to be introduced within the e-Navigation concept in their e-Maritime concept as well [3].

Although IMO's e-Navigation and EU's e-Maritime concept had progress; there is much to be done to achieve the aims of these concepts. A globally interconnected and automated maritime transport would be realized with the emergence of Maritime Intelligent Transportation Systems in the future [3], [74].

CHAPTER 4

BENEFITS OF THE E-NAVIGATION CONCEPT

Generalized benefits of e-Navigation can be categorized into four separate categories, taken the IMO's definition of e-Navigation into consideration [2]:

i. Presentation of maritime information by setting design and usability standards,
ii. Increasing safety and security at sea by developing advanced navigational technologies,
iii. Harmonized collection, integration, exchange and analysis of maritime information by harmonizing information exchange, and
iv. Protection of the marine environment by utilizing the benefits mentioned above and IMO's rule-making power.

Following sub-chapters will be covering the generalized benefits of e-Navigation, per in these four categories.

4.1. Design and Usability Standards

4.1.1. Human Centered Design and Ergonomics

Costa (2016), in her thesis "Human Centred Design for Maritime Safety: A User Perspective on the Benefits and Success Factors of User Participation in the Design of Ships and Ship Systems", states that the maritime safety should be the primary goal that naval architects and ship systems designers should design for. Author also suggests that the design process shall take all human factors and ergonomics (such as human-technology interaction, physical layouts and hazards, rules, procedures and training issues) into account in order to create an efficient, user-friendly, cost-effective and sustainable work environment that meets the needs of the stakeholders of maritime sector and ultimately increase overall safety of navigation [43].

"e-Navigation is about getting ships safely, securely and efficiently from berth to berth in an environmentally friendly way, using globally enhanced systems for navigation, communication and related services – with the human element in focus [85]*"*

As mentioned in the above description of the e-Navigation concept in the 58th meeting of IMO NAV commission report; the primary goal of the concept is to increase overall navigational safety and enhance communication capabilities while taking the human element into account. Therefore, the design of future shipboard and shore-based systems and equipment to be used within the e-Navigation concept should largely benefit from Human Centered Design, as it takes human factors and ergonomic issues related with the human element into account [78].

The e-Navigation Strategy Implementation Plan states that the Human Centered Design (HCD) approach adopted within the e-Navigation concept to identify and meet the diverse needs of ships and shore users. The reason behind this division it that the users on ships and shore have different roles, duties, needs and working environments as the human interactions (with machines, other humans, processes etc.) in these different environments are fundamentally different [9].

The literature on HCD states that the needs of all users shall be carefully evaluated while iterating and determining interactive systems' designs and standards [41]. In order to evaluate the human element and all user needs in the scope of e-Navigation, IMO's Sub-Committee on Safety of Navigation was tasked to identify the possible issues and solutions related with the human element that could be faced within the e-Navigation implementation process [86]. In 2012, the 58th meeting of the IMO Sub-Committee on Safety of Navigation finalized the work on "Gap Analysis and Practical e-Navigation Solutions with Human Element considering HEAP" with the inputs from the Member States. Findings of this work are published in the 1st, 2nd, 3rd and 4th annexes of IMO NAV 58/6 report [85].

Identified user needs and solutions mentioned in the related NAV58/6 report are consolidated and divided into two different user type categories below, for consistency and more straightforward presentation. For the sake of solely focusing on the HCD subject, the user needs without gap definitions and definitions left as *"To Be Described"* in the NAV58/6 report are not included in the list below [85]:

1. <u>Shipboard User Needs:</u>

    i. Systems onboard ships shall be designed in a way that enables the crew to operate at peak efficiency while carrying out their pre-designed duties, in regular and harsh operational conditions.
    ii. Presentation of large amounts of navigational information shall be done via understandable, un-distracting and standardized interfaces.
    iii. Data formats used for ship reporting shall be globally harmonized to promote consistency, compatibility and efficiency. Automated reporting schemes shall be designated for mandatory reporting needs (such as Passage Plan declarations etc.). Automated reports shall

have self-signed certification and date of validity to ensure broadcast of up-to-date information.

iv. A Single Window approach shall be taken to mitigate compatibility and efficiency issues emanating from the usage of different national reporting schemes.

v. Standard Marine Communication Phrases (SMCP) shall be revised to be easier to understand. Usage of visual SMCP instead of voice communication shall be promoted and e-Navigation equipment shall make use of digital communication using visual SMCP, by default.

vi. Performance, ergonomics and Human Machine Interface (HMI) standards on ECDIS equipment shall be re-defined to accommodate:

   a. Usage of standardized interface (e.g., S-Mode) and symbols,
   b. Ability to digitally share and present imminent intended routes between ships and shore stations for increased safety and efficient use of communication channels,
   c. Ability to digitally share and negotiate voyage plans with related authorities,
   d. Ability to request and declare confirmation and approval over changes made on navigational matters in an error-proof and clear manner,
   e. Ability to digitally communicate with VTS, pilotage and port authorities, and
   f. All available Maritime Safety Information (MSI) received (from AIS, NAVTEX, Safety-NET, etc.) shall be presented in real time on relevant interfaces. As MSI currently broadcast in text format which automation systems cannot interpret, a new digital format using SMCP for a correct and clear presentation on navigational interfaces. The validity of MSI messages shall be self-checked and deleted if necessary.

vii. Automated self-check and status indication of the navigational equipment, as well as a clear indication of accuracy, quality and reliability of received data, is critical for increased navigational safety.

viii. E-Navigation systems shall be able to automatically select the source of the navigational data depending on the reliability of the data provided from the source, without requiring interaction from the user.

ix. Standards and guidelines shall be defined to ensure Human-Machine Interfaces used in e-Navigation systems and equipment shall be designed in an easy-to-use manner in all operational conditions (especially ensuring smooth use in heavy weather and sea conditions). Bridge layouts, equipment and systems shall be designed from an ergonomic and user-friendly perspective.

x. Bridge equipment shall have self-description and fault tolerance.

xi. E-Navigation systems and equipment shall include automatic remote software update ability with minimum user interaction or disruption of usage. Hardware and software upgrades of such systems shall be controlled via a secure certification system which can be remotely inspected, to ensure compliance with related regulations, at all times.

xii. Usability evaluation and feedback mechanism for any system and equipment used in the e-Navigation concept shall be available to the user and developers. This will allow developers to frequently update their software according to the needs of the users.

xiii. Pilotage and berthing requirements on communication shall be easily accessible and switchable on the equipment used for communicating with them.

xiv. Regulations shall be revised not based on each equipment but on user needs and function required to provide services in order to reduce the administrative and paperwork.

xv. Training schemes of the crew shall be re-defined taking the full scope and complex nature of e-Navigation. Training could be specific as per ship, user or systems.

xvi. Shipboard communication systems shall be compatible with communicating IP based shore communication systems. Efficient Machine to Machine conversion needed to enable data transfers between IP based and IP-less networks such as internet and VDES. Standards on data transfers (such as IHO S-100) shall promote efficient use of the data bandwidth available while not degrading the reliability of the data.

2. Shore-based User Needs:

i. Systems in shore stations such as VTS, port authorities and other actors of the maritime stakeholders on land shall be designed to utilize their services better and coordinate all related efforts. Standardization of data formats (such as CMDS) and communications infrastructure on an international level is the key to achieve automated, reliable and efficient information sharing among all maritime stakeholders on land and sea, globally.

ii. Reports and documents received from ships shall be internationally harmonized and available to authorities and public (some information can be selectively revealed based on authentication levels, some information can be withheld due to legal reasons, public users can get largely time delayed non-real time information, etc.).

iii. Shore-based systems shall have enough processing power to handle large amounts of sensitive data. Backup systems or non-centralized structures can opt for redundancy.

iv. Presentation of large amounts of navigational data gathered from all ships needs systems capable of information prioritizing and supporting their users in the decision-making process. Performance and design standards (as well as limitations) shall be designated for such intelligent support systems.

v. Any maritime communication system that carries sensitive information (All GMDSS including AIS, VDES, Digital Satellite Communication Service, etc.) shall be encrypted and compliant with national/international data protection laws.

vi. Global agreement and adoption of international standard for digital formats of various report between ship and shore shall be addressed to reduce the workload on the administrative and management work on shore authorities.

vii. VTS Centers shall take necessary hardware and software upgrades ahead of time for the anticipated high amounts of data traffic proactively to prevent information overburden on the user or service disruption.

The e-Navigation is a long-term concept and the driving forces and solutions within e-Navigation are changing as user needs change and technology evolve in time. For example, the NAV 58/6 report mentions the usage of older communication technologies such as Code Division Multiple Access (CDMA) and Worldwide Interoperability for Microwave Access (WiMAX), which are already made obsolete by Long Term Evolution (LTE) and 4.5G networks at the time of writing.

In the future, new technologies and applications that could create new users and needs might be developed. An intuitive proforma example would be some kind of Virtual Reality users who could manage ships remotely and be responsible from the safe navigation of a vessel while being on shore (possibly even on different continents and timelines). Even though they would be technically classified as shore users, they would potentially have similar needs with the ship-borne users. Therefore; in the future, the e-Navigation gap analysis work might need to be repeated to identify and mitigate all user needs of the future.

4.1.2. S-MODE

The e-Navigation concept is currently designed to take advantage of the existing systems and equipment used onboard ships and shore, such as Integrated Navigation Systems (INS) (including ECDIS, AIS, satellite communication, GPS, radar, etc.). The role of these systems are expected to widen as e-Navigation progresses and many different services and solutions depending the capabilities of these systems are to be created within the concept to increase the safety of navigation [9].

Module C of the IMO resolution MSC.252(83) on Revised Performance Standards for INS defines the interface design requirements of INS displays [87]. While the interface requirements aiming to meet user needs (a harmonized alarm management, increased situational awareness and decision-making support the bridge team) are described in length and linked to relevant requirements of SOLAS Convention in this resolution, there is no definition for a standard or unified interface for each type of equipment included. This approach was probably chosen in the name of not interfering with the manufacturers' ability to innovate, yet the effects of such a decision are unclear.

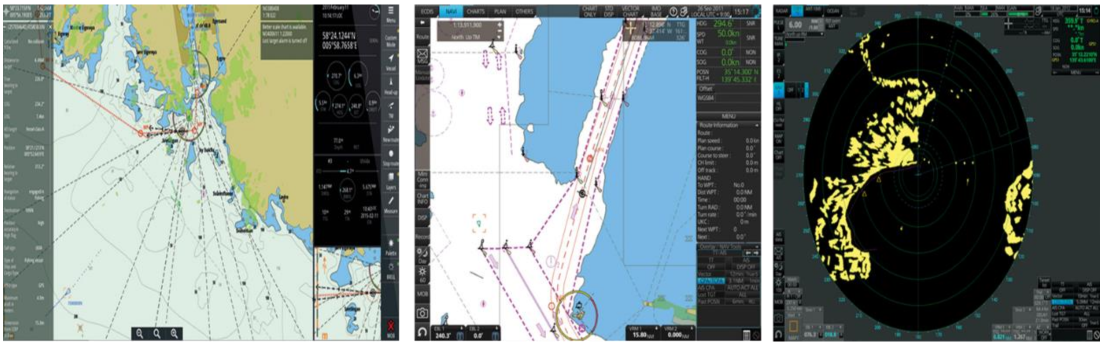

Figure 8. Different interfaces of ECDIS and Radar systems (Left to right: A Simrad ECDIS Interface, a Furuno display ECDIS Interface, a Furuno Radar Interface). Retrieved from [88], [89].

Manufacturers opted in many different features, services and interfaces on their equipment [90]. Different models of navigational equipment that are in different price levels offer different specialized abilities thus leading to the usage of specialized interfaces. Even the same series of navigational equipment of a manufacturer produced in different years might have different interfaces. Interfaces of two ECDIS displays from different manufacturers and a radar display from the same manufacturer is given as examples in Figure 8.

Usage of similar and standardized interfaces on systems which are designed to present maritime related information (such as ECDIS) could be an efficient way to achieve the goals of e-Navigation; as the uniform, consistent and clear presentation of navigational information and alarms is the key to increase navigational safety [91]. IMO NCSR 3/28/1 guidelines on Standardized Modes of Operation (S-Mode) proposes an initial description of the S-Mode, as follows [92]:

"Guidance on the standardization of design for navigation and communication systems, encompassing displays, interfaces, and functionalities able to provide the bridge team and the pilot with timely access to essential information for the conduct of navigation throughout the voyage, from berth to berth."

With the availability of standardized interfaces such as S-Mode; users that regularly interact with these interfaces such as Masters, Pilots and officers could merely switch over to S-mode when needed. Benefits of such ability to switch to a more familiar and standardized interface would be realized as shorter periods required for familiarization to the interfaces of navigational systems -especially on different ships-, shortened mandatory training periods, decreased the risk of human error and increased the safety of navigation [9].

S-mode may not only provide the ability to switch to a standard interface but also could introduce an ability to set user-defined profiles for interfaces, as well. Users could customize the interfaces of navigational displays according to their needs, preferences or the operational circumstances [93].

More, the interface of the S-Mode on all equipment does not necessarily need to be identical neither. However, the usage of standard symbology, icons and color schemes shall be beneficial to the users [91].

The work program included in IMO MSC 95/19/8 report on “Implementing e-Navigation to Enhance the Safety of Navigation and Protection of the Marine Environment” gives the intended progression of the development of S-mode. Complete drafting of an S-Mode guideline for the design of shipboard navigational equipment along with notes for training implications (e.g., model courses) planned to be completed in 2019 [94].

4.2. Advanced Navigation and Communication Tools Onboard

4.2.1. Strategic and Tactical Route Exchange

IMO's e-Navigation SIP mentions the implementation of the navigational systems to be used within the concept that shall support users in the decision-making process. It is envisioned that these support systems onboard ships and shore stations to assist the users in the voyage planning phase, as well. Such systems shall take advantage of existing inter-connected structures such as INS and navigational systems such as ECDIS to a great extent [26].

Systems onboard ships could automatically analyze a proposed voyage plan for compliance with regulations, tidal status and water levels, lock and docking requirements, under keel clearances and air draughts, weather and sea state forecasts, compliance with latest MSI and Notices to Mariners, requirements of the charterer and manager and so on [9]. Such means of automated analysis mechanisms could improve the accuracy, quality and scope of the risk assessment regarding a proposed voyage plan, which is crucial for safe and cost-efficient navigation of a ship.

Shore authorities (such as VTS) could also largely benefit from having information (and a possible input) regarding voyage plans of ships. In case of an emergency, urgency or even a pre-planned work (such as maintaining or laying underwater cables, wind turbines, piers, buoys, etc.) on the sea, operators could have information on all ships that are planning to pass from the vicinity of the area at hand and arrange their coordination efforts accordingly. On the other hand; the communication systems proposed within the e-Navigation concept (such as VDES) could enable high-speed digital communication abilities between ships and shore authorities, enabling them to negotiate changes on voyage plans directly via navigational equipment such as ECDIS.

Proathe (2016), in the study “A navigating navigator onboard or a monitoring operator ashore? Towards safe, effective, and sustainable maritime transportation: findings from five recent EU projects” states that the voyage plan of a ship can be examined in three parts [95]:

i. Strategic Route: The entire voyage plan prepared before the departure of a ship.
ii. Tactical Route: The short-term part of the voyage plan that is soon intended to be actualized.
iii. Predicted Route: The imminent route that is calculated according to the navigational data (speed, course and rate of turn, etc.) gathered about a ship.

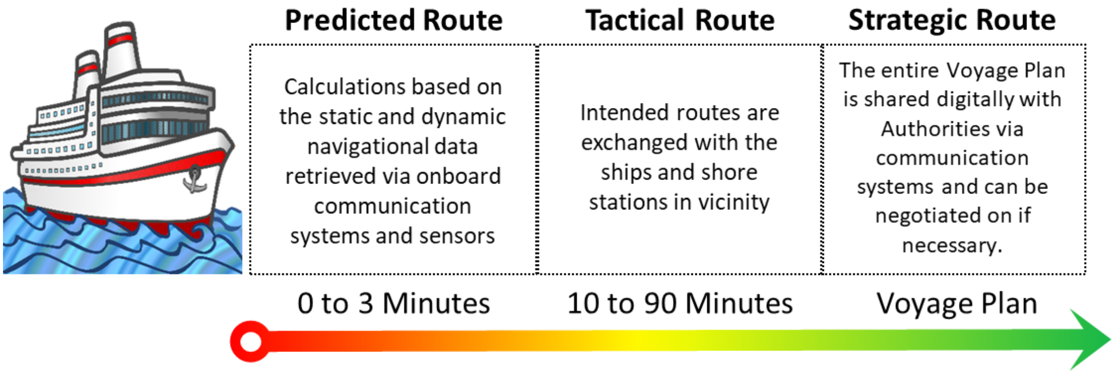

Figure 9. A possible route exchange taxonomy for e-Navigation. Adapted from [95].

Proathe (2016) also states that the proposed digital route exchange, remote monitoring and route management mechanisms were thoroughly researched in ACCSEAS and Efficiensea, MONALISA and MONALISA 2.0 (now known as Sea Traffic Management [STM] Validation) projects [95].

The proposed route exchange system in the ACCSEAS project was a part of a navigational automation system capable of navigating a ship independently from any user input or monitoring, while also trying to keep the users in the decision-making and monitoring loop [96]:

> *"This ideal can be compared to the perfect English butler – always behind his master, serving him when he needs it and will be stopping him from looking like an idiot."*

In the 2015 ACCSEAS Final Annual Conference Report, the results of an experiment on the application of a tactical route exchange system were published. Inputs of the experts (Pilots, Masters and VTS Operators) from the maritime sector were surveyed as they faced several simulated scenarios. The report states that the tactical route sharing application in the ACCSEAS project resulted with 100% *good* or *very good* ratings from the participants and was found to increase shared Situational Awareness across the stakeholders of the maritime sector [96].

The MONALISA project had similar findings with the ACCSEAS project. The diverse nature of the actors in the joint MONALISA project on determining better standards for route exchange via a common interface and data format had importance on meeting the user needs; as it enabled the inputs of private sector, manufacturers and users on the route exchange and management aspects to be used in the e-Navigation concept [97].

The significant improvement of STM Validation project over MONALISA project was integrating real ships with the technology to exchange tactical route data between ships and shore stations. The 2017 International e-Navigation Underway Conference took place on a cruise ship which was a part of the STM network. At the conference; it was demonstrated that the cruise ship automatically shared her voyage plan with the VTS Station and the VTS Authority sent relevant MSI, suggested arrival times and similar navigational information to the cruise ship; all are utilizing similar navigational and communication equipment to be used in the e-Navigation concept. It is also stated that similar STM test beds will span across 300 ships, 13 ports and five shore centers in the future [98].

Salous et al. (2015), in their study "Improving maritime traffic safety by applying routes exchange and automatic relevant radar data exchange", explored the possible outcomes of a tactical route exchange mechanism. The study was based on the information and data gathered from a real-life maritime accident that was later simulated on computers, within the COSINUS project. The study aimed to investigate the possibility of the prevention of that particular accident if a tactical route exchange mechanism had been in place before the accident [99].

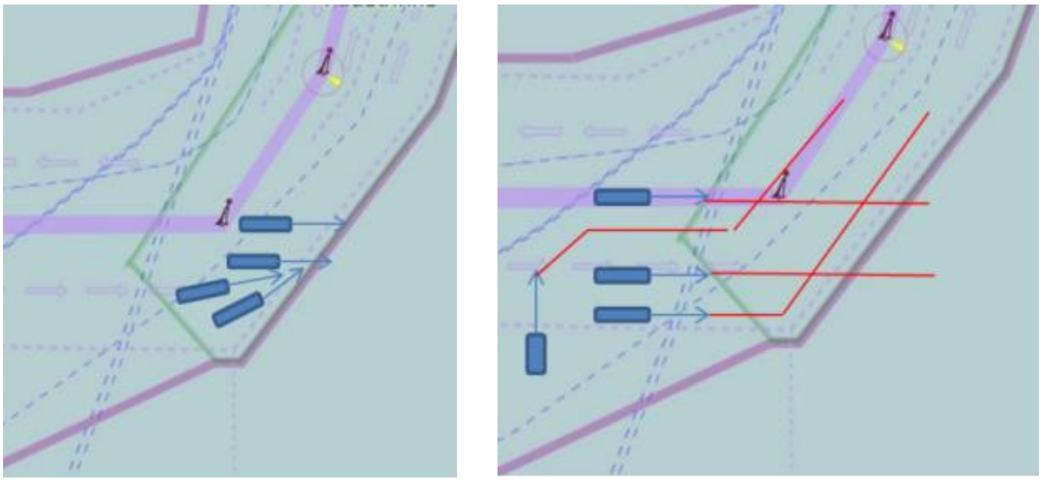

Figure 10. Without the tactical route exchange, the collision occurs (left). With the tactical route exchange, the collision might have been prevented (right). Retrieved from [99].

Authors conclude that the ability to automatically and digitally exchange tactical routes could have prevented the accident as each ships' bridge crew would have been made aware of each other's planned routes before the accident; as Figure 10 shows [99].

It is necessary to mention while there is no digital tactical route exchange system that is installed onboard all SOLAS ships today, as such systems are still mainly at their development phases and there is no international framework on the usage of such systems at the time of writing of this thesis. The visual and auditory communication methods stated in Convention on the International Regulations for Preventing the Collisions at Sea (COLREG), AIS, ARPA Radar and verbal communication over VHF radio are still the most prominent means to gather information about the navigational intentions of other ships. While each of these systems and equipment is capable of providing necessary information regarding the intention of the other ship, they have disadvantages regarding speed and reliability. It should be noted that in events prior to maritime accidents, time management and decision-making based on reliable information has critical importance to avoid the accident.

In this respect; the reliability, time efficiency and effectiveness of an automatically and digitally exchanged tactical route information (which can be instantaneously presented on ECDIS displays) would be unrivaled.

4.2.2. Dynamic Route Optimization

With e-Navigation; ships and shore-based stakeholders of the maritime sector shall have cost-effective access the high-speed access to reliable and accurate information on maritime matters [100]. Accurate data on navigational elements needed for dynamic route optimization can be obtained from a combination of sources (both on land and sea) and processed onboard ships. The cost-saving benefits of accurate and dynamic route optimization of a ship can be further increased when combined with the cost-effective aspects of slow-steaming, as real-time information on a suggested time of arrival to a port can be obtained (probably provided as a service) in a more cost-effective manner compared to present day’s solutions [101], [102].

The concept of Dynamic Route Optimization is not new. There have been many mathematical and programming methods developed towards reaching this goal since the 1950s (e.g., *The Truck Dispatching Problem* published by G. B. Dantzig and J. H. Ramser in 1959, dealing with 653,837,184,000 different routes). Dynamic route optimization methods of the past involved only the essential dynamic elements affecting a ship, due to the sheer amounts of calculations needed to be carried out correctly. With the advancements in computer technology; however, the processing power of computers grown exponentially and made it possible to take many dynamic elements into account [103], [104].

There are several methods of optimizing the route dynamically to save fuel. The weather routing is one of the oldest ways to save fuel, which is selectively adjusting the speed and course of the ship to use the weather and sea conditions to the advantage of the ship rather than battling against them, to save fuel [105]. Also, several advanced weather routing methods are being developed in order to further increase efficiency and navigational safety [103], [105].

There is another practice in the maritime transportation sector for saving fuel, known as slow steaming. Slow steaming can be summarized as; slowing a ship down to a speed that results with the optimal fuel consumption in order to decrease the total fuel consumption of a voyage. Studies reveal that the method of slow steaming can reduce fuel costs and related operating costs [95], [106]. The tradeoff of slow steaming is the trip times get longer as it creates the need for whether more ships or larger ships to accommodate same amounts of demand, while studies suggest that the total cost reduction of slow steaming can be more than the cost of deploying more or larger ships [95].

Today, modern route optimization methods are offered as services by private or public providers [102]. These services may take many dynamic elements that can affect the navigation of a ship -weather and sea states and forecasts, distance, speed, ETA, rudder and propeller rotations, despatch and demurrage costs, traffic separation schemes, bathymetric conditions, port availability and requirements, etc.- and can provide accurate information to optimize routes [102], [107].

The main advantage of the dynamic route optimization is that ships can whether shorten their routes or adjust their speed in order to achieve a higher fuel consumption efficiency, without adversely affecting the safety of navigation [102], [107]. As simulations show; such services can reduce total fuel consumption by creating routes even if the total distance is longer than a traditionally planned route [102], [103].

Fuel costs can represent up to 60% of the total operating costs of a ship. Therefore, the main cost-savings aim of dynamic route optimization is realized as the reduction of total fuel consumption and it is achieved through finding the most efficient speeds on safe routes for the planned voyage [106].

The main issue with the modern dynamic route optimization service is the requirement of large amounts of data communication, insufficient information on ship properties and involvement of experts, which increases the overall costs associated with such services [107].

4.2.3. Resilient Position, Navigation and Timing

As previously mentioned in this thesis; the GNSS currently consists of GPS, GLONASS, Galileo and Beidou systems [46]. These systems are available as free to use for public (hence maritime) domain and shall provide uninterrupted service availability. The positional accuracy of these systems can be increased to sub-3-meter accuracy levels, via application of the Satellite-Based Augmentation System (SBAS) data received from ground-based stations via satellites. Currently, there are 8 SBASs are available for public use [108]:

i. Wide Area Augmentation System (WAAS),
ii. European Geostationary Navigation Overlay Service (EGNOS),
iii. Multi-functional Satellite Augmentation System (MSAS),
iv. GPS Aided Geo Augmented Navigation (GAGAN),
v. Quasi-Zenith Satellite System (QZSS),
vi. System for Differential Correction and Monitoring (SDCM),
vii. Geoscience Australia (SBAS) Test-Bed Project (GATBP) and,
viii. Nigerian Satellite Augmentation System (NSAS).

The advantages of SBAS is that it provides superior position, timing and velocity accuracy over GNSS solutions, and it does not require any additional hardware added to an SBAS-Enabled GNSS receiver as the SBAS data is broadcast via the satellite network and on the same frequency that GNSS receivers use. In the past, mitigation data (on atomic clock drift, ionospheric interference, etc.) was broadcasted via ground-based wireless networks and required an additional receiver (D-GNSS receivers) alongside a GNSS receiver [109].

IMO's Performance Standards for Multi-System Shipborne Radionavigation Receivers (MSC 95/22/Add.2 Annex 17) defines the minimum components and capabilities that a multi-system SBAS receiver shall be capable of. It is stated that with or without augmentation, a multi-system receiver should be capable of producing at least one positional fix every second and capable of detecting the quality and reliability of the signal and navigational data and switch between PNT solutions when necessary. Systems also shall be able to mitigate any interference by utilizing different frequency bands as well [110]. The interference can be natural (space weather and ionospheric interactions with charged particles) or artificial (spoofing, jamming, hacking, etc.). In 2014, two such service disruption events already happened: In April 2014, a configuration error disabled the entire GLONASS for 10 hours. In September 2014, two solar flares affected GPS signals. In one of the solar flare events, GNSS signals were deteriorated to the point that positional accuracy was around 200nm (instead of a couple of meters in normal operation) [96].

In the scope of e-Navigation, there is research already done on interference mitigation. The ACCSEAS project had many important results, but two of them were on the creation of resilient PNT systems to be used in e-Navigation concept: First was the creation of world's first prototype multi-system PNT receiver and the second was the advancement of the ranging mode (R-Mode). Researchers managed to add ranging data alongside the existing AIS VHF and MF radiobeacon broadcasts. They made a receiver capable of receiving AIS VHF signals, land-based MF radiobeacon signals and eLoran signals simultaneously, to be used as a back-up solution if the satellite-based GNSS services are disrupted. The main aim of this application was to utilize some parts of MF (283.5 to 325.0 kHz) and VHF (161.975 and 162.025 MHz) frequency bands for carrying PNT data as a back-up, in case the part of UHF frequency band commonly used by GNSS (1.1GHz to 1.6GHz) is interfered by natural or artificial events. The reason behind the selection of two distinct bands to carry R-Mode data is also related with the coverage of the systems utilizing them as well; as MF radiobeacons are still used for PNT even long distances away from shores while AIS VHF for PNT is proved to be effective only in the coastal areas [96].

MF radiobeacons has been used for PNT in maritime and aviation for many years while AIS is not a standardized nor originally intended solution for PNT. Still, the results of the study are surprising and promising [96]:

i. 3 to 20 meters accuracy using MF radiobeacon PNT signals alone.
ii. 10 to 20 meters accuracy using AIS VHF broadcast for PNT alone.
iii. 10 meters accuracy when combining both systems.

The positional accuracy ranges stated above are deemed to meet the resilient PNT requirements of e-Navigation [96].

There are some drawbacks of using these systems for non-intended purposes. AIS has a limited bandwidth/capacity which can be overloaded with the inclusion of PNT data. This may cause AIS's primary function (collision avoidance) not to work correctly. MF radiobeacon and AIS VHF broadcast is public and can be manipulated [111].

4.3. Harmonized Information Exchange

4.3.1. Inter VTS Exchange

Inter VTS Exchange is a concept of one-way exchange of common maritime traffic data between VTS stations, shore-based e-Navigation stakeholders and ships [96], [112]. The main aim of this concept is to harmonize the traffic data between relevant authorities while decreasing errors and costs related to the gathering of such data. IVE service would be beneficial to all users in the e-Navigation concept as the data provided can be used for many different cases [96]:

i. The gathered information can be shared internationally,
ii. Ports can adjust their operations and queues according to the information gathered via any VTS center within the network,
iii. VTSs can manage maritime traffic using robust information provided for all ships in the system, even the ones out of the direct line of sight, and
iv. Authorities can get critical information about the identity of the ship(s) faster in the event of maritime accidents.

Figure 11 depicts a hypothetical VTS center placement on a hypothetical strait. On the left; there are 4 VTS centers without the Inter VTS Exchange (IVE) capability. Mountainous nature of the strait limits the line of sight of each VTS center. Therefore, two VTS centers on the upper side of the strait may not be able to gather information about the ships beyond their direct line of sight. On the right; there are now 3 VTS centers with the IVE capability to cover the entirety of the waterways. Information can be gathered about all ships in range of the whole network.

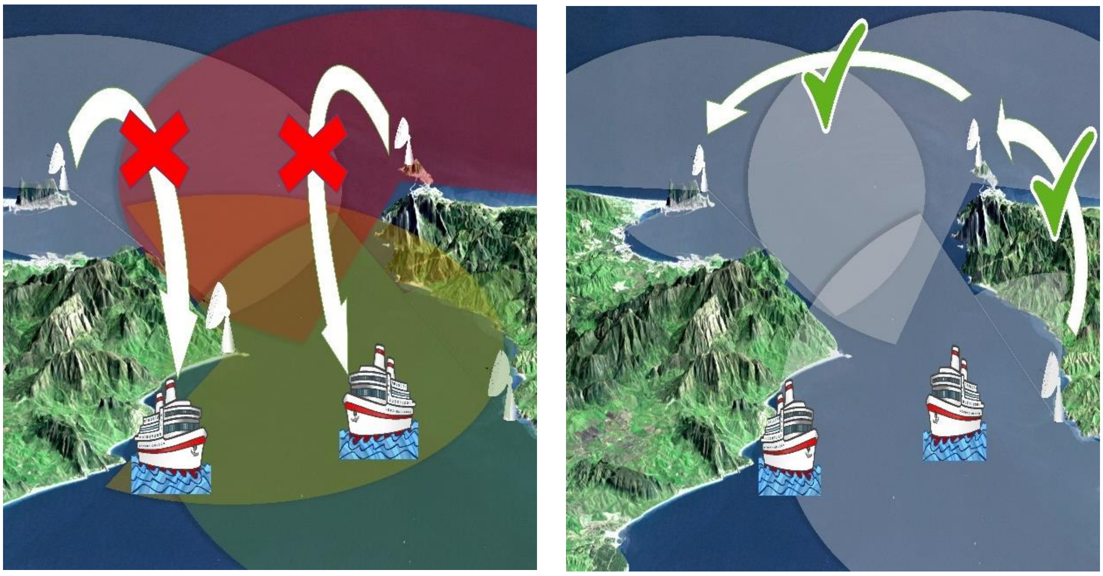

Figure 11. Two hypothetical placements of VTS Stations on a hypothetical Strait. Left: Situation without Inter VTS Exchange capability. Right: Situation with Inter VTS Exchange capability. Terrain image retrieved from NASA [113].

The Inter VTS Exchange Format (IVEF) is the format used for the IVE service within the e-Navigation concept. Users can select the area they are interested in and adjust the data refresh rate and which data they are seeking. This being said, IVEF is not a system nor similar to the AIS. Because of the broad range and sensitivity of the data gathered, to mitigate the related security and data protection concerns, IVEF needs to be encrypted, authorized access only over a segregated network [112].

The IVE service is also a mutual service as VTSs can also share data with other VTSs among the network. This creates the need to define the different areas a VTS center is responsible for and has interest in. The Domain of Interest (DoI) is the geographical area that a VTS has a particular interest while not having authority over the said area. The Domain of Responsibility is the geographical area that a VTS has authority over, or *responsibility*, hence the name suggests. There is one more type of domain arising from the usage of many VTS or sectors of a VTS within a network, Domain of Co-operation (DoC), where two (or more) VTS or sectors has overlapping authorities [112].

Existence of a DoC requires VTS Stations to be equipped with more advanced systems that are capable of keeping track of a single object with multiple sources of navigational information, throughout the entirety of the sensor coverage. Any erroneous sources of navigational information shall be mitigated with the usage of different fallback sensors and sources to provide uninterrupted service availability [112].

In conclusion, IVE [112];

i. Reduces costs associated with the amount of VTS stations, sensors and their maintenance,
ii. Gives the ability to verify unverified data via authenticated authorities or share verified data with authenticated users,
iii. Enables VTSs to reach beyond their line of sight, and
iv. Helps to harmonize maritime traffic management over large bodies of water.

As e-Navigation concept evolves, IVE service will gain more and better abilities that would further increase the benefits and capabilities of the service. For example, the introduction of the MCP and VDES could remove the need to establish a separate network for constellations of VTSs [96].

4.3.2. Rapid Communication Facility

IMO's definition of e-Navigation concept shows the clear need for effective and robust means of communications between ships and shore users. This need comes from the risks and responsibilities associated with navigational safety, security and environmental pollution. One of the key elements to lower these associated risks is the efficient and correct use of communicational facilities [9].

The e-Navigation concept brings solutions to meet the need for robust communication facilities onboard. One of them is the introduction of VDES, as already mentioned in this thesis. Another solution is the possible use of the Wireless Local Area Network (W-LAN) as researchers have promising results with the usage of the technology onboard ships [114].

W-LAN technology have many advantages over many other communication technologies: High data throughput over short distances, very low adoption and operational costs, ability to reach any point in the network by hopping nodes, multi-band operations, small footprint and proven security standards. Modern W-LAN systems have already advanced to the point of reaching gigabyte-per-second levels of throughput. The main disadvantage of the system is the short working range and signal scattering. Because of the signal power limitations; as the distance from the source increases signal interference (and thus the error rate) increases as well, and data throughput drops significantly [114], [115].

Niwa et al. (2015) conducted two on-ship communication trials utilizing W-LAN. Omnidirectional and different types of directional antennas were placed separately on two ships to determine their effects on data throughput and communication range.

The study concluded that while omnidirectional antennas provided all-around communication capability, throughput was on a few hundred kilobytes per second levels. On the other hand, directional antennas achieved a peak of 2.7 megabytes per second data throughput at a distance of 2.500 meters and sustained near 1 megabyte per second data throughput over a distance of 5.500 meters. However, due to the nature of directional antennas and sea surface scattering, communication below 700 meters from the source was not possible [114]. A similar study is conducted by Zainuddin et al. (2018) reached 8.000 meters from the source with a data throughput of 2.43 megabytes per second between a shore W-LAN base-station and W-LAN receiver onboard a ship [115].

There are also other alternative communication technologies such LTE, WiMAX and Satellite-based broadband that can be used onboard ships.

Albeit the very promising technological aspects of LTE (60 nautical miles range, high-speed connection, etc.) connectivity; even prototype LTE based maritime communication solutions have performance and interference issues emanating from the allocation of the LTE frequency bands [116]. They vary vastly different networks and countries [117] and also they can overlap with other frequency bands [116].

WiMAX is a telecommunications technology that provides wireless transmission of data using a variety of transmission modes, from point-to-multipoint links to portable and fully mobile access. The technology is based on the Institute of Electrical and Electronics Engineers (IEEE) 802.16 standard. Albeit to the general belief, WiMAX technology is used fairly commonly. For example, current MOBESE system in Turkey uses WiMAX infrastructure. Similar to W-LAN, WiMAX can either operate at higher bitrates or over longer distances but not both: Operating at the maximum range of 50 km increases error rate and thus results in a much lower bitrate [115].

Conversely, reducing the range allows a device to operate at bitrates up to 75 megabytes per second. Although, the average throughput of WiMAX technology is around 3 megabytes per second per user. The main disadvantage of the WiMAX is the lack of internationally harmonized frequency allocation for the technology. Several countries had allocated the frequency bands to be used by WiMAX for other purposes earlier, which limited the adoption of the technology. Another disadvantage of the WiMAX is the requirement of base stations and frequency licenses, which complicates the operation of the network and increases operational costs [115].

There are many emerging satellite-based broadband service providers today (e.g., SpaceX). Satellite-based communication has its unique benefits; even with a single geostationary satellite, vast areas can be covered and uninterrupted high-speed broadband service can be provided. The main disadvantage of the satellite-based connections is the high initial installation and subscription costs. As these systems become more widespread and related costs reduce, satellite-based data broadband communication could become the de-facto data communication method in the maritime sector [51].

While there are many promising technologies available today capable of megabyte-level throughput over relatively long distances, the free to use nature of W-LAN technology could make it a practical addition to onboard communication technologies in the near future. Information and updates on MSI, ECDIS charts, Notices to Mariners, etc. could be downloaded (and uploaded) at the connection speeds that W-LAN is capable of reaching.

In the future, the user needs within the e-Navigation concept could require even more advanced communication solutions. Precise point-to-point communication systems could utilize AIS and VDES to determine the exact direction and height that a communication beam to be sent. That beam could be in the form of a laser or a directional millimeter wave W-LAN signal, capable of reaching multi-gigabytes per second [118], [119].

4.3.2.1. Non-Solas Ships

Sari (2017), in her dissertation, states that the unequal integration approach of the e-Navigation concept will divide ships into two tiers: Compliant ships and non-compliant ships. The author states that this is because the e-Navigation concept mostly focuses on utilizing the communication and navigation systems that SOLAS ships obligated to have, and does not correctly recognize the capabilities and needs non-SOLAS ships [120].

As SOLAS ships must be equipped with a broader array of communication and navigation systems than non-SOLAS ships, they can also utilize services that are not available to non-SOLAS users. Vice-versa is also possible as various services that could be provided explicitly for non-SOLAS ships may not be available to SOLAS ships [121].

Another important aspect of this two-tier approach is the safety of navigation. Problems rooting from the usage of different communication equipment on non-SOLAS and SOLAS ships may decrease the safety of navigation. Sari (2017) explains the possible advantages and disadvantages of utilizing different communication systems. One case is the usage of different classes of AIS transceivers onboard non-SOLAS (Class B AIS) and SOLAS ships (Class A AIS) which may cause VTS Centers and other ships not to properly receive the broadcasts made from these ships, which may lead to dangerous situations or even accidents [120].

Another case is the usage of satellite-based communication onboard SOLAS ships. With the aid of VDES and satellite-based digital communication, global and uninterrupted communication availability shall enable SOLAS ships to utilize e-Navigation services even in the open seas and harsh weather conditions. Non-SOLAS ships may not have such communication capabilities and therefore may not fully utilize e-Navigation services beyond the communication range of their equipment [120].

Sari (2017) foresees that there will be problems as the SOLAS ships will become the de-facto e-Navigation compliant ships while non-SOLAS ships will become the non-compliant ships. The author states that such a diversion (SOLAS/non-SOLAS) between ships will create inequalities and additional challenges for e-Navigation service providers and users [120]. It is logical to assume that non-SOLAS ships will not have reasons to adopt the costly and space consuming systems that are designed for the professional use onboard SOLAS ships by themselves any time soon and therefore users of non-SOLAS ships may adopt more cost-effective alternative specialized e-Navigation solutions that are suitable for their needs.

An (2016), in the paper named "E-navigation Services for Non-SOLAS Ships", states that the e-Navigation services for non-SOLAS ships shall be in the forms of decision-making support and robust communication of critical maritime information. The author also states that in order to increase the safety of navigation and utilize all benefits of e-Navigation concept has to offer for non-SOLAS ships, the services provided to non-SOLAS ships shall improve the poor navigational conditions that they usually navigate in [121].

The Republic of Korea houses various scientific studies on e-Navigation, and the Korean Ministry of Oceans and Fisheries launched the SMART Navigation project identify the current status, problems and possible solutions related with the provision of e-Navigation services to non-SOLAS ships [122]. The primary reason behind the Republic of Korea focusing in this particular field could be due to the fact that the 90 percent of the Korean fleet consists of non-SOLAS ships [121] while these non-SOLAS ships are also the majority of ships involving in maritime accidents under the Korean flag [123]. It is expected that the SMART Navigation project could reduce the total accidents of ships under the Korean flag by a combined 56.6 percent (13% of SOLAS ships and 43.6% of non-SOLAS ships) [124].

The SMART Navigation project was launched in 2013. The project aimed to identify the special needs of non-SOLAS ships in the IMO's e-Navigation concept, provide solutions to meet these needs and prevent accidents involving ships by increasing the overall safety of navigation for non-SOLAS ships by providing e-Navigation services to these ships [122].

However, some technical difficulties and barriers must be taken into consideration in order to successfully implement the SMART Navigation projects finding. As previously mentioned, there are different radio communication and navigation equipment carriage requirements between SOLAS and non-SOLAS ships. There are also different radio communication and navigation equipment carriage requirements between non-SOLAS ships, which could make the implementation process more complicated. Furthermore, non-SOLAS ships users tend to have a communication barrier, unlike the professionals working onboard SOLAS ships [121].

Therefore, the solution was to reduce the need for vocal radio communication and utilize digital communication technologies more; in order to establish proper communication between non-SOLAS and SOLAS ships. It was proposed in the SMART Navigation project to utilize a new, fast and robust digital communication technology onboard these non-SOLAS ships which enables them to access e-Navigation services. Long Term Evolution for Maritime (LTE-M) decided to be developed for this need [121].

Studies and field tests carried out on LTE-M communication prototypes show promising results. Figure 12 shows the results of a range, Reference Signals Received Power (RSRP) and throughput benchmark of the LTE-M communication in Korea, done in 2018. Depending on these results, the range of the LTE-M technology makes it suitable for the coastal use where most of the non-SOLAS ships navigate in. The LTE-M prototype network manages to keep its high throughput performance even in the ranges up to 100 kilometers by utilizing multi-cast and broadcast streams [121], [125].

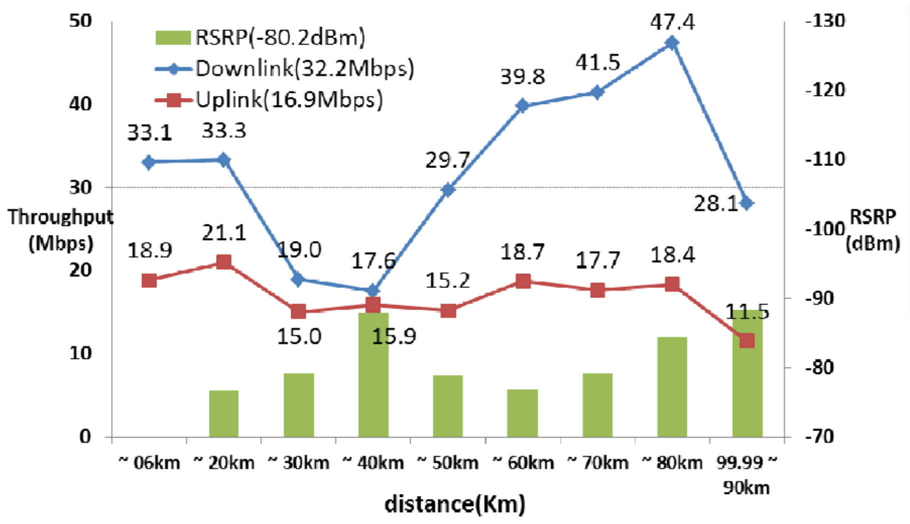

Figure 12. The results of a range, Reference Signals Received Power (RSRP) and throughput benchmark of the LTE-M communication in Korea, in 2018. Retrieved from [125].

These high throughput performances and range values can enable e-Navigation service providers to offer web-based (or application-based) services which can be streamed from shore. While there could be countless applications of these services, an example would be the small craft or fishing ship gaining the ability to see the tactical route of a large commercial vessel from the screen of their LTE-M enabled tablet and be warned in case of a close-approach situation, without the need of an ARPA Radar or AIS installed onboard. Another example would be the ENC updates being downloaded from any approved source simultaneously within the LTE-M network (like an ad-hoc source), rather than all users downloading them from a single source [121].

4.3.3. Maritime Connectivity Platform

The IMO e-Navigation SIP stresses the need for a CMDS to be used in order to mitigate compatibility, security and efficiency problems [26].

The first case of the need for or a CMDS arose from the communication problems between prototype e-Navigation testbeds and services. The first actual cases of issues were faced within the EfficienSea project and as a result, a prototype CMDS platform was created within the MONALISA project, which then was improved further within the ACCSEAS project. The final prototype platform was then named the “Maritime Cloud” [96].

As the number and scope of prototype e-Navigation services grew over time, the need for a globally harmonized and standardized means of data communication gained more importance [96], [126]. As a result, the Maritime Connectivity Development Forum (MCDF) was formed to govern the development of Maritime Cloud, design the organizational structure and harmonize the international standards on technical aspects of the platform through the utilization of international bodies such as International Organization for Standardization (ISO) and IEC [126].

Upon the beginning of EfficienSea 2 project, the name of the platform was changed to Maritime Connectivity Platform (MCP, formerly known as the Maritime Cloud) to clarify that the platform wasn’t a data storage solution but rather a connectivity platform, as the word “cloud” used in IT sector became more associated with online data storage services over the years.

Recently, the MCDF has been evolving into an international Maritime Connectivity Platform Consortium (MCC) [127]. Today; EfficienSea 2, STM Validation Project (MONALISA 2.0) and SMART-Navigation projects are actively utilizing and developing the MCP [127].

The MCP is established as [127]:

> *"An open source communication framework enabling efficient, secure, reliable and seamless electronic information exchange among all authorized maritime stakeholders across available communication systems."*

According to this definition; the scope of the MCP goes beyond the needs defined in the IMO e-Navigation SIP (needs mostly based on navigation and reporting related data and information exchange) and the EU e-Maritime initiative (needs mostly based on maritime administrations and business's information requirements). By definition, MCP is designed to meet all information exchange needs of all stakeholders across the entire maritime sector while respecting confidentiality by offering levels of user authorization and data security. Therefore, by definition, MCP has the potential to become "the ultimate single window" to be used globally by the maritime sector [127].

The vision of the MCP is to become the reliable, non-biased, transparent and open source powered de-facto maritime information exchange platform. MCP aims to [127];

i. Increase overall safety and efficiency of the maritime sector,
ii. Utilize existing and successfully applied international standards and communication technologies of the maritime sector in order to provide the best cost-efficient service and most efficient use of available bandwidth,

iii. Develop guidelines on developing and improving the quality of commercial and non-profit software, especially regarding concerns over information confidentiality and authenticity verification, and
iv. To be recognized (and also governed and supported) by important organizations of the maritime sector, such as IMO, IALA, IHO, etc.

Currently, MCP has three different core components [126]:

i. Maritime Service Registry,
ii. Maritime Identity Registry, and
iii. Maritime Messaging Service.

The Maritime Service Registry (MSR) is a tool to manage the technical services that could be provided by projects and organizations, such as the proposed e-Navigation services. Management role of the MSR database can be distributed between the authorities and recognized non-governmental organizations (such as Classification Societies). The Maritime Identity Registry (MIR) enables the authentication of information and identity of the maritime stakeholders in an attempt to solve the issues regarding the information security and confidentiality [127].

Any service providers or hosts seeking to use the MCP needs to register their services to the MSR and provide detailed information on the technical aspects of their services to be accepted. Service providers or hosts can add maritime identities (such as ships) and users of their services to MSR database only once their identity is approved and authenticated by relevant authorities [127], [128].

A digital Public Key Infrastructure (PKI) is adopted to establish and maintain a trustworthy network environment within the MCP. The role of digital public keys is vital as a Certificate Authority can only issue them and they prove that any requested information is provided by an authenticated user (the digital PKI holder). An example would be the remote checking of a ship's certificates by a Port Authority: The Master or an officer onboard a ship can sign the issued ship certificates with his/her PKI to state the conformity of the certificates with the ship and regulations, while a Port State Control inspector could acknowledge the validity of these certificates, without the need of any physical copies of the mentioned ship certificates [128].

MCP inherits an authorization system which is based on the availability of permissions. After successful authentication, the abilities that the user is authorized to access is permitted. In other words, there is hierarchical permission deployed within the MCP system which allows users abilities regarding their authorization levels. For example, while authorities (such as VTS, Port State or Flag State administrations) may have full access (read, write, change, add, delete, etc.) to the MCP, a service provider (such as a maritime business) could have limited access to MCP but full access within their own domain and a regular user (a ship) may only access read-only information (such as weather forecasts) [127], [128].

There are several cryptography, privacy and data security technologies (which are proven their reliability and efficiency, adopted industry-wide, and also used by IT giants such as Microsoft and Google) considered to be used within the MCP infrastructure. Full technical details of the MCP are still not clear today [128] and therefore will not be included in this thesis.

MCP portal is currently in a beta test phase. This means that MCP is open to development and requires further research to reach a more stable and mature state that is suitable for international use cases [127].

4.3.4. Automated FAL Reporting

One of the first international conventions developed by IMO was the FAL Convention, in 1965. FAL convention successfully reduced the paperwork required to enter, to navigate in and to leave any sovereign nations' waters by harmonizing and unifying the possible different requirements, procedures, standards and formats that were enforced by different nations [129]. The 4^{th} amendment made to the FAL Convention, which entered into force in 2018, states that electronic exchange of information via a digital Single Window will be mandatory within 12 months from April 2019 [129]. This mandatory application of digital Single Window could have an unprecedented effect on the maritime industry: Modern digital Single Window applications such as SafeSeaNet (Norwegian Single Window reporting solution) already reduced the paperwork considerably; over 245.000 forms were automatically reported (equivalent of 1 year manual work of 140 full-time workers) in 2013 alone [96].

Second prioritized solution within the e-Navigation SIP (S2) states that there shall be a means for standardized and automated reporting within e-Navigation structure; including automated collection of internal ship data for reporting and documents representation using Single Window mode and harmonized national reporting requirements to apply standardized digital reporting formats based on internationally recognized standards to be developed by IMO [26]. This automated reporting envisioned to be done in the form of Automated FAL Reporting [96].

Similar to MCP, a proven authentication and cryptography system (Rivest–Shamir–Adleman [RSA]) will be in place within the Automated FAL Reporting network. Any entity in the network (equipment, users, businesses, service providers, authorities, etc.) will be authenticated via the usage of digital certificates. Authorized users such as authorities will have the ability to issue, control and revoke those digital certificates. Networks will be designed to work with online and offline entities, a necessary feature for incorporating ships into the network [130].

One of the first prototypes of such network structure was produced within the ACCSEAS project. While it was a fundamental testing environment, it provided valuable insight know-how on setting up such a network between e-Navigation testbeds [96]. MONALISA and EfficienSea projects further developed the prototype network. EfficienSea 2 project launched to develop a global maritime communication network (e.g., MCP) which will include automated reporting functions [29], [131].

EfficienSea 2 project held a meeting with a High-Level User Group (HLUG) consisting of the representatives of ship owners, business associations, ports, service providers, authorities, maritime organizations and developers of maritime equipment to identify user needs of a proposed automated reporting network [132]. In the HLUG meeting, the Baltic and International Maritime Council (BIMCO) presented five different scenarios which the automated reporting network could be used for [132]:

i. Scenario 1: Exchange of information between ship and port,
ii. Scenario 2: Port information for fine-tuning the voyage plan,
iii. Scenario 3: Seafarers' licenses and STCW documents,

iv. Scenario 4: Coordinating the port call, and
v. Scenario 5: Emissions information shared with authorities, ports and potential third parties.

After careful consideration and inputs from all HLUG representatives, the “Scenario 1 Exchange of information between ship and port” was accepted as the first priority for the future work of the EfficienSea 2 project in an attempt to increase automated reporting capabilities. HLUG states that there are two options for how Scenario 1 can be realized [132]:

i. Defining automated reporting network standards and waiting for maritime stakeholders to adopt these standards, and
ii. Setting up an actual service (an automated reporting network with communications systems, databases, etc.) and trying to commercialize it.

It could be argued that the struggle of MCP to be accepted by international maritime authorities and way that the e-Navigation SIP manages the automated reporting systems could require a mixed method to be developed: Similar to the history of INMARSAT; an international non-profit body could be founded to solely define standards and operate an international automated single window reporting system; to be privatized later in order to bring profits and offer more services that suit the needs of all users.

4.4. Environmental Protection

The e-Navigation concept can directly contribute to the pollution prevention effort. Integrated e-Navigation capable systems onboard a ship could report the data on exhaust emissions and fuel consumption that is gathered directly from the sensors of engines, auxiliaries and other power-generation systems. This data can be stored inside an e-Navigation network (such as MCP) and then could be transferred to relevant users and authorities ashore in real-time, in fixed-intervals or even on-demand.

Such an application would not only be useful for enforcing international and national regulations on ships. The reporting format could be widened to include detailed information on the status of onboard propulsion and navigation systems and therefore could also be used for many different purposes. Data generated in real-life operating conditions can be valuable to manufacturers for bettering their engine and ship designs. Ship-operators can also vastly benefit from such information, as abnormal emissions could be early signs of deteriorating or failing systems such information can give companies the valuable time to react proactively, which can make diagnosing malfunctions easier and repairs less costly.

Services provided within the e-Navigation concept -such as Dynamic Route Optimization- may also help reducing emissions by reducing overall fuel consumption and increasing fuel consumption efficiency. IMO MEPC published a study named “Opportunities for Reducing Greenhouse Gas (GHG) Emissions from Ships” in 2008. Study shows that it is possible to reduce the GHG emissions by reducing or optimizing fuel consumption of ships. The report of the study explains the technological and operational measures to reduce the GHG (such as NO_x, N_2O, CO, CO_2) and Particulate Matter (PM) emissions from ships while evaluating different methods for reducing fuel consumption. The part of the report on operational measures states that slow-steaming and better ship routing can decrease fuel consumption and related costs and emissions by a considerably significant margin [63]. The report states that; for large commercial ships, a 10% reduction in a ships speed is assumed to reduce fuel consumption, GHG emissions and PM emissions by 23%, on average. On the other hand, a 34% reduction in the speed of a ship is assumed to reduce fuel consumption, GHG emissions and PM emissions by 57%, on average. Apart from speed reduction, weather routing and dynamic route optimization are estimated to further reduce the overall fuel consumption, GHG and PM emissions of a ship cumulatively up to 9%. According to the findings of the study, it is possible to reduce the GHG and PM emissions from ships up to a cumulative extend of 66% [63]. However, sustainability of such methods is not investigated in this study. For the adoption of such methods in the shipping industry, it is an important aspect to be investigated.

Andersson and Ivehammar (2016), in their study “Cost-Benefit Analysis of Dynamic Route Planning at Sea”, investigated the effects of dynamic route management and slow steaming on ships’ fuel consumption and environmental pollution, in the Baltic Sea and the North Sea. In the study, the AIS data of 3.055 ships (which was gathered in a 72-hour period) that are over 60 meters and 300GT is evaluated. It is stated that a plausible reduction of a 1% in the total voyage distances of ships by utilizing the Dynamic Route Planning (a proposed dynamic route optimization system within the MONALISA project) system would have reduced the total fuel consumption and related emissions by about 3%. It is stated that this 3% reduction in total fuel consumption would have annually saved 28 million Euros in the form of reduced fuel costs and another 52 million Euros as the benefits to society in the form of reduced air and water pollution. The study stresses that an annual total of 80 million Euros of benefits derived from implementing the dynamic route optimization service is more than five times of the total cost of the said service (which is estimated to be around 15 million Euros annually) [104]. This finding is particularly important as it shows that the route optimization applications can be effective tools to reduce emissions from ships and total benefits of route optimization applications can actually surpass their costs.

Primary aims of the e-Navigation concept include improving navigational safety, increasing efficiency and providing easier access to information. It envisioned that the e-Navigation concept shall help better protection of the environment by introducing advanced navigation and communication systems that can help ships and authorities prevent maritime accidents. Number of navigational accidents can be further reduced with the aid of highly precise navigation systems, high-speed digital communication systems and intelligent decision-making support systems. Preventing maritime accidents reduces the risks of environmental pollution ships can cause [9].

To sum up; e-Navigation concept can provide the means and tools to protect the environment by integrating existing systems and future technologies in a way that would enable controlling maritime pollution at its source while also providing cost-reductions and increased reliability in shipping operations.

CHAPTER 5

BENEFITS OF THE E-MARITIME CONCEPT

Many maritime practices, procedures and regulations are still based on maritime law that was adopted decades ago when ICT were not as widespread and capable as they are today. As a result, paper-based communication and paperwork are still widely used in maritime information exchange today [3].

The main objective of the EU's e-Maritime concept is to increase the efficiency of maritime businesses and administrations by utilizing advanced ICT. Successfully implementing modern ICT applications (in both technology and legislative means) to the maritime industry is imperative for reaching the EU's e-Maritime objectives [3], [74], [133, Ch. 7].

Possible benefits of the EU's e-Maritime concept and some of the possible ICT applications within the concept will be explored in the following subchapters.

5.1. Connected, Automated and Optimized Maritime Transportation

Digitalization and modern ICT applications in the maritime industry shall enable new and better services to be provided to a larger portion of the actors of the industry. Such services promise to reduce the costs related to ships' energy and fuel consumption, performance and monitoring by offering optimization and automation of onboard operations. As atmosphere, seas and all living beings in them are being adversely affected by the pollution created as a result of maritime transportation activities; the benefits of such optimization services are particularly important as they not only provide economic savings, they also indirectly help to reduce the anthropogenic effects to the environment [74].

High-speed information exchange (especially from and to ships) ability with the adoption of advanced ICT systems can affect the entire EU maritime industry. Masters and officers onboard ships can save the time and energy that spend for preparing and sending repetitive reports to multiple administrations and businesses as the preparation, retrieval and approval of such reports can be instantaneous and automated [74].

Ports, factories and all other stakeholders of the European logistic chain could adjust their schedules and stocks for precise and continuous timing estimations effortlessly exchanged between all actors involved. Such abilities shall reduce the time and resources wasted for ensuring the uninterrupted flow of goods in logistic chains and therefore increase efficiency, profitability and effectiveness of environmental protection measures [74].

Modernization of old communication technologies onboard ships and systems by maritime administrations could provide instant access to correct and comprehensive information in time-critical situations; while modernized equipment and technology could also provide additional protection against cybersecurity threats [74].

Large amounts of data and information collected from ships could be used to early identification of problems with ships. For example, sensors and monitoring technologies that continuously monitor every single system and integrity of the ship can give reports on weak points and malfunctioning parts of systems. The ability to get and analyze such precise information from ships can pinpoint the parts of systems are about to fail and could prevent more prominent problems that may cause more costs, more delays and more damages. Such ability also could change the practice of mandate of fixed-time periods for dry docking and allow flexibility which could further reduce the costs of operating a ship [74].

5.2. European Maritime Single Window and Paperless Ships

The EU's e-Maritime concept promotes the efficient use of modern ICT systems to reduce the administrative burden on the maritime industry. In this aim, there are several modern ICT solutions already applied that provide benefits that paper-based systems cannot. For example; automated declaration and verification of ship reports and certificates via utilizing digital communication technologies is possible and has been widely adopted [3].

There were several research and development efforts already done within the EU's e-Maritime concept to develop a Single Window application and eMAR project was one of them [80]. The eMAR project resulted in the EMSF and a prototype Single Window gateway called "i-Ship" [82].

The EMSF is particularly crucial as it defines the processes, actors, rules, information flows, domain entities within the EU's e-Maritime concept and recommends standards, policies and technologies for meeting information exchange requirements of the EP Directive 2010/65/EU on "Reporting formalities for ships arriving in and/or departing from ports of the Member States" [73], [82]. As the goal of the EP Directive 2010/65/EU was to establish National Single Window applications throughout the EU until 1st June 2015; the EMSF's primary purpose was to serve as a reference domain which was designed to guide the EU Member States in the process of establishing their own Single Window applications [73], [79], [82].

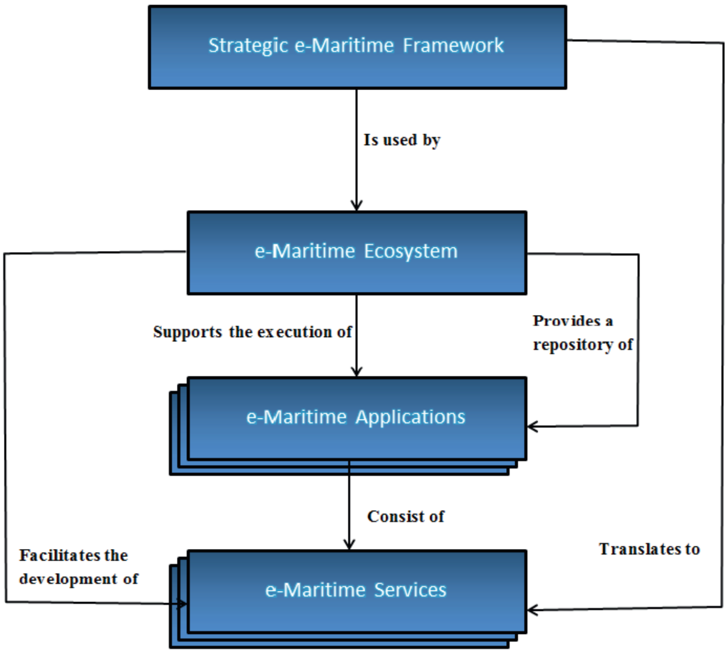

Figure 13. The relationship between EMSF and e-Maritime ecosystem, applications and services. Retrieved from [73].

Another output of the eMAR project was the i-Ship gateway, which was an essential step on the road ultimately leading to paperless ships. The i-Ship gateway is capable of automatic exchange of large amounts of maritime related information and data that is compatible with formats required by the EU directives and international regulations. The i-Ship gateway is compatible with other Single Window systems outside (such as e-NOA of USA and e-PANS of Singapore) and inside of EU. [82].

Even though it was enforced by the directives of EP for the Member States to adopt a National Single Window until June 2015, the actual adoption and implementation of such systems have been relatively low [134].

Therefore, there is still much paperwork occurring between the actors of the European maritime industry that could be digitalized and automated in the future. Detailed information on cargo (physical properties of cargo itself, status of cargo handling systems, etc.), propulsion systems (status of engines, auxiliaries, fuel consumption etc.), storages (bilge, sludge and other oily waters) and crew (working & resting hours, health status, training, etc.) can be automatically transmitted from ships to administrations and businesses. Administrations can automatically control the data and information gathered from ships for enforcing compliance with national and international regulations [74].

As Weintrit (2016) states, a global grassroots movement of the maritime industry would show that the e-Navigation concept is embraced by the industry [3]. Perhaps; a similar movement is needed in the EU maritime industry to embrace the e-Maritime concept, as well.

CHAPTER 6

DEVELOPMENTS REGARDING THE E-NAVIGATION AND E-MARITIME CONCEPTS IN TURKEY

6.1. National Strategies and Policies of Turkey on Maritime Intelligent Transportation Systems

The Action Plan for Medium Term Program for 2012-2014, assigned the Ministry of Transport, Maritime Affairs and Communications (together with other relevant institutions) to prepare the National Intelligent Transportation Systems (ITS) Strategy Document. In order to create a roadmap for the National ITS Strategy Document, a workshop was held with the participation of all stakeholders in 2012 and the results of this workshop were reflected in the National ITS Strategy Document [135].

In 2014, the Ministry of Transport, Maritime Affairs and Communications published the National ITS Strategy Document and Action Plan. The National ITS Strategy Document and Action Plan states that there was a need for comprehensive planning and setting overarching standards to rapidly spread the ITS applications in all transport modes in Turkey, and the National ITS Strategy Document and Action Plan was established as a result of this need [135].

In its current form, the National ITS Strategy Document and Action Plan largely covers ITS applications on land transportation. However, the National ITS Strategy Document and Action Plan states that the international maritime and air transportation industries have already been utilizing ITS solutions and also recognizes that these well-established and widely used ITS solutions in the international maritime and air transportation are results of the international regulations and standards [135].

In 2013, The Ministry of Transport, Maritime Affairs and Communications[6] of Turkey declared the 2023 and 2035 Goals on Maritime Transportation and Management. One of the 2035 Goals is the promotion and development of the Maritime ITS infrastructure, applications and support services. It is stated that supporting the development and investment in the Maritime ITS field is especially important as it would enable Turkey to modernize its existing maritime digital information and communication infrastructure, keep the balance on the intermodal transport, increase the overall safety of navigation, reduce the environmental impact of maritime industry, create opportunities to invest on the maritime research and development, and increase the regional co-operation [7].

In 2015, the Ministry of Transport, Maritime Affairs and Communications published the Transportation Strategy Plan for 2015. The plan included the goal number *DZY2015-1-06* on the "Development of e-Navigation Systems" which aims the development of the national e-Navigation standards and infrastructure. It is stated that the same vision with IMO's e-Navigation concept is shared within the vision of this goal. The primary aim of this goal is the development of the critical national research and development capabilities on the Maritime ITS concept, which shall lay out the foundation for the development of e-Navigation systems. Interconnected e-Navigation capable VTS systems and e-Navigation applications as Tactical Route Exchange and advanced digital communication capabilities between ships and shore stations are other expected results of this goal [6].

[6] The new name of the ministry is *"The Ministry of Transport and Infrastructure",* since 2018.

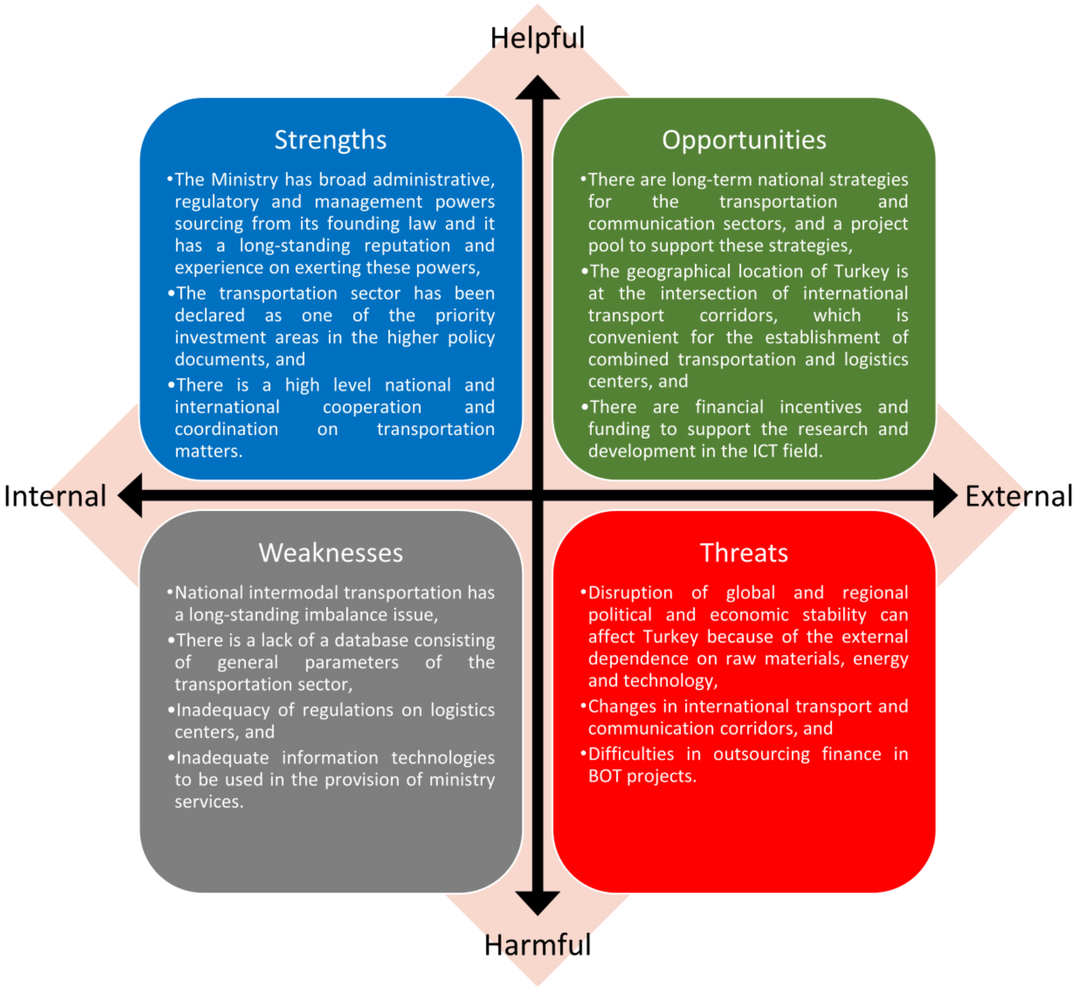

Figure 14. The summary of the SWOT Analysis published in the 2017-2021 Strategic Plan, analyzing the Ministry of Transportation and Infrastructure and transportation in Turkey. Adapted from [136].

In 2017, the Ministry of Transport, Maritime Affairs and Communications published the 2017-2021 Strategic Plan. The 2017-2021 Strategic Plan states that preserving the position of Turkey on the White List of the Paris Memorandum of Understanding on Port State Control, which is considered as an indicator of reliability in maritime transport, is a policy objective [136]. The 2017-2021 Strategic Plan also included a SWOT analysis of the present state of the Ministry and transportation in Turkey [136]. The results of the SWOT analysis are summarized in Figure 14.

The 2017-2021 Strategic Plan establishes several goals that are related to the scopes of the IMO's e-Navigation and EU's e-Maritime concepts; including digitalization, research and development, international co-operation and national capacity building. Goal A1 on the research and development states that Turkey shall develop international cooperation with EU countries, neighboring countries and Developing Eight (D8) countries. Goal A4 on research and development states that Turkey shall promote the production of transport, maritime, communication and space technologies by creating a culture of domestic and national production based on innovation. The aim H4.2 specifically states that promoting and universalizing the production of transport, maritime, electronic communications, aviation and space technologies with national resources is one of the priorities in the strategic plan. Goal A5 on digitalization states that integration and harmonization technologies shall be facilitated for easier information exchange and communication with other institutions and organizations. "The National Maritime Trade Information System" shall be established in order to provide accurate predictions to the sector with timely and accurate analysis in maritime trade. The system shall also collect, organize and analyze the Big Data, and results shall be utilized in the strategy development and decision support processes [136].

Turkish Directorate General of Coastal Safety (DGCS) is an authority (operating under the Ministry of Transport and Infrastructure) that provides the necessary infrastructure and services to ensure the safety of navigation of all ships navigating in Turkish waters, in compliance with national and international law. Turkish DGCS have an IMO Delegation Membership and IALA Council Membership regarding this duty. Turkish DGCS carries the responsibility to build, provide, manage and audit the infrastructure and equipment involved in the monitoring and management of the maritime traffic. Turkish DGCS operates through seven main branches which include the Turkish VTS [137].

DGCS declared its 2016-2020 Strategic Plan in 2016. The plan includes several goals in the scopes of the IMO's e-Navigation and EU's e-Maritime concepts. Goal H1.2 on improving the effectiveness of maritime communication services states that the number of VHF stations and equipment shall be increased until 2018 to ensure undisrupted availability of the IP based maritime communication services. Goal H1.3 on improving vessel traffic and guidance services state that VTS systems shall be modernized and equipped with broader capabilities until 2018 (This project has been extended to be completed until 2020 [138], [139]). The Goal H1.5 on improving AtoN service quality states that on top of the 140 already modernized AtoNs, 140 more AtoNs shall be modernized until 2020 [140].

6.2. The Turkish VTS System

Today, there are about 500 VTS systems in 50 countries. Turkey has a total of 5 VTS systems, namely; the Turkish Straits VTS system, the Izmit VTS system, the Izmir VTS system, the Mersin VTS system and the Emergency Backup VTS system. All these VTS systems are connected to the Vessel Traffic Management Center (VTMC) in Ankara by direct lines and internet connection. There are also backup lines for emergency uses [141], [142]. The connections between Turkish VTMC and VTS systems are shown in Figure 15.

Today, the Turkish Straits VTS system is one of the largest VTS systems in the world, especially considering the size of the managed area, amount of traffic and number of the utilized equipment. The Turkish Straits VTS system manages the maritime traffic in the Istanbul Strait, Marmara Sea, and Çanakkale Strait utilizing 16 unmanned Traffic Monitoring Stations that span across 165 nautical miles of seaways [137], [141]. The Izmit VTS system consists of 1 VTS Center and 4 Traffic

Monitoring Stations and it has been operational since 2016. The Izmir VTS system consists of 1 VTS Center and 12 Traffic Monitoring Stations and it has been operational since 2017. The Mersin VTS system consists of 1 VTS Center and 8 Traffic Monitoring Stations and it has been operational since 2018 [141].

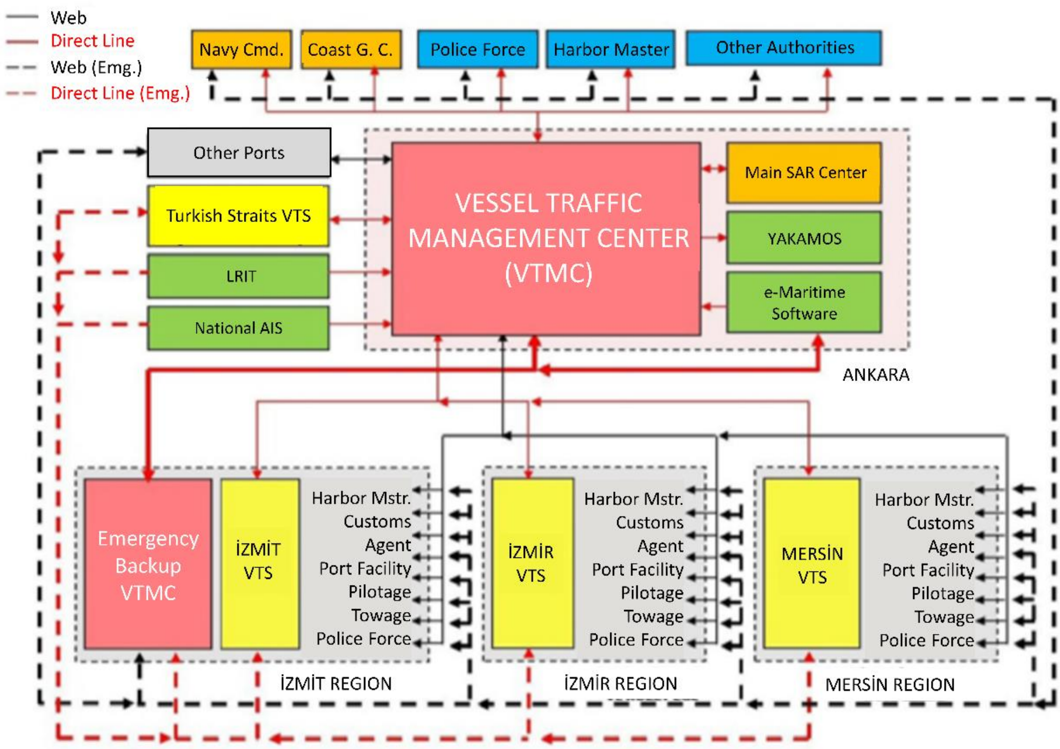

Figure 15. Schematic is showing the information flow between the Turkish VTMC, Turkish Straits VTS and other regional VTS centers, Turkish Navy and other national authorities. Translated from [141].

IMO's e-Navigation and EU's e-Maritime concepts shall utilize the existing AIS, the proposed VDES and similar future terrestrial radio based digital communication technologies for robust, fast and cost-effective digital communication between ships for exchanging navigational data and between ships and shore stations for exchanging information [74].

Today, over 30 AIS base stations [143], [144] and a total of 396 AIS equipped "Aids to Navigation" (AtoNs) (out of a total of all 611 AtoNs) work in conjunction with VTS Centers and cover all coastal waters of Turkey Centers [137]. There is already a network linking all the AIS-AtoNs which provide the ability to access and manage all AIS-AtoNs configuration from a Single Window [143]. Furthermore, it is stated that all AtoNs in Turkish waters are *e-Navigation ready* and meet the IALA specifications by operating at a service availability rate of 99.84% [137].

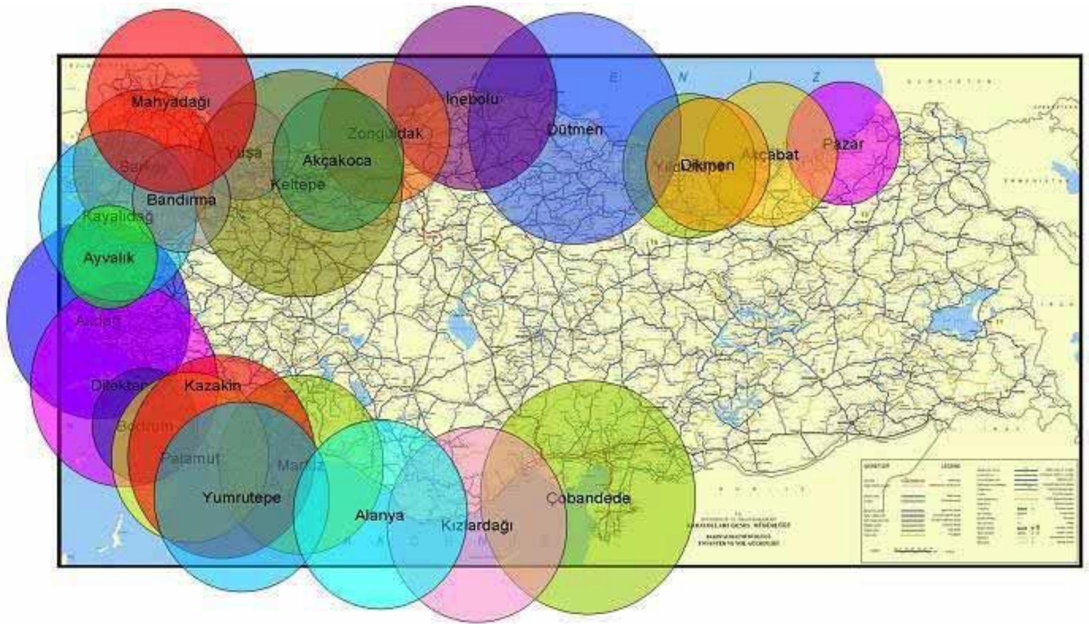

Figure 16. A visualization of the Turkish AIS network and its coverage area. Retrieved from [143].

Over 200 operators interact with the AtoN network through the Main Control Center located at DGCS Center in Istanbul. AtoNs are connected to a central server in the DGCS, utilizing the GPRS and DSL communication technologies. GPRS connections are the primary method of communication between servers and AtoNs while DSL serves as the backup. The central server gathers and exchanges data on maritime traffic monitoring and evaluation, and controls the configurations and functions of the AtoNs. All data in the AtoN network is exchanged through the utilization of the VDL and AIS data channels, as addressed binary messages or infrequent broadcast/addressed single slot binary messages [145]. As stated in the DGCS's 2016-2020 Strategic Plan Goal H1.5 on improving AtoN service quality, the modernization process of the older AtoNs in the network is already underway. [140]

6.2.1. The Turkish Straits VTS System

Located in the heart of Istanbul, the most populated city of Turkey and one of the most populated cities in the world [146], the Istanbul Strait is the most critical natural narrow waterway in the world [5]. Istanbul Strait, together with the Çanakkale Strait and the Marmara Sea form the Turkish Straits. Turkish Straits are the only natural waterway between the Black Sea and the Mediterranean Sea [5].

The Turkish Straits play a unique role in the marine life of the region. The Black Sea receives big rivers and a large amount of rain input that supplies fresh water into the surface of the basin. Brackish and nutrient-rich surface waters of the Black Sea pass the Istanbul Strait and flow into the upper layer of the Marmara Sea (See Figure 17), which would then continue to flow towards the Mediterranean Sea through the Çanakkale Strait. The nutrient input to the upper layers of the Turkish Straits and the Marmara Sea enables several marine species to do photosynthetic primary production. This energy then can be transported to the different trophic levels of other living consumers and decomposers, and therefore can increase the demand for oxygen in the region. On the other end of the Turkish Straits, the salty (denser) deep waters coming from the Mediterranean Sea passes through the Çanakkale Strait into the deep layer of the Marmara Sea, which would then continue flowing through the Istanbul Strait.

Figure 17. The satellite view of the Istanbul Strait is showing the southerly currents in the upper layer. Retrieved from [147].

When this deep layer flow reaches the Black Sea, it continues to flow over the continental shelf and continental slope forming a kind of waterfall. This is particularly important as lower layer flow coming from the Mediterranean Sea prevents the depletion of oxygen and suffocation of oxygen-consuming marine species in the lower layer of the Turkish Straits [148]. Therefore; it could be said that the Turkish Straits are quite vital from the ecological perspective and ensures the continuum of the marine life in the region.

It could be said that the unique location of the Turkish Straits gives it a critical ecological, economic and political status which affects the Black Sea and Mediterranean region. Therefore, any serious threat emanating from a maritime accident could lead to large scale issues such as polluting and damaging the ecosystem of the Turkish Straits and the ecological balance of the surrounding regions, blocking the passage of ships and stopping the maritime transportation in the region, and even putting the lives and well-being of the surrounding populous in danger [5].

To increase the navigational safety in the Turkish Straits and manage the risks coupled with ever-increasing size of commercial vessels and density of the maritime traffic; Turkey invested into a multi-million dollar project called "The Turkish Straits Vessel Traffic Management and Information System Project"[7] to build a VTS system that met the IALA Recommendations, in 2000 [149], [150]. This VTS system was the first ever deployed in Turkey and provided Turkish authorities the ability to monitor and manage the maritime traffic continuously utilizing electronic navigational and communication aids, and coordinate the emergency response in the Turkish Straits [150]. In 2003, the Turkish Straits VTS began its operation and reached full operational capability at the beginning of 2004 [151].

The size of commercial vessels kept growing dramatically throughout the first two decades of the 21st century. Today, commercial vessels have reached massive proportions in terms of size and cargo holding capacities. For example, one of the

[7] The TÜRBO Project.

largest container ships ever built at the time of writing, the *OOCL Hong Kong*, broke the 21.000 TEU mark by the year of 2017. At the beginning of the millennium, the largest container ship ever constructed had less than half of the cargo holding capacity of OOCL Hong Kong [152].

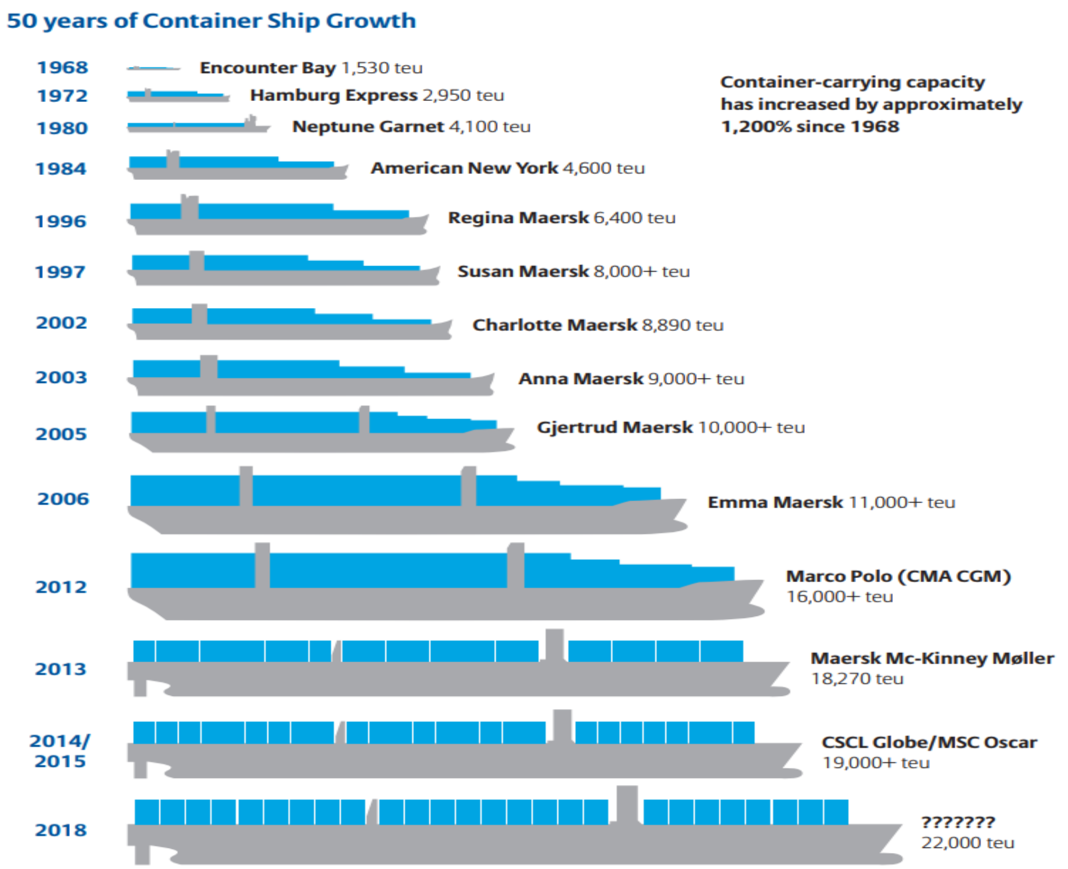

Figure 18. From 1968 to present: Carrying capacity of the largest container ship increased approximately 12-fold over 50 years, reaching 21,000+ TEUs. Retrieved from [153].

As a result of this dramatical increase in vessel sizes and increasing vessel traffic volume, the Turkish Straits VTS system needed to be further upgraded. At the time of writing, the Turkish Straits VTS system is undergoing a modernization upgrade which will advance the technology and equipment used on par with the state of the art vessel tracking, decision-making and support technologies; including advanced risk assessment systems (which shall automatically calculate the risks for each vessel using information on the type, age, size, flag, cargo of the ship and the accident, malfunction and violations that each individual vessel had involved in the last 6 months; for all ships in the Turkish Straits VTS area) and portable simulator systems for training purposes [8], [139]. The modernization upgrade process was started in 2017 and is planned to be completed until 2020 [138], [139].

6.3. Single Window Applications and Online Services

The Ministry of Transportation and Infrastructure has been developing and providing software-based solutions and services in the maritime industry. The Ministry of Transportation and Infrastructure currently operates a Single Window system which has been branded as "The e-Maritime System". The e-Maritime System in Turkey is the whole set of projects which are developed to regulate national and international maritime activities and related certification, information and monitoring operations in the electronic environment [8].

The e-Maritime System (and its subsystems) in Turkey is interconnected with the systems and e-services of other authorities in Turkey, which provides time and cost efficiency. The external e-Services, systems and projects that the e-Maritime system is connected are as follows [136]:

i. Amateur Maritime and Short Distance Radio Operator Exams,
ii. Coasting Information System,
iii. Criminal Information System,

iv. e-Collection Project,
v. Electronic Certificate System for Ships,
vi. Flag and Binding Log Operations,
vii. Guidance Information System,
viii. Management Information System,
ix. Maritime Accidents Information System,
x. Piracy Information System,
xi. Port Information Sharing System,
xii. Port Management Information System,
xiii. Port Operations Basic Information System,
xiv. Property Survey Information System,
xv. SCT-Free Fuel Information System,
xvi. Sea Line Application System,
xvii. Seafarer Certificate and Document Verification System,
xviii. Seafarer Information System,
xix. Seafarer Qualification Exams,
xx. Seafarer Training System,
xxi. Ship Agencies Registration and Information System,
xxii. Ship Name Registration and Information System,
xxiii. Ship Name Requisition System,
xxiv. Tonnage Operations,
xxv. Transit Log Operations, and
xxvi. Maritime Industry Database Information System.

There are several web-based *e-Services* directly provided by the Ministry of Transport and Infrastructure and DGCS. Most of these e-Services are open to the public and are related with the safety of navigation and management of maritime traffic in the Turkish Straits, the ship reporting regulations and applications, the services provided by the Turkish Straits VTS Center and the application and control of seamen and ship certificates. The e-Services related with the safety of navigation include (but not limited to) the broadcast of opening and closing hours (for transit maritime traffic) of the Turkish Straits, information on ships to sail across the Turkish Straits, safety information and NAVTEX broadcasts, weather, sea and tidal status in the Turkish Straits. All of the e-Services above are publicly accessible except the e-Services regarding ship reporting requirements which are only accessible by the authorized actors of the maritime industry [154].

The Ministry of Transport and Infrastructure utilizes the Enterprise Service Bus (ESB) for the harmonization of information between the e-Maritime System, its applications and externally connected e-Services, systems and projects mentioned above. The ESB enables management of clustered and different applications of the e-Maritime System from a Single Window. Furthermore, the ESB also converts requested data to related format to enable different systems to communicate and exchange information with each other [8]. It could be argued that the "e-Maritime System" of Turkish Ministry of Transportation and Infrastructure is a national Single Window application which works similarly with the MCP of the e-Navigation concept and the i-Ship gateway (which was developed within the eMAR project) of the e-Maritime concept.

Turkey utilizes the "Port Single Window (PSW) System" since 2018. The PSW system enables pre-arrival and pre-departure operations (such as reporting, information exchange, data requisition and gathering, authorization, etc.) made with the relevant authorities within the Ministry of Transportation and Infrastructure, Ministry of Interior, Ministry of Health, Ministry of Commerce and Ministry of Environment and Urbanization to be easily accessed, managed and viewed from a single window. PSW provides increased safety and efficiency in the maritime industry via the elimination of unnecessary delays and paperwork [141].

6.4. Compliance with IMO Conventions

Aydogdu et al. (2014) refer to the legal aspect of the implementation of e-Navigation and e-Maritime concepts in Turkey. Authors state that while Turkey has been continuously improving its technological and technical capacities regarding the e-Navigation and e-Maritime concepts on par with the modern world, yet little had been done on the legal front for the implementation of international regulations and standards on these concepts to the national law regarding maritime matters [155]. However, remarkable developments were achieved in this front since 2014.

Akpinar (2014), in their expertise thesis, stated that Turkey voluntarily requested to be audited by IMO in 2009, in order to reveal the status of the harmonization of the Turkish National Law and legal system with the IMO legislations, applications and regulatory systems. Four years later, in 2013, the Voluntary IMO Member State Audit Scheme (VIMSAS) was carried out in Turkey [156]. The author states that Turkey successfully completed the 2013 VIMSAS audit and as a result improved its status in the *White List* of the Paris Memorandum of Understanding (MoU) on Port State Control (PSC) [156]. As a result of this development, the frequency of PSCs on commercial ships carrying the Turkish flag was relaxed up to once in 36 months; which was carried out once between 6 to 12 months before.

Improving the status in the *White List* was particularly important [8] as it was the result of the policy of Turkey on strictly enforcing international regulations and

[8] The *White List* of the Paris MoU on PSC represents quality flags with a consistently low detention record [166]. As ships carrying the flags of nations in the Grey or Black List cannot enter the ports of the 27 Member States of the Paris MoU on PSC, being in the White List of the Paris MoU on PSC is advantageous for Turkey [141].

national law on its fleet [141]. At the time of writing, Turkey is still in the *White List* of the Paris MoU on PSC.

The 2013 VIMSAS audit in Turkey covered a vast range of benchmarks and audits which included the matters related to the safety of navigation as well as compliance with the IMO'S international agreements, regulations and recommendations [156], [157]. Turkey audited for compliance with the mandatory requirements of the following international IMO treaties [157]:

i. The International Convention for the Safety of Life at Sea, 1974, as amended (SOLAS 1974);
ii. The International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978, as amended (MARPOL 73/78, Annexes I, II, and V);
iii. The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers 1978, as amended (STCW 1978);
iv. The International Convention on Load Lines, 1966 (LL 66) and the Protocol of 1988 relating to the International Convention on Loadlines, 1966;
v. The International Convention on Tonnage Measurement of Ships, 1969 (Tonnage 1969); and
vi. The Convention on the International Regulations for Preventing Collisions at Sea, 1972, as amended (COLREG 1972).

The final report on the 2013 VIMSAS audit includes the findings on the Turkish legal framework [157]:

> *"Turkey has made a lot of efforts since 2011 when the Ministry of Transport, Maritime Affairs and Communication was established and the maritime administrative framework was completely reorganized. A number of important instruments were implemented in this period of time and the effort made is recognized by the audit team. However, it also was found that a number of circulars and guidelines were only adopted and published within the last few weeks and days prior to the audit. As such it was not fully possible for the audit team to verify the effectiveness of the implementation of the newly adopted guidelines."*

Esenli (2018), states that IMO treaties, circulars and guidelines, and resolutions of the MSC and MEPC committees were implemented prior to the 2013 VIMSAS audit, but later, the execution process was sub-optimal. The author states that there are several amendments on IMO treaties that are needed to be incorporated to the Turkish national legislation on maritime. The author also states that the Ministry of Transport and Infrastructure has primary responsibility in the process of implementing the amendments of international IMO treaties to national legislation and follow-up of the changes, review, evaluation, translation, legalization, the approval process of the international legislation should be carried out by the Ministry. Additionally, the author states that this issue can be solved by allocating specialized experts in this field and by establishing a separate division under the Ministry that is founded specifically and solely for the incorporation of IMO treaties, regulations, protocols, amendments, resolutions and circulars to the national legislation [158].

Esenli (2018), states the amendments to IMO regulations are accepted according to the *Implied Consent* procedure and are tried to be applied by the Ministry and the

Recognized Organizations in practice, ahead of the actual implementation of the amendments to the national legislation [158].

In 2017, the Ministry of Transport, Maritime and Communications published the 2017-2021 Strategic Plan. The plan states that Turkey will focus on establishing international co-operation, and ratification, incorporation and compliance with the international legislation (and amendments) on land, maritime, aviation and space transportation technologies and their services [136]. This statement in the 2017-2021 strategic plan of the Ministry could show that authorities in Turkey are working to fix the issues related to the timely implementation of the amendments of the IMO regulations.

6.5. The Role of Universities on Developing Maritime ITS in Turkey

In 2012, Middle East Technical University organized a workshop on ITS in co-operation with Okan University. The purpose of this event was to bring together academicians and experts from ITS implementing public institutions (such as Ministry of Transport, Maritime Affairs and Communications, Ministry of Development, Ministry of Science, Industry and Technology, General Directorate of Highways, Turkish State Railways, General Directorate of Security) in order to create a network for efficient information sharing among the contributing parties. Another purpose of the event was to contribute to the development effort of the national ITS vision of Turkey [159].

In 2016, the Council of Higher Education of Turkey initiated the *"Specialized Faculty Member Training Program"*. The main aim of this program was to train a total of 110 research assistants in the priority fields which included the Intelligent

Transportation Systems. The responsibility of training ten research assistants[9] in the ITS field was assigned to the Bandırma Onyedi Eylül University. These research assistants then were sent to study at the technical universities in Turkey -including METU- to get specialized training in the ITS field, who then shall come back to Bandırma Onyedi Eylül University to conduct specialized academic research on the ITS field [160].

In 2017, Bandırma Onyedi Eylül University set up the ITS Research and Application Center and ITS Department with an MSc programme. The center and department will house students at undergraduate, graduate and doctorate levels, as well as academicians from different backgrounds working on the transportation modes including road, rail, aviation and maritime transportation [161].

In 2018, Bandırma Onyedi Eylül University organized its *1st International Conference on ITS* with the participation of domestic and international scholars and experts in the ITS field. The conference aimed to contribute to the scientific efforts and increase the diversity in the academic knowledge in Turkey on the ITS field by publishing results of researches and studies in different disciplines [162].

In 2018, Istanbul University set up ITS MSc and Ph.D. programmes within the Institute of Science and Technology. The execution of these programmes is carried out jointly with Computer, Civil, Electric Electronics, Maritime Transportation Engineering Faculties. These programmes aim to train qualified academicians in the ITS field [163].

[9] Author is one of the research assistants assigned to train in the ITS field who have a background in Maritime Transportation and Management Engineering field.

The ITS Turkey[10] is an association that acts as the platform in Turkey where authorities, institutions, businesses and experts from all over the world meet to discuss matters related to the ITS and share their expertise. ITS Turkey has a mission to create and harmonize national and international associations and therefore serve in the purpose of progressing the development in the ICT and ITS fields in Turkey. In this aim, the *1st International ITS Summit* was organized in 2019 by ITS Turkey, with the contribution of a total of 41 NGOs, universities, institutions, organizations and authorities [164].

[10] Akıllı Ulaşım Sistemleri Derneği (English translation: *Intelligent Transportation Systems Association of Turkey*). The association also calls itself "AUS Türkiye" (English translation: ITS Turkey).

CHAPTER 7

CONCLUSIONS

The e-Navigation concept is an IMO led, user-needs driven and human-centered concept. Although the concept is often the misinterpreted as AI -literally- taking the helm, the e-Navigation concept actually focuses on assisting mariners by utilizing benefits of advanced navigation and communication technologies. Such assistance becomes significantly beneficial in time critical situations and other operations that are dependent on reliable information and fast decision-making. With the advancement of technology, one day, e-Navigation systems can advance to a point where they can proactively correct erroneous navigational information or unhealthy decisions made by the users and assist them accordingly.

Maritime accidents -together with other several severe and long-term issues mainly on cost-effectiveness and efficiency- have been plaguing the international maritime industry for a long time and formed a significant portion of the driving forces behind the emergence of the IMO's e-Navigation concept. As of today, IMO's GISIS database includes over 3800 maritime accidents that are in the "Very Serious[11]" category, alone. The e-Navigation concept shall provide vastly useful tools for preventing maritime accidents and reducing the human error, as it is main aim is to increase overall safety of navigation, globally. With the aid of highly automated precise navigation systems, high-speed digital communication systems, intelligent decision-making support systems, designs and standards taking human ergonomics and needs into account; e-Navigation can further reduce the number and frequency of maritime accidents.

[11] Casualties to ships which involve total loss of the ship, loss of life, or severe pollution [38].

One of the other driving forces behind the emergence of the e-Navigation concept is the usage of aging formats and standards for maritime communication and data exchange. Inflexible and non-upgradable data formats and standards created for onboard navigational and communication equipment in an era that digital communication was not wide-spread or accessible in the maritime industry, made it impossible to extend the capabilities of these devices. With the e-Navigation concept, the full potential of the navigational aids onboard can be utilized. For example, by adopting IHO S-100 series data exchange standards on ECDIS devices, ECDIS devices could be used for digital and interactive communication between ships and shore stations. More comprehensive digital services can be provided to SOLAS and non-SOLAS ships, which shall offer higher efficiency, increased safety of navigation and better protection against cybersecurity threats, compared today's solutions.

Reducing the pollution from ships was another driving force behind the emergence of the e-Navigation concept. With the increasing international awareness on Global Warming and Climate Change, the pressure on every polluter is increasing. Maritime industry shall have no exception on this matter as it contributes to the anthropogenic pollution, as well. The IMO's e-Navigation concept can directly and indirectly help protect the environment from maritime pollution. The e-Maritime concept envisions applications that shall allow in situ and remote monitoring and management of shipping activities. These applications can directly contribute to the pollution prevention efforts in the form of reduced GHG emissions and indirectly contribute by preventing navigational accidents (such as grounding, collusions, etc.) and therefore associated pollution risks (such as disruption of the marine ecosystem or ecosystem services by oil spills and spills of hazardous substances in bulk, lost cargos, etc.).

The e-Navigation concept can also enable provision of services to remotely monitor, evaluate and optimize voyage plans and fuel consumption efficiency of ships. As a result, maritime businesses can enjoy the benefits of reduced bunkering and fuel costs and optimized time schedules and authorities can remotely monitor emission levels of all ships in their jurisdiction at considerably reduced costs. In addition, any reduction in the emissions from ships would be beneficial for the society (mostly in the form of reduced air pollution and cleaner seas).

European Commission introduced the e-Maritime concept (and related directives) to increase the efficiency of maritime transportation in the European Union and reduce the associated paperwork. Several large-scale projects were coordinated on the development of the e-Maritime concept by the Member States of the EU. The strategy and framework of the EU's e-Maritime concept were developed with the findings of these projects, the prototype applications of these projects, and scientific research; while they were also beneficial for the development the IMO's e-Navigation concept.

The e-Maritime concept aimed to implement a union-wide harmonized Single Window in the EU. It was envisioned that this Single Window would have eliminated the different formats, formalities and practices enforced by the different EU Member States. Such level of harmonization between the EU Member States would reduce the paperwork, promote efficient use of time and other resources, and, most importantly, increase the overall competitiveness of the EU maritime industry. However, the union-wide Single Window application aim of the e-Maritime concept was not achieved in the intended time frame, as several EU Member States failed to fulfill the requirements of the EC's 2010/65/EU directive on *Reporting formalities for ships arriving in and/or departing from ports of the Member States*. Still, today, the aims of the EU's e-Maritime concept are more than relevant.

Most of the technologies needed for the implementation of the IMO's e-Navigation and EU's e-Maritime concept exist today. However, due to their different costs and benefits, ships and land-based domains of the maritime industry currently use different specialized technologies and systems that are suitable for their practices. For example, today, both ships and shore stations use satellite and terrestrial radio based long range, low-speed digital communication technologies while shore stations also enjoy the benefit of high speed, reliable and cost-effective communication solutions such as broadband internet and LTE.

The usage of different communication technologies, networks and systems (e.g., IP-based and IP-less systems, etc.) on ships and land-based domains create an incompatibility problem for exchanging data between these domains. Before reaching to its destination, the requested data needs to be converted into a compatible format so that it could be *understood* by the system in the receiving end of the communication. Solution is the usage of a CMDS so that any requested data or information shall be created in a universally accepted data format (such as S-100 data model) at its source and then will be transferred to an international harmonization network (such as MCP). The harmonization network then will process the data (encrypt, compress, store, synchronize, decrypt, convert into a specifically requested format, etc.) so that the users can access that the data they requested. Therefore, the success of high-speed digital communication systems (such as VDES) and networks to be used by IMO's e-Navigation and EU's e-Maritime concepts will be significantly based on the degree of international co-operation and proper harmonization of standards.

The effects of the IMO's e-Navigation and EU's e-Maritime concepts will be seen at international level. The IMO's e-Navigation and EU's e-Maritime concepts have been shaping up with the combined efforts of all contributing nations. Many IMO and EU Member States already assumed responsibilities in these efforts, which let them to directly involve in the development of these concepts. However, the entire global maritime industry will be affected by the outcomes of these concepts. This could be beneficial for the Member States that involve in the development phases of these concepts as they would have relatively invested more time and may have already built capacity to implement these concepts.

Implementing large-scale concepts such as IMO's e-Navigation and EU's e-Maritime concepts require a certain degree of technological capabilities and Maritime ITS infrastructure, which not all IMO and EU Member States may have equally invested in. Some Member States will need to invest more than others to catch up with the technological and infrastructural requirements of these concepts, which can lead to problems with the actual implementation of the concepts. Additionally, improper or sub-par implementation of these highly specialized concepts may cause more problems than they might have solved. In this regard, the development of consistent strategies and the continuum of the investment from the state, maritime authorities and private sector could be advantageous for Turkey in favor of adopting the IMO's e-Navigation concept and the suitable aspects of the EU's e-Maritime concept. However, for proper (internationally compatible, connected and harmonized) implementation of these concepts in Turkey, as the national strategies and goals state, international cooperation is vital. Therefore, in the long term, it would be beneficial for Turkey to sustainably develop its national Maritime ITS capacity while participating in the IMO's e-Navigation development efforts.

Concerning the implementation of the IMO's e-Navigation and EU's e-Maritime concepts and developing strategies to implement Maritime ITS in Turkey in general; it could be argued that the state institutions and authorities have been leading the implementation effort. Although, recently, the Ministry of Transportation and Infrastructure adopted strategies and goals to attract the private sector into the Maritime ITS field and the effects of such strategies and goals can already be seen today. For example, in 2018, the tendered Turkish Straits VTS Upgrade and Extension Project was won by a Turkish company [138]. This particular advance may also suggest that the strategies and investments made in the national and domestic capacity building -especially regarding Maritime ITS- have been successful and Turkey is now starting to utilize this capacity.

National ITS Strategy planning and development is crucial for the development and implementation of Maritime ITS applications, and inputs of scientific research should be greatly considered in these phases. Such planning efforts should also smooth the adoption period and maximize the benefits that can be derived from the application of IMO’s e-Navigation and EU’s e-Maritime concepts. The 2014 ITS Strategy Document and Action Plan explains the importance of the ITS developments and applications in Turkey and sets out plans for implementations on the national scale. However, in its current form, it generally acknowledges that ITS applications have been widely used by the maritime transportation sector for a long time. In the long term, it would be beneficial for Turkey if future ITS Strategy Documents and Action Plans include comprehensive plans and guidelines for incorporating international regulations and standards on IMO’s e-Navigation concept and Maritime ITS into the national law.

Yalcin (2014), in his thesis on the IMO’s e-Navigation concept and its applications in Turkey, stated that while there are adequate number of technical experts working on the IMO’s e-Navigation concept at Turkish maritime authorities and private sector today, there will be a need for more experts and professionals in this field in the future [165]. Perhaps, adopted policies and educational investments made since

2014 suggest that the decision makers in Turkey also have been aware of such a need and has been building the capacity to bring more experts in the ITS field. The preliminary realization of this training effort has recently been achieved with the establishment of the first higher education programs on ITS and ITS Research Centers in Turkey. Bringing experts in this field of the maritime industry together on developing national strategies and action plans is also essential for national and domestic capacity building on Maritime ITS field and training more experts on the IMO's e-Navigation and EU's e-Maritime concepts in Turkey.

Established long-term strategies, policies and investments on maritime transportation technologies and infrastructure for the adoption of modern Maritime ITS solutions, already utilized Single Window applications and online services, and growing academic capacity in the ITS field indicate that Turkey is getting prepared for the arrival of IMO's e-Navigation [137] and EU's e-Maritime concepts.

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APPENDIX A

Required tasks for the implementation of five prioritized solutions described in the e-Navigation SIP. Adapted from e-Navigation SIP Tables 1 - 5 [28].

RCO	Sol.	Description	Task Action	Task
1	S1.6	Information accuracy/reliability indication functionality for relevant equipment.	Develop a testbed demonstrating technically how the accuracy and reliability of navigation equipment may be displayed.	T6
	S1.7	Integrated Bridge Display System (INS) for improved access to shipboard information.	INS systems which integrate navigation equipment data already exist but are not mandatory carriage to resolution MSC.252(83). E-navigation relies on integration and without mandatory carriage of INS, it would be difficult to achieve the solutions. The carriage of an INS or maybe something more straightforward performing integration should be investigated.	T7
	S3.1	Standardized Self-Check/Built-In Integrity Test (BIIT) with interface for relevant equipment (e.g. bridge equipment).	Equipment should be developed with standardized BIIT built in. The general requirements in resolution A.694(17) as tested by IEC 60945 should be investigated to see if more definition and testing is required.	T10
	S3.2	Standard endurance, quality and integrity verification testing for relevant bridge equipment, including software.	Software quality assurance especially lifetime assurance methods need to be developed into draft guidelines. The type approval process needs to be developed further to ensure that the equipment used in e-navigation is robust in all aspects.	T11
	S3.3	Perform information integrity tests based on the integration of navigational equipment - application of INS integrity monitoring concept.	This task is very similar to that described for S1.6.	T6
	S4.1.2	Standardized interfaces for data exchange should be developed to support the transfer of information from communication equipment to navigational systems (INS).	Most equipment already uses one of the IEC 61162 series interface standards, although IMO only refer to it by footnote. The testing standards for shipboard equipment developed by IEC all refer to this standard. IEC should make sure that at the highest level the interfaces meet the S100 principle although it may not be necessary to use this standard between simple equipment.	T14
	S4.1.6	Provide quality assurance process to ensure that all data is reliable and is based on a Consistent Common Reference System (CCRS) or converted to such before integration and display.	Ensure data quality and CCRS are met with new Quality Assurance.	T11
2	S1.5	All bridge equipment to follow IMO BAM (Bridge Alert Management) performance standard.	Ensure that all equipment is checked during type approval and that it meets the requirements of resolution MSC.302(87) on Bridge Alert Management, as may be updated.	T5
3	S1.4	Standard default settings, save/recall settings, and S-mode functionalities on relevant equipment.	The performance or technical standards mandating the features on relevant equipment. Develop a testbed demonstrating the whole concept of standardized modes of operation including store and recall for various situations as well as S-mode functionality on relevant equipment.	T4
4	S2.1	Single-entry of reportable information in single-window solution.	Develop testbeds demonstrating the use of single window for reporting along with S2.4.	T8, T15
	S2.2	Automated collection of internal ship data for reporting.	Much data is already collected in the navigation equipment – investigate the use of this data for reporting of ship navigational information.	T9
	S2.3	Automated or semi-automated digital distribution/communication of required reportable information, including both "static" documentation and "dynamic" information.	Review the original AIS long-range port facility as well as the new long-range frequencies made available at WRC 2012 described in the latest revision of ITU-R M.1371-5, the revised IEC 61993-2, or the developments within VDES (VHF Data Exchange System) and see if the information could be used for no cost or low cost automated or semi-automated reporting. The long-range port was not used during the development of LRIT due to the cost to shipowners of sending this information.	T9 T15
	S2.4	All national reporting requirements to apply standardized digital reporting formats based on recognized internationally harmonized standards, such as IMO FAL Forms or SN.1/Circ.289.	Liaise with all Administrations and agree on standardized formats for ship reporting to enable "single window" worldwide. In this respect, national and regional harmonization is the first step.	T8
5	S3.4	Improved reliability and resilience of onboard PNT information and other critical navigation data by integration with and backup of by integration with external and internal systems.	IMO is already drafting performance standards for a multi-system navigational receiver designed to use all available systems for an improved and more reliable PNT solution. There may be traditional methods and other terrestrial systems which should also be investigated as the external input. Backup arrangements for critical foundation data, particularly in the event of an interruption to cloud-based solutions should be investigated. Administrations need to indicate their support for terrestrial systems.	T12
6	S4.1.3	Provide mapping of specific services (information available) to specific regions (e.g. maritime service portfolios) with status and access requirements.	Ensure that the correct and up-to-date information for the area of operation is provided by the shore side and that the mariner gets the information for the area of operation.	T13
	S9	Improved communication of VTS service portfolio (not limited to VTS stations)	Communications is a key factor in the e-navigation concept. This task needs to identify the possible communications methods that might be used, and testbeds need to be built to demonstrate which systems are best in different areas of operation. (e.g. deep sea, coastal and port).	T15 T17
7	S1.1	Ergonomically improved and harmonized bridge and workstation layout.	Draft Guidelines on Human Centered Design (HCD) for e-navigation systems. Draft Guidelines on Usability testing, Evaluation and Assessment (UTEA) for e-navigation systems. Resolutions A.694(17), A.997(25) and MSC.252(83) and MSC/Circ.982, SN.1/Circ.265, SN.1/Circ.274 and SN.1/Circ.288 are of relevance.	T1 T2