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Technological developments in modern e-navigation systems

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LIST OF ABBREVIATIONS

ABS	American Bureau of Shipping
AIS	Automatic Identification System
AtoN	Aids to Navigation
CMDS	Common Maritime Data Structure
COMSAR	Radio-Communications and Search and Rescue Sub-Committee
EC	European Commission
ECDIS	Electronic Chart Display and Information System
EU	European Union
FSA	Formal Safety Assessment
HEAP	Human Element Analyzing Process
HMD	Head Mounted Display
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities
IFSPA	International Forum on Shipping, Ports and Airports
IHO	International Hydrographic Organization
IMO	International Maritime Organization
ITU-R	International Telecommunication Union Recommendation
MSC	Maritime Safety Committee of IMO
MSP	Maritime Service Portfolio
NAV	Sub-Committee on Safety of Navigation of IMO
NCSR	Sub-Committee on Navigation, Communications and Search and Rescue
NTSB	National Transportation Safety Board
PLL	Potential Loss of Life

PNT	Position, Navigation and Time
RCO	Risk Control Option
SAR	Search and Rescue (SAR)
SIP	Strategic Implementation Plan
SMART-Navigation	Korean Approach of Implementing the e-Navigation Concept
S-Mode	Standardized Modes of Operation
SOLAS	International Convention for the Safety of Life at Sea,1974
STW	Standards of Training and Watch-keeping Sub-Committee
VDES	VHF Data Exchange System
VTS	Vessel Traffic Service
W-LAN	Wireless Local Area Network
WG	Working Group
WWRNS	World Wide Radio Navigation System

ABSTRACT

The majority of accidents in the maritime domain is caused to by human errors. One of the measures to reduce human-related marine accidents is proposed to implement the e-Navigation concept according to the International Maritime Organization's (IMO) strategy implementation plan. E-Navigation is harmonized collection, integration, exchange and presentation of information that facilitate berth to berth operations. To achieve this, the introduction of electronic means, including state-of-the-art information and communication technologies, is the key to support ship operators on-board as well as ashore. Considering the fact that around 50% of accidents occurring at sea are attributed to navigational challenges, a systematic maritime traffic management seems to be necessary. On the other hand, modern ship operations rely on a small number of crew whose responsibilities for safe and efficient navigation are increasingly high. Without operational support from the shore, using a reliable technology-based system, it would be challenging to reduce marine accidents. e-Navigation, provides a great potential to help mitigate incidents such as collisions, grounding problems, oil spills and piracy. It also allows a certain flexibility in utilizing both new and existing technologies which are acceptable within the operating standards. In this paper, the authors study the modus operandi of the proposed e-Navigation concept in terms of its requirements and implementation plans as well as the potential limitations and benefits around the concept.

KEY WORDS

E-Navigation, Navigation support, Internet of Things (IoT), Artificial Intelligence

1. INTRODUCTION

1.1 Background

The idea of e Navigation was initially presented to the IMO in 2006 during the session of the Maritime Safety Committee (MSC 81. May 06). During that time the committee was asked to approve this project as a work program, due, to its significant importance that still exists today.

> *There is an compelling necessity to provide users and those responsible, for the safety of shipping with modern proven tools that are optimized for making good decisions. The objective is to enhance navigation and communication making them more reliable and user friendly. The ultimate goal is to enhance navigation safety and reduce errors. However if current technological advancements continue without coordination there is a risk that the future development of navigation systems will be hindered due to a lack of standardization both on board and ashore incompatibility between vessels and an unnecessary increase, in complexity.*

During that time Efthimios Mitropoulos, the Secretary General of the International Maritime Organization (IMO) who has emerged as an advocate, for the concept of e Navigation cautioned against relegating mariners to monitors. He emphasized the importance of considering the Human Element and its vulnerabilities when developing aspects of e Navigation. It was emphasized from the beginning that e Navigation should be driven by user needs than dictated by technologists or regulators. From 2006 to 2008 an international exercise was carried out by the IMO e Navigation Correspondence Group (CG) with support from organizations like IALA and The Nautical Institute to identify these needs. Various potential users of e Navigation both, at sea and onshore were. Asked to define their requirements in terms of harmonized collection, integration, exchange, presentation and analysis of information using electronic means.

It is important to highlight that this exercise might have been one of the user needs analyses ever conducted in the maritime industry. Valuable lessons can be drawn from this experience. Specifically it was observed that most end users struggle to articulate their needs and often tend to focus on what they have or prefer.

This necessitated an amount of examination to extract the requirements from the personal preferences.

1.2 Revolution of shipping age

The maritime era has gone through transformations, over centuries witnessing changes, in various aspects. With the impact of the Industrial Revolution the shipping industry has been evolving from large scale navigation to navigation both presently and in the future. The types of ships, industrial revolution advancements and business models have all transitions.

1.3 Industrial revolution

The initial wave of industrialization was fueled by the emergence of steam power, railways and mechanized production. Subsequently in 1890 the second phase of industrialization arose with the advent of electricity and new manufacturing techniques utilizing assembly lines and mass production. The third phase, known as Industry 3.0 emerged in the 1960s with the proliferation of computers and the internet driven by semiconductors. Presently we find ourselves amidst the industrial revolution centered around cyber physical systems. Figure 1 provides an illustration of Industry 4.0 and its four distinct phases of revolution. As we transitioned from Industry 1.0 to Industry 4.0 new technologies such, as intelligence have gradually found their application, in sectors including shipping. Building upon the three revolutions which involved steam engine adoption large scale production methods and electronic information technology advancements; we are now experiencing an era of industrial intelligence characterized by intelligent manufacturing practices based on big data utilization and predictive technologies.

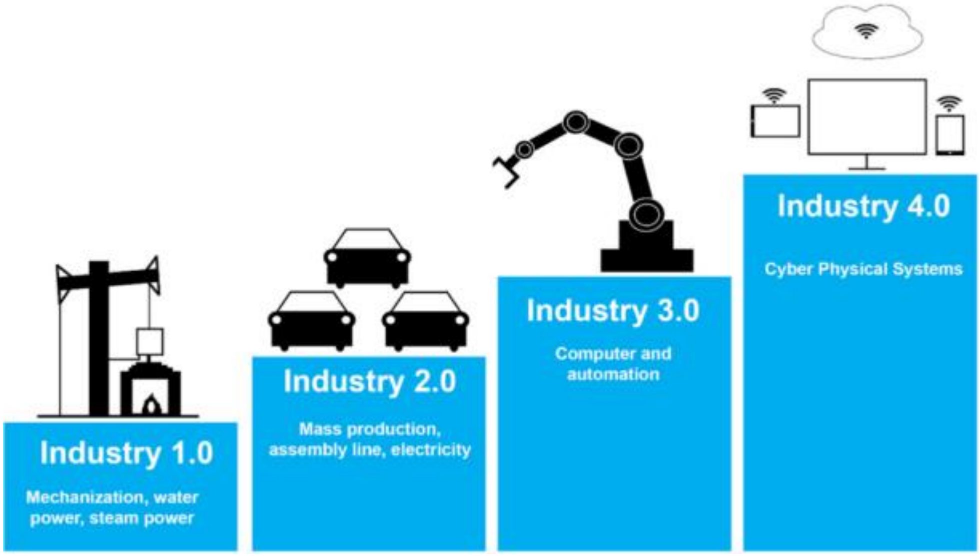

Figure 1. Industry 4.0 and its four industrial revolutions

2. E-NAVIGATION CONCEPT

2.1 Definition of the e-Navigation - Overview of IMO

The concept of e Navigation is an initiative that aims to transition maritime navigation into the digital age. Its goal is to integrate existing tools ensuring a comprehensive and organized approach, to transmitting, manipulating and displaying navigational information in electronic format. The International Maritime Organization (IMO) has defined e Navigation as the harmonized collection, integration, exchange, presentation and analysis of information using means. This initiative seeks to enhance navigation from berth to berth improve safety and security at sea and protect the marine environment. By establishing standards for cost effective shipping the e Navigation system aims to reduce accidents, errors and failures in navigation while addressing both future user requirements. The IMO emphasizes the importance of providing vessel masters and those responsible for shipping safety with tools that enhance reliability and user friendliness in navigation and communications. These advancements are crucial, for minimizing errors and promoting shipping practices.

However if we don't properly coordinate the advancements there's a chance that the future progress of marine navigation systems will face obstacles due, to a lack of standardization both on ships and on land. This could lead to compatibility issues between vessels and an unnecessary increase, in complexity.

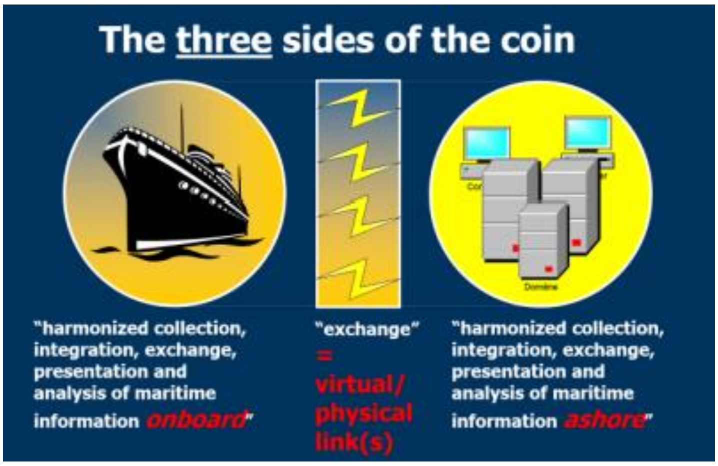

Figure 2. Three main faces of e-Navigation concept

2.1.1 History of e-Navigation

The use of electronic navigation aids and equipment has a long history in the maritime industry. Some of the earliest electronic navigation aids, such as radar and loran (long-range navigation), were developed during the 20th century and have been widely used in the shipping industry for many decades.

The concept of e-navigation, as it is understood today, began to emerge in the early 21st century with the development of new technologies and the increasing reliance on electronic systems in the maritime industry.

In 2002, the International Maritime Organization (IMO) established the International Maritime Electronic Navigation Forum (IMENF) to promote the development and implementation of e-navigation systems. In 2007, the IMO adopted a resolution on e-navigation, which outlined the principles and goals of e-navigation and established a roadmap for its implementation.

Since then, e-navigation has become an increasingly important part of the maritime industry, with many ships and ports around the world adopting electronic navigation aids and equipment as a means of improving safety, efficiency, and environmental protection. Today, e-navigation is considered a key component of the modern maritime industry and is supported by a range of international organizations, including the IMO, the International Hydrographic Organization, and the International Association of Marine Aids to Navigation and Lighthouse Authorities.

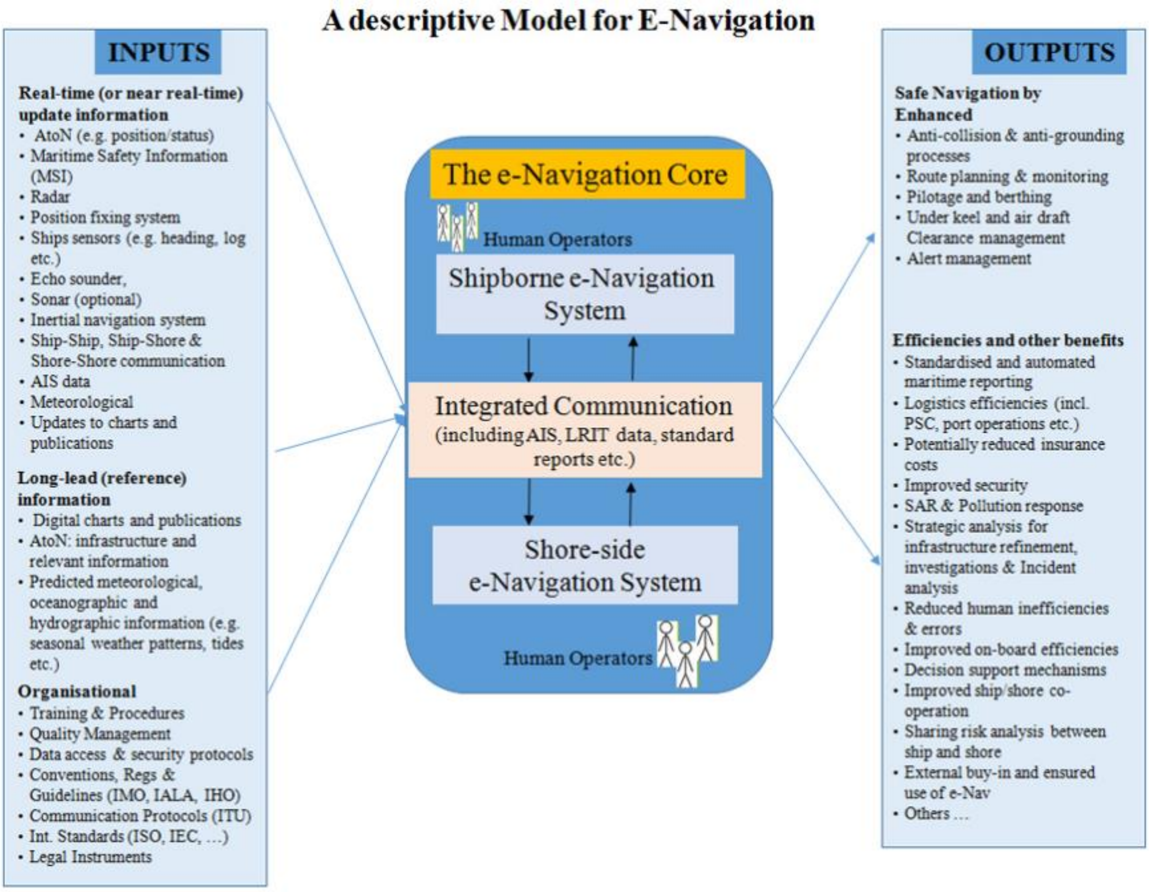

Figure 3. A descriptive model of e-Navigation (adapted from IMO/IALA documents)

2.1.2. Objectives of e-Navigation

The core objectives of e-navigation concept include:

1. Improving situational awareness: By providing real-time information on vessel traffic, weather conditions, and other relevant data, e-navigation systems can help mariners make more informed decisions and avoid collisions and other accidents.
2. Enhancing navigation safety: E-navigation systems can help mariners navigate more safely by providing them with detailed information on the location of hazards, such as shallow waters, rocks, and other obstacles.
3. Improving efficiency: By providing mariners with real-time information on traffic patterns, weather conditions, and other factors, e-navigation systems can help them plan their routes more efficiently and reduce fuel consumption and emissions.

4. Enhancing communication: E-navigation systems can help mariners stay in contact with other vessels, ports, and coastal authorities, improving communication and coordination in the event of an emergency or other incident.
5. Enhancing sustainability: By helping mariners navigate more efficiently and reducing emissions and other environmental impacts, e-navigation systems can contribute to the overall sustainability of the maritime sector.
6. Enhancing security: E-navigation systems can aid in the detection of vessels that may pose a security threat to a country.
7. Provide opportunities for improving the efficiency of transport and logistics

Overall, e-navigation is an ambitious concept that aims to transform maritime navigation by leveraging the latest technology to improve safety, efficiency, and sustainability, while also improving communication and coordination among all stakeholders in the maritime sector. Implementing e-navigation is a global effort and many countries are working together to develop standards, guidelines and best practices to ensure that e-navigation systems are reliable, effective and easy to use.

2.1.3 Strategic Implementation Plan (SIP) of IMO

In 2014 MSC 94 introduced an implementation plan (SIP) as part of NCSR 1/28 Annex 20. The SIP plays a role, in implementing e Navigation by providing solutions to analyze gaps and meet user requirements through the Formal Safety Assessment (FSA). These challenges are addressed in the seven sections of the Regulatory Coordination Organization (RCO). The sixteen services offered by the Maritime Service Portfolio (MSP) both of which are included within the SIP. These sections and services act as tools to achieve the five prioritized e Navigation solutions along, with their sub solutions.

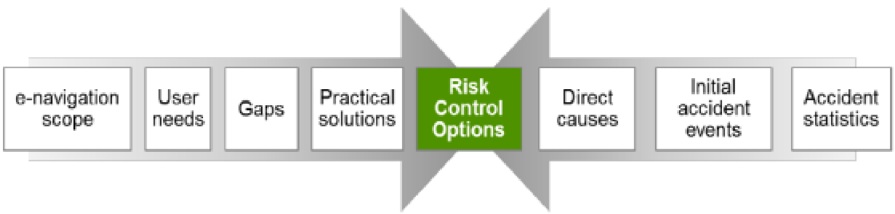

Figure 4. RCO Identification Process

Solution	Sub Solution
S1 Improved, Harmonized and User-Friendly Bridge Design	(S1.1) Ergonomically improved and harmonized bridge and workstation layout
	(S1.2) Extended use of standardized and unified symbology for relevant bridge equipment
	(S1.3) Standardized manuals for operations and familiarization to be provided in electronic format for relevant equipment
	(S1.4) Standard default settings, save/recall settings, and S-mode functionalities on relevant equipment
	(S1.5) All bridge equipment to follow IMO Bridge Alert Management
	(S1.6) Information accuracy/reliability indication functionality for relevant equipment
	(S1.6.1) Graphical or numerical presentation of levels of reliability together with the provided information
	(S1.7) Integrated bridge display system (INS) for improved access to shipboard information.
	(S1.8) GMDSS equipment integration – one common interface.
S2 Means for Standardized and Automated Reporting	(S2.1) Single-entry of reportable information in single-window solution.
	(S2.2) Automated collection of internal ship data for reporting.
	(S2.3) Automated or semi-automated digital distribution/communication of required reportable information, including both "static" documentation and "dynamic" information.
	(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.
S3 Improved	(S3.1) Standardized self-check/built-in integrity test (BIIT) with interface for relevant equipment (e.g. bridge equipment).

Reliability, Resilience and Integrity of Bridge Equipment and Navigation Information	(S3.2) Standard endurance, quality and integrity verification testing for relevant bridge equipment, including software.
	(S3.3) Perform information integrity tests based on integration of navigational equipment – application of INS integrity monitoring concept
	(S3.4) Improved reliability and resilience of onboard PNT information
S4 Integration and Presentation of Available Information In Graphical Displays Received via Communication Equipment	(S4.1) Integration and presentation of available information in graphical displays (including MSI, AIS, charts, radar, etc) received via communication equipment
	(S4.1.1) Implement a Common Maritime Data Structure and include parameters for priority, source, and ownership of information.
	(S4.1.2) Standardized interfaces for data exchange should be developed to support transfer of information from communication equipment to navigational systems (INS).
	(S4.1.3) Provide mapping of specific services (information available) to specific regions (e.g. maritime service portfolios) with status and access requirements.
	(S4.1.4) Provision of system for automatic source and channel management on board for the selection of most appropriate communication means (equipment) according to criteria as, band width, content, integrity, costs.
	(S4.1.5) Routing and filtering of information on board (weather, intended route, etc.).
	(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.

	(S4.1.7) Implement harmonized presentation concept of information exchanged via communication equipment including standard symbology and text support taking into account human element and ergonomics design principles to ensure useful presentation and prevent overload.
	(S4.1.8) Develop a holistic presentation library as required to support accurate presentation across displays.
	(S4.1.9) Provide Alert functionality of INS concepts to information received by communication equipment and integrated into INS.
	(S4.1.10) Harmonization of conventions and regulations for navigation and communication equipment
S5 Improved Communication of VTS Service Portfolio	Improved communication of VTS service portfolio (not limited to VTS stations)

Table 1. Solution and Sub-Solutions Prioritized e-Navigation (Source. Annex 7 NCSR 1/28)

A Strategic Implementation Plan (SIP) is a document that specifies the exact activities and strategies that will be taken by an organization to attain its goals and objectives. To achieve these objectives, the IMO has created a variety of strategic projects and programs.

The IMO's SIP would begin with the establishment of defined and quantifiable goals and objectives. These might include minimizing the frequency of maritime accidents, reducing ship pollution, and increasing the shipping industry's general efficiency and effectiveness.

Following the establishment of goals and objectives, the next stage would be to create a thorough action plan stating the precise activities that will be followed to attain these goals. This might involve creating new shipping norms and standards, increasing the number of ship inspections and audits, and boosting the use of technology to increase safety and efficiency.

The IMO would then need to allocate resources and assign responsibilities for the action plan's implementation. This might involve recruiting more people, acquiring new equipment, and developing alliances with other firms.

Along with these procedures, the IMO would need to create a mechanism for tracking and evaluating progress. Setting up a system for recording the number of accidents and incidents, monitoring the level of pollution from ships, and performing frequent audits and evaluations of the shipping sector might all be part of this.

Finally, the IMO would need to inform all stakeholders, including member states, industry groups, and the general public, on the status of the SIP. This might involve regularly publishing reports and updates, having public meetings and discussions, and interacting with stakeholders via social media and other communication channels.
Overall, the IMO's SIP would be a thorough and detailed plan outlining the exact activities and strategies that would be done to fulfill the organization's aims and objectives for shipping safety and security, as well as the avoidance of maritime pollution caused by ships.

2.1.4 Risk Control Option (RCO)

Risk control options in the maritime sector refer to the various methods and strategies that organizations and individuals can use to manage and mitigate the risks associated with the shipping industry. These risks can include accidents and incidents at sea, environmental damage, and economic losses. Some examples of risk control options in the maritime sector include:

1. Safety management systems: These systems are designed to identify and manage the risks associated with the operation of ships. They typically include procedures for risk assessment, incident reporting, and emergency response planning.
2. Training and education: Ensuring that crew members and other personnel are properly trained and educated on safety procedures and regulations can help to reduce the risk of accidents and incidents.

3. Regulations and guidelines: Governments and international organizations, such as the International Maritime Organization (IMO), establish regulations and guidelines for the shipping industry in order to promote safety and reduce the risk of accidents and incidents.
4. Technology: Advancements in technology, such as the use of automated systems and remote monitoring, can help to improve safety and reduce the risk of accidents and incidents.
5. Insurance: Organizations can purchase insurance to mitigate the financial risks associated with accidents and incidents.
6. Risk assessment and analysis: organizations can conduct risk assessment and analysis of the shipping operation to identify potential hazards and implement mitigation measures.
7. Emergency response plans: Having a well-defined emergency response plan in place can help organizations to quickly and effectively respond to accidents and incidents, thereby reducing the risk of harm and damage.
8. Audits and inspections: Regularly conducting audits and inspections of ships and operations can help identify and address potential safety hazards, thereby reducing the risk of accidents and incidents.
9. Cybersecurity: With the increasing reliance on technology, organizations should implement cybersecurity measures to protect their ships and operations from cyber-attacks

2.2 E-Navigation. How does it work?

As already mentioned, E-navigation is the concept of using electronic means to enhance the safety, efficiency and effectiveness of navigation at sea. One important aspect of e-navigation is the development of an architecture that allows for seamless integration of different navigation systems and technologies.

The e-navigation architecture is made up of several layers, including:

1. The Data Collection Layer: This layer is responsible for collecting and distributing navigation-related data, such as vessel position, weather, and tide information. This

data can come from a variety of sources, including ships, shore-based systems, and satellite-based systems.

2. The Data Management Layer: This layer is responsible for managing and storing the navigation-related data collected by the Data Collection Layer. This includes tasks such as data validation, data fusion, and data distribution.
3. The Information Services Layer: This layer is responsible for providing navigation-related information to the users. This includes tasks such as information display, decision support, and route planning.
4. The Communication Layer: This layer is responsible for providing communication between different e-navigation systems and technologies. This includes tasks such as data transfer, voice communication, and messaging.
5. The Security Layer: This layer is responsible for providing security to the e-navigation systems and technologies. This includes tasks such as authentication, encryption, and access control.

The architecture is designed to be flexible and scalable, allowing for the integration of new technologies and systems as they become available. Additionally, it is designed to support the needs of different types of vessels and different navigation scenarios. E-navigation architecture is a key component in the development of the global e-navigation strategy. To get it how it works, the figure no 5 and 6, will offer assistance to envisioning the e-Navigation engineering provided by IMO and also can be visualized by the 7 columns concept.

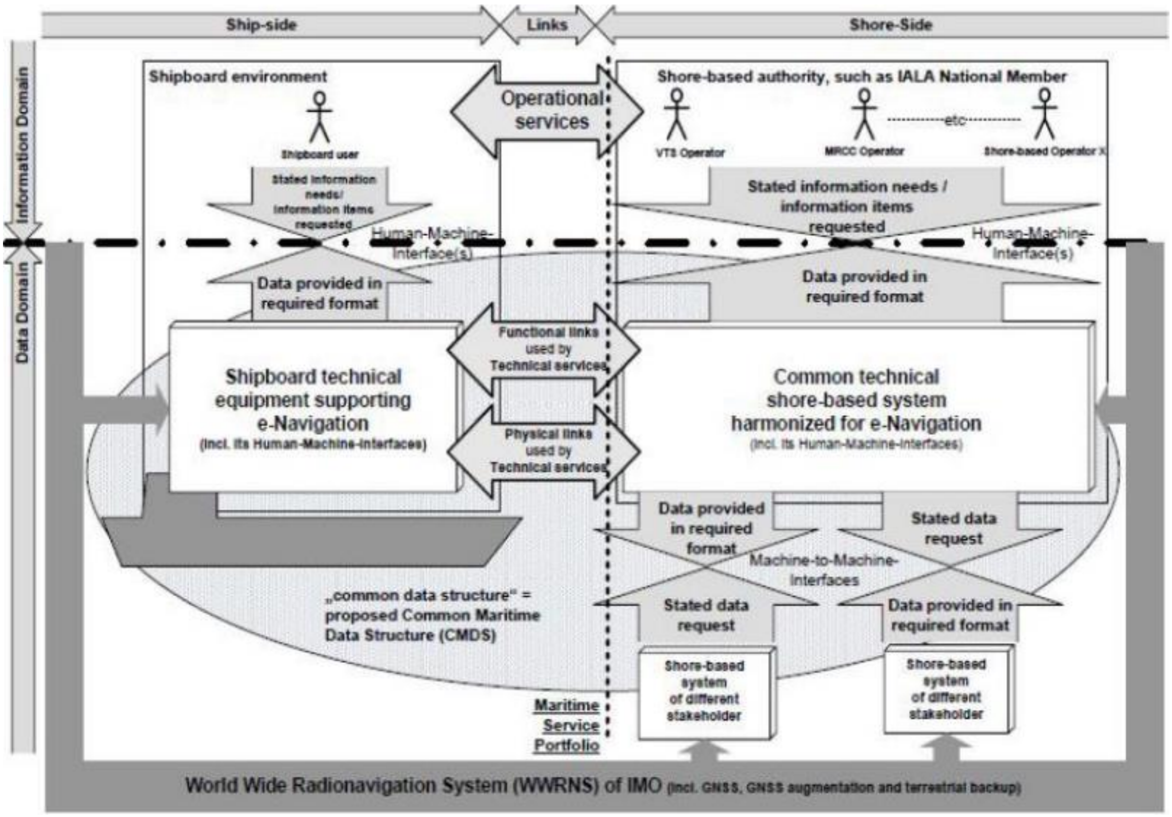

Figure 5. E-Navigation architecture (Annex 7 of NCSR 1/28 page 18)

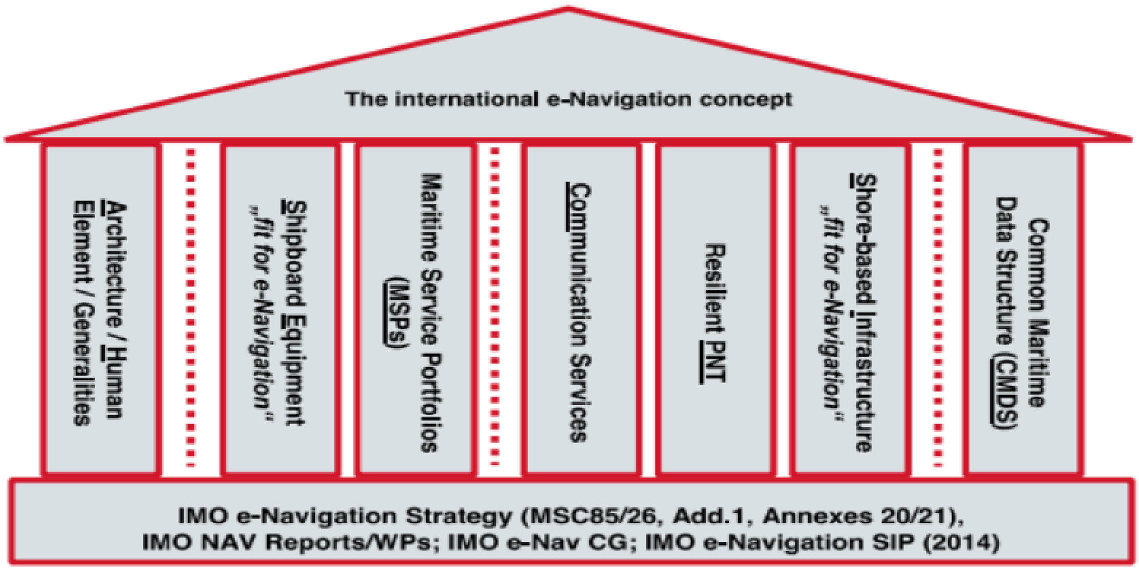

Figure 6. The 7 pillars of e-Navigation

2.2.1 Ashore

MSC 85/26/Add.1, annex 20, point number 4, described the shore-based related part of e-Navigation as:

Enhancing the management of vessel traffic information and related services from shore involves improving the provision, coordination and exchange of data in formats that can be easily understood and utilized by operators, on land. This is done to support vessel safety and efficiency.

The implementation of protocols is crucial, for routing and seamless data exchange in e navigation. The main goal is to eliminate information and ensure the transmission of data. In sea operations it's essential to follow established procedures and legal frameworks while providing information. Accurate information should never be overlooked as it plays a role in ensuring sailing of ships. Gathering information from sources, such as radar, AIS, VDES LRIT, ship databases and SAR systems used in onshore infrastructure is necessary. These sources provide services like positioning assistance, route guidance, arrival schedules, instructions, pilotage and tug support, search and rescue operations, marine safety advice, traffic information among others. It's important to note that even boat operators need to communicate information to the control department. Regular upgrades are required to maintain ship safety.

Additionally e navigation aims to provide 16 services known as MSPs (Maritime Service Portfolios). To successfully implement e navigation systems, collaborative maritime community systems are essential, for retrieving route information from its source and delivering it to the users. The ultimate objective is to improve and optimize the efficiency of these services.
Moreover prior, to the implementation of the Stay at Home order efforts were already underway to establish shore based systems for e Navigation. For example various projects initiated by the European Community such as Vessel Traffic Monitoring and Information System (VTMIS Net) SafeSeaNet (SSN) Sea Traffic Management (STM) which was developed and conducted by Sweden and ACCSEAS a project completed in 2015 have all been working towards enhancing traffic safety by mitigating risks. Additionally in the region South Korea has introduced the SMART Navigation system to facilitate the adoption of e Navigation technology on vessels. In a research study conducted by Mrever and Hng (2016) they investigated the effectiveness of e Navigation in reducing accidents using the SMART navigation concept.

Despite advancements these initiatives are being pursued to explore and further develop potential e Navigation services. However it is crucial that all stakeholders have access to digitalized infrastructure of quality. For instance during interviews, with five participants (35%, n=14) it was emphasized that the ENC streaming platform would be considered an robust communication channel.

IH is currently working on expanding the availability of ENC. It is expected that the framework will align with the IALA standard, for e Navigation technical services.

As mentioned in the IALA (2015) report on e Navigation architecture ENAV17 10.4.2 a thorough understanding of the architecture is important to gain an overview of e Navigation. Operators and other support personnel should undergo training that equips them to handle the process (IALA, 2015). Although a couple of interviewees suggest that onshore operators may differ from VTS operators most interviewees agree that HCD should provide a way for operators to interact. Since e Navigation heavily relies on machine to machine communication operators in this context need to have expertise to maintain their skills adapt to new technologies identify problems and respond accordingly. This requirement applies to both onboard operators, within the e Navigation framework.

However it seems that each country will have its approach when it comes to implementing the concept of e Navigation.

During the interview the participants mentioned that some capital states might face challenges in offering an e Navigation information service. This is because upgrading their systems will require time and not every capital state will need to provide all aspects of the Maritime Service Portfolio (MSP). Consequently it becomes crucial for e methods to coexist harmoniously as they need to operate alongside each other.

2.2.2 On board

According to MSC 85/26, annex 20, paragraph 4, described on board-based related part of e-Navigation as:

> *Navigation systems benefit from the integration of sensors, on the ship helpful information, a user friendly interface and a comprehensive system for managing guard zones and alerts. The key components of such a system involve involving the mariner, in the navigation process to perform their duties while avoiding distractions and excessive workload.*

Vessels always need, up to date information to effectively warn sailors when necessary and ensure navigation. On the ship they use charts, documents and standard SOLAS equipment such as radar, AIS and LRIT communications. Sharing information like chart updates, weather forecasts, passage planning suggestions and MSI should help the bridge team operate equipment smoothly and understand the provided information effortlessly. More and more ships are installing IBS systems that can transmit data to cabins or equipment when needed. Vessels capable of transmitting data over a communication network can be considered compliant with e Navigation requirements. Apart from onboard processes, e Navigation also promotes information sharing among vessels and other entities onshore.

Moreover e Navigation facilitates machine to machine communication which reduces the need for involvement to some extent. In the coming years it is expected that the Officer of the Watch (OOW) will only need to be familiar, with how the equipment functions and how to extract desired data. Since each vessels navigational bridge has equipment setups operators must go through a familiarization process.

This claim is supported by the findings presented in the ACCSEAS Training Needs Analysis Report (Baldauf, 2015). Moreover one respondent mentioned that there would be a quality indicator to inform mariners in the future e Navigation reality. So the information obtained is reliable and accurate. However, in cases where there is conflicting information from another source the competence of seafarers (Master/OOW) is still necessary and subject to scrutiny in situations. Based on their experience and professional judgment it became clear during the interview that addressing this issue would be crucial. The effective use of efficient data by sailors is expected to have an impact on the performance of the e Navigation concept. Consequently it will enhance ship navigation safety while enabling Officers of the Watch (OOW) to dedicate time to optimizing their role. Nonetheless there are debates regarding how seafarers should utilize the information they gather since they have decision making authority. The outcomes of the interview serve as evidence of Bridge Team Management

(BTM) and demonstrate the competencies exhibited by mariners—an essential requirement, for successfully implementing e Navigation functions.

3. BENEFITS OF E-NAVIGATION CONCEPT

The overarching advantages of e-Navigation can be classified into three distinct categories according to the International Maritime Organization's characterization of e-Navigation in analytical terms:

- Designing and establishing user-friendly guidelines for the optimal presentation and functionality of marine information,
- Harmonized aggregation, assimilation, dissemination, and examination of maritime data, and
- Protection of the maritime environment is achieved through the utilization of the aforementioned benefits and the enforcement authority exercised by the International Maritime Organization (IMO).

The following sub-chapters will discuss the comprehensive advantages of e-Navigation across three categories.

3.1 Design and Usability Standards

3.1.1 Human Centered Design and Ergonomics

The primary objective, for architects and ship system designers should be the promotion of safety at sea. It is crucial to take into account elements and ergonomics such as the interaction between humans and technology physical layouts and potential hazards rules and procedures as well, as training concerns. This holistic approach ensures the creation of a user cost effective and environmentally sustainable work environment that addresses the requirements of stakeholders in the maritime industry while enhancing overall navigation safety.

> “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"

As mentioned earlier the main objective of this concept is to enhance safety in navigation and improve communication skills taking into account the factor. Therefore when designing systems and equipment, for ships and shore based operations within the e Navigation framework it would be beneficial to incorporate Human Centered Design. This approach considers human factors and addresses ergonomic challenges related to involvement.

According to SIP (System Interface Plan) the e Navigation concept embraces a strategy known as Human Centered Design (HCD) to understand and meet the needs of both ship users and shore users. This distinction is important because individuals on ships and those on shore have responsibilities, duties, requirements and work environments due to their interactions with elements such, as people and processes.

<u>Shipboard User Needs:</u>

- The systems installed on ships must be designed to enable the crew to perform their tasks effectively in challenging situations.
- It is important that navigational information is presented in a consistent and easy to understand manner. Data formats used for ship reporting should be globally standardized to ensure consistency, compatibility and efficiency. Automated reporting systems should be implemented for reporting requirements such, as Passage Plan declarations.
- The Standard Marine Communication Phrases (SMCP) are currently undergoing revisions to enhance their clarity. It is recommended to use SMCP for both digital communication. Visual representation of SMCP through e Navigation equipment should be the default requirement.
- There is a need for improvements, in performance, design and the Human Machine Interface (HMI) of ECDIS equipment. Here are some suggested upgrades:

    a. Implementing an interface like S Mode. Using standardized symbols,

    b. Enhancing the capability to digitally communicate and display planned routes between ships and shore stations for safety and efficient utilization of communication channels,

c. Enabling discussions and negotiations, with authorities regarding travel arrangements,

d. Skill to request and declare verification, as well as approve modifications made in navigational concerns, in an error-free and unambiguous way.,

e. Ability to digitally communicate with VTS, pilotage and port authorities.

f. It is necessary to display all Maritime Safety Information (MSI) in time, on interfaces, including information from systems, like AIS, NAVTEX and Safety NET. Since MSI is currently transmitted in text format, which automated systems cannot comprehend a new digital format based on SMCP is being created to ensure clear presentation of navigational interfaces. It is important to verify the authenticity of MSI messages and remove them if necessary.

- The safety of navigation greatly relies on automating self checks and status indications of devices well as ensuring clear indicators of data reliability, accuracy and quality.
- E Navigation systems should be able to select the suitable source, for navigational data based on its reliability without requiring user input.
- Standards and guidelines should be established to ensure that Human Machine Interfaces (HMIs) used in e Navigation systems and equipment are user friendly and easy to use under all operating conditions, including weather and sea conditions. The design of bridge layout, equipment and systems should prioritize considerations for usability.
- Bridge equipment should possess self description capabilities along with fault tolerance measures.
- E navigation systems and equipment should have the ability to update firmware automatically with user intervention or interruption in operation. To ensure compliance with requirements these systems should come with a certified and auditable hardware and software control system.

- Both users and developers must have access to usability assessments as well as feedback mechanisms, for any system or equipment implemented within the e Navigation concept.
- Therefore software developers need to update their programs in order to cater to the preferences and desires of their customers.
- Shifting, between berthing, piloting and communication can be easily managed with the communication equipment.
- To streamline administrative tasks and paperwork regulations should be revised based on the specific requirements and functions needed for service provision rather than on each individual piece of equipment.
- E Navigation will revolutionize crew training methods due to its extensive scope and overall nature. However training can also be tailored to suit ships, users or systems involved.
- The shipboard communication systems should be compatible with IP based ship communication systems. This will enable data exchange between IP based networks (such as internet connections or VDES) and networks that do not rely on IP. It is crucial to adhere to data transmission standards, like IH S 100.
- Optimizing bandwidth while ensuring data security and reliability is of importance.

<u>Shore-based User Needs:</u>

- To effectively utilize the services provided by maritime stakeholder communities in shore states it is important to establish systems such, as VTS (Vessel Traffic Services) and involve authorities and other relevant parties. By standardizing data formats like CMDS (Common Maritime Data Structure) and establishing communication infrastructures we can create a automated, reliable and efficient exchange of information among all marine players worldwide.

- However achieving harmonization of reports and documents from vessels well as making this information accessible to authorities and the public will take some time.

- Shore based systems need to be capable of handling volumes of information. To ensure redundancy and reliability backup systems and decentralized architectures should be implemented.

- To effectively present amounts of data in a user friendly manner for all ships prioritizing intelligent support systems is crucial. These systems should have clearly defined performance standards and design specifications or limitations.

- In anticipation of volumes of data traffic VTS Centers must make hardware and software adjustments to avoid disruptions, in user services caused by information overload.

The idea of e Navigation is a long term one and the driving factors and solutions, within it are continuously evolving to meet changing user demands and advancements in technology. We may witness the emergence of technologies and applications that cater to consumers and their specific needs. For instance there could be individuals using Virtual Reality to operate ships and ensure their navigation even when they are onshore or possibly in different continents and time zones. This scenario serves as an illustration of the future, in e Navigation.

3.1.2 S-MODE

Integrated Navigation Systems (INS) are one example of the equipment and systems that are now employed on ships and on land that can be utilized by the e-Navigation concept (including ECDIS, AIS, satellite communication, GPS, radar, etc.). As e-Navigation develops, it is anticipated that the function of these systems will expand, and numerous services and solutions based on their capabilities will be developed as part of the notion to improve navigational safety.

The design guidelines, for INS displays are specified in Module C of the IMO decision MSC.252(83) on Revised Performance Standards for INS. While this resolution outlines the interface requirements to meet user needs such as alarm management, enhanced situational awareness and support for decision making by the bridge team it does not provide an unified interface definition, for each device type included. This approach was likely taken to avoid hindering manufacturers freedom to develop their interfaces although the consequences of such a decision remain uncertain.

Figure 7. 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 [1], [2]

Manufacturers included a wide range of features, services, and interfaces on their equipment. Different versions of navigational equipment at distinct price points provide different specialized skills, necessitating the use of specific interfaces. Even the same manufacturer's navigational equipment developed in various years may have different interfaces. Figure 7 depicts interfaces of two ECDIS displays from different manufacturers.

Using standardized interfaces, in systems designed for presenting information like ECDIS can be an effective approach to achieving e Navigation objectives. The uniformity, consistency and clarity in how navigation information and alarmsre displayed play a role, in enhancing navigational safety. The IMO NCSR 3/28/1 recommendations on Standardized Modes of Operation (S-Mode) suggest the following first definition of the S-Mode: [3]

> "Advice on standardizing the design of navigation and communication systems, including screens, interfaces, and functionalities that can give the bridge crew and the passenger prompt access to vital information for the navigation system's conduct throughout the voyage, from berth to berth."

Due, to the availability of interfaces like S Mde, individuals who frequently interact with these interfaces, such as Masters, Pilots and Officers can easily switch to S Mde when necessary. The advantages of utilizing a standardized interface include shorter adaptation periods to navigate different ships interfaces reduced mandatory training durations, decreased potential, for human error and enhanced navigational safety.

S mode not only offers the capability to switch to a standard interface but also allows users to customize their profile files for the interfaces. This enables users to personalize displays according to their requirements, preferences and operating conditions.

3.2 Harmonized Information Exchange

3.2.1 Rapid Communication Facility

The definition of e-Navigation by the International Maritime Organization demonstrates the evident necessity for effective and strong ways of communication between ships and shore users. This requirement stems from the dangers and duties linked with navigational safety, security, and pollution. The efficient and accurate use of communicational facilities is one of the main components in lowering these associated hazards.

The e-Navigation concept provides ways to address the demand for reliable communication aboard. As previously stated in this thesis, one of them is the introduction of VDES. Another option is to employ the Wireless Local Area Network (W-LAN), which has shown promising results when used onboard ships by researchers.

Wireless LAN (W LAN) technology offers advantages compared to communication technologies. These include data speeds, for distances, low adoption and operational costs the ability to cover the entire network through node hopping, support for multiple frequency bands a small physical footprint and robust security standards. Modern W LAN networks have already achieved gigabyte per second throughput. However one limitation of this system is its operating range and signal dispersion. As the distance from the source increases signal interference and error rates also increase, affecting data throughput.

Additionally there are communication technologies such, as LTE, WiMAX and satellite based broadband that can be utilized onboard ships.

Despite the technological features of LTE connectivity, such, as a range of 60 nautical miles and high speed connection even prototype LTE based marine communication systems face performance and interference concerns due to the allocation of LTE frequency bands. These frequency bands vary significantly between networks and countries sometimes overlapping with bands.

On the hand WiMAX is a data transmission system that offers various transmission modes. It supports point to multipoint networks as portable and completely mobile access. This technology is based on the recognized 802.16 standard developed by the Institute of Electrical and Electronics Engineers (IEEE). Contrary to belief WiMAX technology is commonly used. However it's important to note that while WiMAX can operate at bitrates or across distances, like W LAN it cannot achieve both simultaneously. Operating at the range of 50 km increases error rates significantly resulting in an overall bitrate.

Reducing the range on the hand allows a device to operate at bitrates of, up to 75 Mbps, where Mbps stands for megabytes per second. However the average data transfer speed of WiMAX technology is 3 megabytes per second per user. One major disadvantage of WiMAX is the absence of regulated allocation for this technology. Various governments have previously assigned channels for different purposes related to WiMAX which limited its adoption. Another drawback of WiMAX is the requirement for base stations and frequency licenses leading to complexity in network operations and increased costs.

Currently there are emerging providers offering internet services through satellite based communication (SpaceX). Satellite communication offers advantages as it can cover regions with just one geostationary satellite while providing continuous high speed broadband service. However one significant drawback of satellite based connectivity is the installation and subscription costs associated with it. As these systems become more common and their associated expenses decrease over time satellite based data broadband communication has the potential to become the technology, in the marine sector.

Currently there are options available that can achieve high data transfer rates over long distances. However considering the cost effectiveness and accessibility of W LAN technology it may become a choice, for communication systems. With the connection speeds that W LAN offers it would be possible to download and upload information such as MSI updates ECDIS charts, Notices, to Mariners and more.

In the future, the e-Navigation concept's user demands may necessitate even more complex communication methods. AIS and VDES might be used by precise point-to-point communication systems to identify the exact direction and height of a communication beam to be broadcast. This beam might be a laser or a directed millimeter wave W-LAN transmission capable of multi-gigabytes per second.

3.2.1.1 Non-SOLAS Ships

The approach of the e concept divides ships into two categories; ships and non compliant ships. This categorization is based on the focus of the e Navigation concept, which primarily utilizes communication and navigation systems that SOLAS (Safety of Life, at Sea) ships are obligated to have. However it does not accurately recognize the capabilities and needs of SOLAS ships.

SOLAS ships are required to have a range of communication and navigation systems compared to SOLAS ships allowing them access to certain services that non SOLAS users cannot utilize. On the hand it is possible that services specifically provided for SOLAS ships may not be available to SOLAS ships.

Another important aspect of this two tier approach is safety. Issues may arise from using communication devices on SOLAS and SOLAS vessels potentially compromising navigation safety. The advantages and disadvantages of utilizing communication channels are discussed in detail. For instance using classes of AIS transceivers (Class B AIS for SOLAS ships and Class A AIS, for SOLAS vessels) could result in VTS Centers and other ships not properly receiving broadcasts from these vessels leading to hazardous situations or even accidents.

Another example involves the utilization of satellite communication, on ships adhering to the Safety of Life at Sea (SOLAS) regulations. By employing VDES and satellite based digital communication SOLAS ships will have global communication availability enabling them to utilize e Navigation services even in challenging conditions such as open seas and extreme weather. On the hand non SOLAS ships may lack advanced communication capabilities, which could limit their ability to fully embrace e Navigation services when outside the range of their own equipment.

According to a research paper titled "E navigation Services for Non SOLAS Ships " it is crucial that e Navigation services offered to SOLAS ships provide decision making support and deliver essential maritime information effectively. In order to enhance safety and maximize the benefits offered by the concept of e Navigation, for SOLAS vessels these services must address and improve the often poor navigational circumstances encountered by these types of ships [4]

The Republic of Korea conducts studies, on e Navigation and the Korean Ministry of Oceans and Fisheries has initiated the SMART Navigation project to investigate the current status, challenges and potential solutions related to providing e Navigation services for non SOLAS ships. The main reason for Koreas focus on this matter may be the fact that 90% of their fleet consists of SOLAS ships [4] which also account for a majority of maritime incidents involving Korean flagged vessels. It is anticipated that the SMART Navigation project could significantly reduce ship accidents under the flag by a combined 56.6% (13% for SOLAS ships and 43.6%, for non SOLAS ships) [6]. In the following chapter we will delve further into explaining and analyzing the SMART concept.

3.2.2 Maritime Connectivity Platform

The importance of a CMDS (Communication, Mitigation and Data System), in the IMO e Navigation SIP (Strategic Implementation Plan) is emphasized to address compatibility, security and efficiency challenges [7]. The need for a CMDS arose from communication difficulties experienced between prototype e Navigation testbeds and services. The initial problems were encountered during the EfficienSea project leading to the development of a prototype CMDS platform during the MONALISA project. Subsequently further enhancements were made during the ACCSEAS project resulting in the creation of the "Maritime Cloud" as the prototype platform.

As prototype e Navigation services emerged over time there was an increasing demand for a coordinated and standardized approach to data transfer. Consequently the Maritime Connectivity Development Forum (MCDF) was established to oversee the development of the Maritime Cloud. Its responsibilities included designing structures and aligning requirements and technical features through collaboration with international bodies like the International Organization, for Standardization (ISO) and International Electrotechnical Commission (IEC).

The platform was renamed as Maritime Connectivity Platform (MCP) previously known as the Maritime Cloud at the beginning of the EfficienSea 2 project. This change aimed to clarify that MCP is not just a data storage solution. A comprehensive connectivity platform. The term "cloud" has become more associated with data storage services, in the IT sector over time.

According to the established definition [8] MCP is an open source communication framework that enables reliable and seamless electronic information exchange, among all authorized maritime stakeholders across various communication systems. The scope of MCP goes beyond the requirements outlined in the IMO e Navigation SIP (which primarily focuses on navigation and reporting related data and information exchange) and the EU e Maritime initiative (which primarily addresses information requirements of administrations and businesses). In essence MCP aims to meet the information exchange needs of all stakeholders within the marine industry while ensuring confidentiality through user permissions and data protection.

The main objectives of the Maritime Connectivity Platform (MCP) are as follows:

- Enhance safety and efficiency, in the industry

- Utilize well established international maritime standards and communication technologies effectively to offer cost effective services and optimize available bandwidth usage.

- Establish guidelines for developing and enhancing both nonprofit software with a focus on maintaining information confidentiality and verifying authenticity.

- Gain recognition from organizations in the maritime sector, such, as IMO, IALA, IHO, etc.

3.3 Environmental Protection

The idea of e Navigation has the potential to contribute directly to pollution prevention. Onboard ship systems enabled with integrated e Navigation can collect data, on exhaust emissions and fuel consumption from sensors on engines, power units and other power generation equipment. This data can be stored in an e Navigation network like MCP. Then transmitted to shore based users and authorities in real time at regular intervals or upon request.

The services offered as part of the e Navigation concept, such as optimized routes in time can also help reduce emissions by minimizing fuel usage and improving fuel efficiency. According to a report titled "Opportunities for Reducing Greenhouse Gas (GHG) Emissions from Ships" released by IMO MEPC it is feasible to decrease GHG emissions by optimizing or reducing ship fuel consumption. The report explores operational measures to reduce emissions of GHGs (such as NOx, N2O, CO, CO2) and particulate matter from ships while evaluating different approaches, for decreasing fuel consumption. It highlights that adopting speeds during voyages and implementing better ship routing can significantly lower both fuel costs and associated emissions.

4. THE EFFECTS OF E-NAVIGATION

4.1 Development of formula to evaluate the effects of e-navigation

The percentage of risk reduction calculated as "65%" by the IMO e navigation Correspondence Group (CG) does not indicate a decrease, in the number of accidents. Instead it reflects a reduction in the proportion of each cause that can potentially result in loss of lives (PLL) and should be converted to the actual rate at which RCOs reduce risks associated with each direct cause. It is important to consider both the volume of accidents and how much they can be decreased by RCOs.

To ensure calculations regarding the impact of E navigation, under real conditions researchers propose using the following formulas:

Sav = Σ (rsad * arr)

= Σ (rsad * c * arr)

= Σ c (rsad * ahe * atf * aef)

where is :

c = Coefficient (65% for SOLAS ships, 55% for non-SOLAS ships)

Sav = Actual Volume of selected accident to be reduced among total accidents

rsad = Rate of selected accident distribution

arr = Actual Rate of risk reduction of each direct cause to be reduced

with arr = ahe + atf + aef

ahe = Rate of risk reduction of each detailed direct cause of Human Error

atf = Rate of risk reduction of each detailed direct cause of Technical Failure

aef = Rate of risk reduction of each detailed direct cause of External Factor

For instance when examining the data, from the Norwegian Maritime Authority (NMA) utilized by the FSA we can determine that 22.7% of total accidents, which encompass collisions and groundings are effectively reduced through the implementation of RCOs. This calculation is derived using the formula mentioned above.

4.2 The SMART-navigation concept

4.2.1 Background of SMART-navigation

The Global Positioning System (GPS) has revolutionized the way we navigate and travel, and its applications are becoming increasingly important in various fields, including transportation, logistics, and emergency services. However, traditional GPS technology has its limitations, such as low accuracy, signal blockages, and inadequate positioning in urban canyons or indoor environments. In response, researchers and engineers have been developing and implementing smarter and more efficient navigation systems, known as SMART-navigation, which utilize advanced sensors, algorithms, and communication technologies to enhance the performance and reliability of GPS-based navigation.
SMART-navigation can be defined as a set of technologies and methods that enable efficient and reliable navigation in complex and dynamic environments, such as cities, highways, and off-road terrains. It aims to overcome the limitations of traditional GPS navigation by integrating multiple sources of positioning, such as GPS, inertial sensors, vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication, and map data. By fusing these sources, SMART-navigation systems can provide accurate, reliable, and continuous positioning and guidance, even in challenging scenarios where GPS signals are weak or blocked.
The development of SMART-navigation can be traced back to the late 20th century, when the first GPS navigation systems were introduced in military and civilian applications.

However, it was not until the 21st century that the concept of SMART-navigation began to emerge as a multidisciplinary research and development field, involving expertise from various domains, such as electrical engineering, computer science, geomatics, and transportation.

One of the key drivers of SMART-navigation has been the growing demand for efficient and sustainable transportation, particularly in urban areas, where congestion, pollution, and safety issues are major concerns. SMART-navigation systems can help to address these challenges by providing real-time and personalized navigation services that optimize the route, speed, and mode of transportation, based on the user's preferences and the current traffic and environmental conditions. For example, a SMART-navigation system can recommend the most fuel-efficient and low-emission route for a hybrid or electric vehicle, or guide a pedestrian to a safer and more accessible path.

Another driver of SMART-navigation has been the advancement of sensor and communication technologies, which have enabled the integration of multiple sources of data and the development of new algorithms and models for positioning and navigation. For instance, inertial sensors, such as accelerometers and gyroscopes, can provide high-frequency measurements of the vehicle's motion and orientation, which can be used to improve the accuracy and continuity of positioning, especially in urban canyons or tunnels where GPS signals are weak or blocked. Similarly, V2V and V2I communication technologies can enable vehicles to exchange real-time traffic and environmental information, such as congestion, accidents, and roadworks, which can be used to update the navigation plan and avoid delays or hazards.

In the field of maritime transportation, the e-Navigation initiative, led by the International Maritime Organization (IMO), aims to enhance the safety, efficiency, and environmental performance of shipping by providing seamless and interoperable navigation services based on advanced communication and positioning technologies. The e-Navigation concept includes several components, such as electronic charts.

According to the table provided below cargo ships that operate in areas regardless of their length and fishing vessels that're less, than 20 meters in length do not possess nautical charts for navigation purposes. Furthermore small ships that are than 12 meters in length and fishing vessels under 10 tons do not have equipment such, as position fixing devices, compasses or radar. The Global Positioning System (GPS) can be utilized by fishing vessels equipped with radio equipment as mandated by the Fishing Vessels Act.

Ships \ Nav. equipment			Chart	GPS	Magnetic compass	Radar	Gyro compass
Cargo ships	less than 12m in length	near-coastal zone	×	×	×	×	×
		coastal zone	○	×	×	×	×
	12m or over in length	near-coastal zone	×	500GT↑	×	100GT↑	×
		coastal zone	○	20GT↑	500GT↑	100GT↑	500GT↑
Fishing vessels	less than 10 GT	○	×	○	×	×	×
	10 GT or over	lee than 20m	×	○	×	×	×
		20m or over	○	○	×	×	×
		24m or over	○	○	○	×	×
		35m or over	○	○	○	○	×
		45m or over	○	○	○	○	○

Table 1. Requirements of shipboard Navigational Equipment

Because maritime charts are crucial, for navigation at sea as for determining position SOLAS mandates that all vessels regardless of size must carry nautical charts to plan and visualize their intended voyage. They are also required to plot and monitor their positions throughout the journey.

On the hand GPS plotters are commonly used on SOLAS vessels for convenience purposes. However it's important to note that GPS plotters are not officially approved navigation equipment. The zoom in and zoom out features of chart displays on GPS plotters could potentially pose a risk to mariners, in situations.

4.2.2 Components of the SMART-navigation

Smart-navigation is a concept that refers to the use of technology to facilitate the navigation and access of information within a system. It involves the use of various components and tools that work together to provide an efficient and seamless navigation experience for users. In this article, we will explore the main components of smart-navigation.

- User Interface

The user interface (UI) is the visual representation of the system that users interact with. It includes elements such as menus, buttons, icons, and other graphical elements that users use to navigate through the system. The UI is a critical component of smart-navigation because it is the first point of contact between users and the system.

A well-designed UI is essential for providing an intuitive and seamless navigation experience for users. It should be easy to use, visually appealing, and provide clear and concise feedback to users. The UI should also be adaptable to different devices and screen sizes to ensure that the system can be used on a wide range of devices.

- Input Methods

Input methods refer to the various ways in which users interact with the system. Different users have different preferences when it comes to input methods, and the system should be designed to accommodate a wide range of options. Common input methods include touchscreens, keyboard and mouse, voice commands, and gestures.

The choice of input methods is an important consideration in smart-navigation because it directly impacts the ease of use and efficiency of the system. The input methods should be intuitive and easy to use, to reduce the learning curve and improve user satisfaction.

- Navigation Modes

Navigation modes refer to the different ways in which users can navigate through the system. Common navigation modes include browsing, searching, and filtering. The system should be designed to provide a flexible and adaptable experience, allowing users to navigate through the system in a way that suits their needs and preferences.

The navigation modes should be designed to meet the specific needs of the target audience and provide a seamless and efficient experience. The system should also be able to provide contextual feedback to guide users through the navigation process and prevent errors or confusion.

- Search Functionality

Search functionality is a critical component of smart-navigation, allowing users to quickly and easily find the information they need within the system. The search functionality should be designed to be intuitive and user-friendly, allowing users to easily enter their search terms and receive relevant results.

The search functionality should also be customizable, allowing users to refine their search criteria and filter the results to meet their specific needs. The system should also be able to provide suggestions and recommendations based on the user's search history and behavior.

- Personalization

Personalization is a key component of smart-navigation, allowing the system to provide a personalized experience for each user. The system should be able to learn from the user's behavior and preferences and adapt the navigation experience accordingly.

Personalization can take many forms, including customized menus, personalized search results, and personalized recommendations. The system should also be able to provide personalized feedback and guidance to help users navigate through the system more efficiently.

- Feedback and Analytics

Feedback and analytics are critical components of smart-navigation, allowing the system to gather data on user behavior and performance. The system should be able to provide feedback to users on their navigation progress and suggest ways to improve their navigation experience.

Analytics should be used to gather data on user behavior, preferences, and pain points. This data can be used to identify areas for improvement and refine the system over time. The system should also be able to provide detailed reports and insights to help stakeholders make informed decisions about the system's performance.

- Integration with Other Systems

Smart-navigation systems should be designed to integrate with other systems and applications, such as social media platforms, messaging apps, and email clients. Integration with other systems helps to improve the overall user experience by providing users with easy access to the information.

4.2.3 Architecture of SMART-navigation

The architecture of SMART-navigation is composed of several components, each of which is designed to enhance the navigation experience. In this article, we will discuss the different components that make up the architecture of SMART-navigation.

The first component of SMART-navigation architecture is the user interface (UI). The UI is the part of the system that the user interacts with. It is essential that the UI is designed to be intuitive and easy to use. Navigation systems with complicated UI can lead to frustration and confusion. The UI should be designed to provide the user with relevant information in a clear and concise manner. The UI should also be customizable, allowing users to choose the information they want to see and how it is presented.

The second component of SMART-navigation architecture is the data collection and analysis. Navigation systems rely on accurate and up-to-date data to provide accurate and reliable directions. Data collection and analysis are crucial for the success of SMART-navigation. The data collected can come from various sources, including GPS, traffic sensors, and user input. The data is analyzed and used to generate real-time information about traffic conditions, road closures, and other factors that may affect the navigation experience. The accuracy and reliability of this data are critical to the success of SMART-navigation.

The third component of SMART-navigation architecture is the route optimization algorithms. Once the data is collected and analyzed, the system can use route optimization algorithms to provide the most efficient route for the user. These algorithms take into account factors such as traffic conditions, road closures, and other factors that may affect the navigation experience. The algorithms can also be customized to take into account user preferences, such as avoiding toll roads or highways. The goal of these algorithms is to provide the user with the fastest and most efficient route to their destination.

The fourth component of SMART-navigation architecture is the integration of real-time traffic data. Real-time traffic data is collected from various sources, including traffic sensors and user input. This data is analyzed and used to provide real-time information about traffic conditions. This information can be used to provide alternate routes to avoid traffic jams or to alert users to delays in their current route. The integration of real-time traffic data is critical to the success of SMART-navigation, as it allows the system to provide the user with the most up-to-date information about their route.

The fifth component of SMART-navigation architecture is the integration of voice recognition technology. Voice recognition technology allows users to interact with the navigation system using voice commands. This technology is particularly useful in situations where the user needs to keep their hands free, such as when driving. The integration of voice recognition technology makes the navigation system more user-friendly and convenient.

The sixth component of SMART-navigation architecture is the integration of augmented reality (AR) technology. AR technology allows users to see virtual objects overlaid on the real world. This technology can be used to provide the user with more detailed information about their route, such as the location of landmarks or points of interest. AR technology can also be used to provide the user with a more immersive navigation experience, making it easier to navigate unfamiliar areas.

The seventh component of SMART-navigation architecture is the integration of machine learning algorithms. Machine learning algorithms are used to analyze user data and provide personalized recommendations. These algorithms can be used to recommend alternate routes based on the user's preferences or to provide suggestions for places to visit along the way. The integration of machine learning algorithms makes the navigation system more personalized and user-friendly.

In conclusion, the architecture of SMART-navigation is composed of several components, each of which is designed to enhance the navigation experience.

5. NEW TECHNOLOGY INTEGRATION FOR E-NAVIGATION

E-Navigation refers to the use of electronic technology to enhance the safety and efficiency of navigation. It is a concept that has been around for over a decade and has continued to evolve with the advancement of technology. The integration of E-Navigation into the maritime industry has brought about significant changes, and the future prospects are even more promising. In this article, we will discuss the future prospects of integration for E-Navigation.

Some of the future prospects of integration for E-Navigation can be reffered as the use of autonomous ships. Autonomous ships are vessels that operate without human intervention. They rely on various sensors and communication systems to navigate and operate. E-Navigation technology will play a significant role in the development of autonomous ships. The integration of advanced sensors, communication systems, and artificial intelligence (AI) will make autonomous ships safer and more efficient. E-Navigation will enable autonomous ships to make real-time decisions based on accurate and reliable data, leading to improved safety and efficiency.

Another future prospect of integration for E-Navigation is the use of augmented reality (AR) technology. AR technology can provide real-time information about the ship's surroundings, such as the location of other vessels, navigational hazards, and weather conditions. This technology can improve situational awareness and enable better decision-making. The integration of AR technology with E-Navigation systems will enable maritime personnel to have a more comprehensive understanding of their surroundings, leading to improved safety and efficiency.

The integration of E-Navigation with other industries is also a future prospect. The maritime industry relies on various industries to function, such as the shipping and logistics industry. The integration of E-Navigation with these industries will lead to improved communication and collaboration, leading to improved safety and efficiency. For example, the integration of E-Navigation with the shipping industry will enable better coordination of vessel traffic, leading to improved safety and reduced congestion in ports.

Another future prospect of integration for E-Navigation is the use of blockchain technology. Blockchain technology can provide secure and transparent data sharing, which is critical in the maritime industry. The integration of blockchain technology with E-Navigation systems will enable the secure and efficient sharing of data, leading to improved collaboration and efficiency.

The use of big data analytics is also a future prospect of integration for E-Navigation. Big data analytics can provide insights into the performance of vessels, which can be used to optimize operations and reduce costs. The integration of big data analytics with E-Navigation systems will enable the collection and analysis of vast amounts of data, leading to improved decision-making and efficiency.

Finally, the integration of E-Navigation with environmental protection is a future prospect. The maritime industry is one of the largest emitters of greenhouse gases, and there is a growing need for the industry to reduce its carbon footprint. E-Navigation technology can be used to optimize vessel operations, leading to reduced emissions and improved environmental protection. The integration of E-Navigation with environmental protection initiatives will enable the industry to reduce its impact on the environment while maintaining safety and efficiency.

In conclusion, the future prospects of integration for E-Navigation are promising. The integration of advanced technology such as AI, AR, blockchain, and big data analytics will lead to improved safety, efficiency, and collaboration. The use of E-Navigation in autonomous ships, environmental protection, and other industries will also have a significant impact. As the maritime industry continues to evolve, the integration of E-Navigation will play a crucial role in its success.

5.1 Advanced Ship Connectivity

5.1.1 Introduction

In the year 1865 the installation of the transatlantic cable took place. It had a capacity of 8 words, per minute which may seem low by todays standards not to mention the cost of $10 per word (to $134 in todays values). Within ten years a network of cables was established, connecting cities around the world. By 1897 there were 162,000 miles of cable spread across various locations with London serving as the central hub for this communication network within the Commonwealth. This remarkable communications system revolutionized shipping communication. Brought about transformations in the shipping industry. Prior to its establishment ships often had to wait idle in ports for weeks awaiting instructions on what goods to load as return cargo. As of mid 2012 existing transatlantic systems demonstrated a design capacity of 49.5 Terabytes, per second (Tbps).

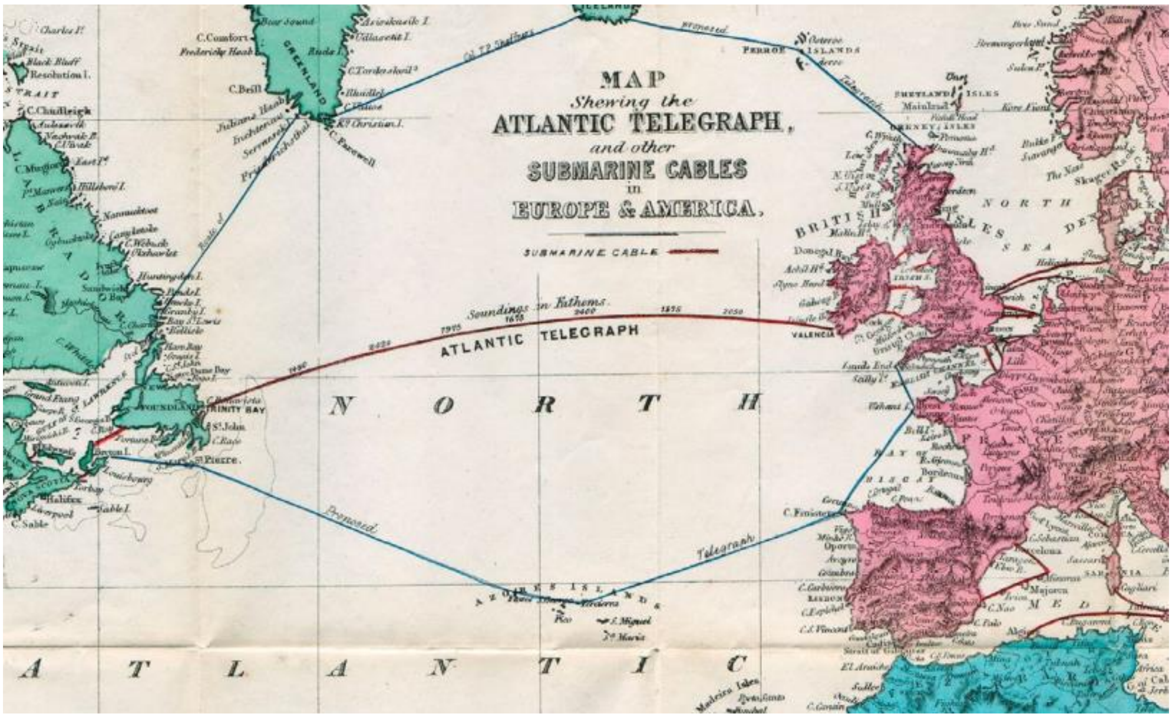

Figure 8. The transatlantic telegraph cable of 1865, Source: Atlantic-Cable.com

In particular and taking into account the above, ship connectivity refers to the use of advanced communication technologies to improve communication and data sharing between ships and shore-based operations. It is a concept that has become increasingly important in the maritime industry as vessels become more connected and data-driven. In this article, we will discuss the importance of advanced ship connectivity, the technologies involved, and the benefits it offers.

In today's world, communication is critical in all aspects of life, and the maritime industry is no exception. In the past, communication between ships and shore-based operations was limited to voice and radio communication. However, with the advancement of technology, communication has become more advanced, and data sharing has become more critical. Advanced ship connectivity enables real-time communication and data sharing, leading to improved safety, efficiency, and collaboration.

The era of ship connectivity is upon us and will make a dramatic impact on ship operations as we know it today.

5.1.2 Historic and current drivers

In 1988 the Global Maritime Distress and Safety System (GMDSS) was established with the goal of enhancing safety and facilitating the rescue of ships. Chapter IV of the International Convention, for the Safety of Life at Sea (SOLAS) introduced regulations that defined the functionalities and communication equipment required for GMDSS. These regulations are applicable to all passenger and cargo vessels above 300 tons engaged in voyages.

The GMDSS primarily relies on radio systems such as VHF, MF and HF which do not provide data services. The digital satellite communication systems used in GMDSS like Inmarsat C and EPIRB have limited data rates that're suitable for distress alerting and safety messaging purposes. Since its inception there have been changes to GMDSS regulations with little new technology being introduced. However the International Maritime Organization (IMO) is currently reviewing these requirements to establish an updated set of GMDSS standards by 2017.

Communication in operations also serves as an aid and is mandatory for reporting to maritime authorities. For instance;

- Two way voice communication via radio or satellite plays a role as it allows bridge navigators to exchange information, with vessels or shore based parties regarding route choices, weather conditions or navigational hazards.

- Automatic Identification System (AIS); AIS messages are transmitted on VHF channels to provide information, about vessel identification, position, course and speed for the purpose of collision avoidance. These messages can be received by vessels or AIS base stations. There is now a satellite overlay (S AIS) to expand coverage.

- Long range identification and tracking (LRIT); This system requires vessels to report their identification and position to their flag administration four times a day typically using satellite communication.

- Vessel traffic service (VTS); This is a traffic monitoring system established by harbor or port authorities to air traffic control for aircraft. VTS systems commonly utilize radar, CCTV, AIS data and VHF radio communication for two way exchanges to track vessel movements and ensure safety within a geographical area.

- Port arrival notifications (FAL requirements) and various ship reporting schemes, for port states; These requirements often pertain to goods transportation and prevention of marine pollution issues.

There is another form of communication driver that is related to the purpose of the vessel. Unlike the discussed drivers this particular communications application is not mandated by regulations. Rather implemented voluntarily to enhance operations and achieve cost savings for shipowners or improve service quality, for charterers. Some examples of applications may include:

- Cargo logistics and monitoring applications
- Route planning and energy efficiency applications
- Administrative communication between the vessel and the shipowner’s HQ.
- Upload of gathered data (e.g. seismic data or environmental data)

Investing in communication equipment, on ships has been driven significantly by the need to provide welfare and entertainment to crew and passengers. Ship owners have recognized that offering access to TV and the internet is crucial to attracting top quality crew members. All, who would want to be stuck on a vessel for weeks without the ability to connect with loved ones on Facebook during their off duty time?. Who would want to spend a holiday on a cruise ship where they can't check their emails or watch their favorite team play in the Champions League? The influence of our habits is evident in this development along with the decreasing costs and increased competition, within satellite communication industry.

5.1.3 State of the art communication and future developments

VHF, MF and HF are widely used radio systems, in the community. They play a role in meeting the GMDSS requirements, for SOLAS vessels. The services offered through these systems share similarities.

- Duplex voice service, with digital selective calling (DSC) for automated call setup
- Distress alerting capability
- Telex with printing facilities

The differences between the systems relate to the frequency bands used and the coverage areas.

SYSTEM/BAND	TYPICAL COVERAGE FROM EARTH STATION
VHF	40 - 60 nautical miles
MF	150 - 200 nautical miles
HF	Worldwide (given appropriate conditions & frequency)

Table 2. Typical coverage of radio systems

These historical radio systems are typically operated by authorities on a commercial basis and are offered as a free service, to the nautical community.
Although having a free service is beneficial for seafarers maritime authorities do not actively promote the growth of maritime broadband communications. This lack of enthusiasm and limited technological advancements pose as barriers contributing to the scarcity of data services in the VHF, MF and HF bands. Since the available bandwidth in these bands is already quite restricted any new data service would remain band compared to alternatives like satellite and mobility. Furthermore there are limitations on service coverage. Limited to distances from base stations (VHF and MF). Well as constraints on service quality for long distance connections (HF).

Because of these restrictions, development in legacy radio systems often faces limitations. However there is hope, in the concept of VDES (VHF Data Exchange System) which seeks to provide a data service using existing VHF radio infrastructure.

The International Association of Marine Aids, to Navigation and Lighthouse Authorities (IALA) has developed a technology called VDES with the aim of improving upon the existing VHF Data Link (VDL) used by AIS. The goal is to create a channel for data exchange that can support e Navigation applications. VDES is based on ITU R M.1842 1, which introduces modem techniques and enables higher data rates reaching up to 307.2 kbps per 100 kHz. This represents an improvement as it is 32 times faster and 8 times more efficient compared to the AIS channels that operate at 9.6 kbps, per 25 kHz.

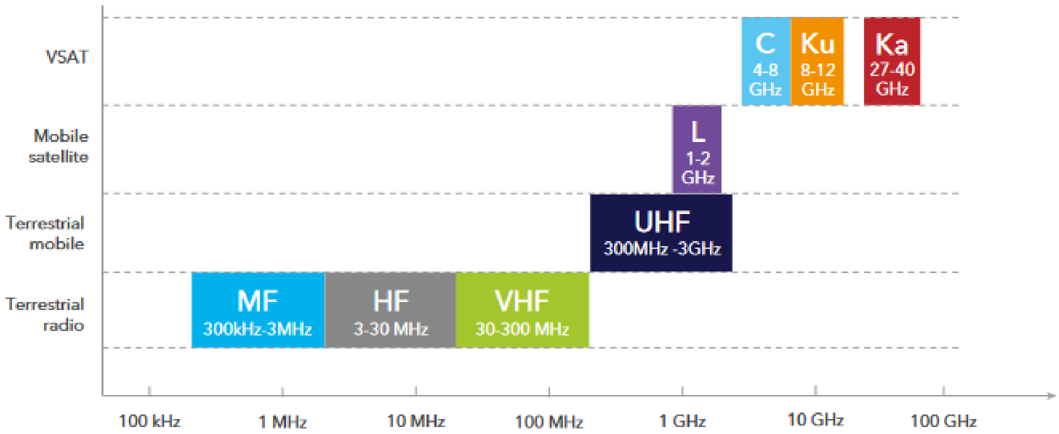

Figure 9. Frequency bands relevant for maritime communications

Since its establishment, in 1976 Inmarsat has been a trusted provider of satellite communication services to the community. It operates a network of L band satellites positioned in Geostationary orbit at an altitude of 35,786 km along with gateways connected to networks. Inmarsats L band satellites offer a range of services. One such service is Inmarsat C, which's a low rate messaging product introduced in 1992 and commonly used for GMDSS boat system setup. Another offering is Fleet Broadband, a family of broadband products launched in 2007 that are designed for the Inmarsat 4 satellites and capable of delivering speeds reaching, up to 500 kbps. [10], [11]

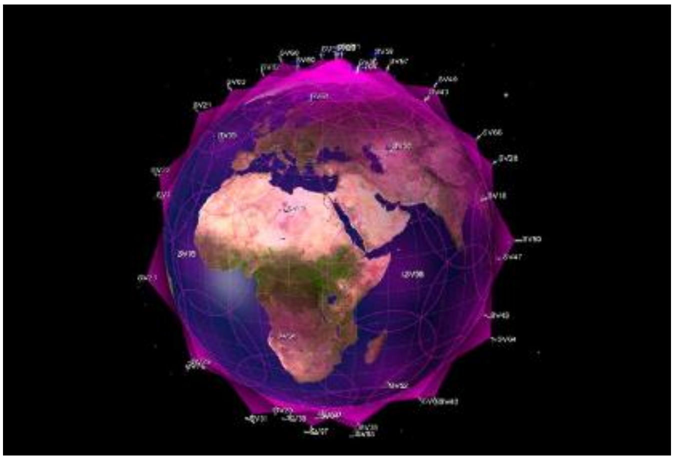

Figure 10. Iridium's constellation of 66 LEO satellites

Similar, to Inmarsat Iridium operates as an L band satellite provider. However Iridiums satellites are positioned in Low Earth Orbit (LEO) at an altitude of around 780 km. The operational commencement of Iridium dates back to 1998 when they deployed a constellation consisting of 66 satellites. These Iridium satellites have the ability to directly communicate with neighboring satellites through Inter links (ISL) which reduces the reliance on gateways and ground switching. With a speed of 27,000 km/s it takes about 100 minutes for the satellites to complete one orbit around the Earth and roughly 8 minutes to cross the horizon from a fixed ground location. This dynamic nature poses challenges such, as Doppler effects and satellite handovers when users are engaged in sessions. One notable advantage of Iridium lies in its moving LEO satellite constellation that ensures coverage over the entire surface of our planet including polar regions. [12]

5.1.4 Ship connectivity in the future

Existing connection services are being pushed to their limits in a marine industry where requirements are continually growing and data demand is rapidly increasing. With a further 7 Global Xpress satellites entering operation by 2025, Inmarsat has committed significant time and money in building a new generation of connectivity solutions and a step-change in the capacity accessible through its networks.

Fleet Xpress Enhanced is the version of Inmarsats connectivity service, which offers an integrated solution powered by the most advanced satellite network, in the world the Global Xpress Ka band network. This technology allows owners to easily adjust their allocation and adopt applications as their needs evolve. The result is improved efficiency, sustainability and staff well being. In addition this enhanced offering provides Inmarsat partners with a platform to offer value added services and host applications while shipping companies have access to a range of functions from office tools to cutting edge powered solutions.

Fleet Xpress Enhanced facilitates an step by step approach to transformation contributing to long term initiatives aimed at reducing carbon emissions and improving crew welfare. Importantly this technology is designed for integration with communication networks, particularly Inmarsats proposed multi dimensional network called ORCHESTRA. This innovative method has the potential to revolutionize connectivity on a scale and at various hotspots around the world.

ORCHESTRA by Inmarsat will be a network, in its category.

A unique and revolutionary global network, consisting of dimensions will redefine connectivity on a scale. It aims to offer the mobility capacity including hotspots with unparalleled speed and the lowest latency, among all existing or planned networks. This innovative solution, called ORCHESTRA represents a transformation of Inmarsats services by combining their ELERA (L band) and Global Xpress (Ka band) networks with terrestrial 5G capabilities. Additionally it incorporates targeted earth orbit (LEO) capacity and dynamic mesh technologies to create a single solution for global mobility needs. The purpose of this approach is to meet the growing demands for bandwidth from diverse applications in both commercial and government mobility sectors. By utilizing the strengths of each component ORCHESTRA enables high performance connectivity anywhere while effectively resolving standing congestion issues at high demand hotspots like major ports, airports, sea canals and airline corridors. This integration seamlessly combines Inmarsats existing GEO) networks with 5G infrastructure, alongside the deployment of a new LEO satellite system.

- **ELERA:** provides a critical layer of always-on connectivity with all-weather resilience.
- **Global Xpress:** delivers reliable, high-speed, global coverage with security and full redundancy.
- **Terrestrial 5G:** adds ultra-high capacity at specific high demand hot spots, such as busy ports, airports, straits and sea canals.

- **LEO:** a small, targeted constellation of 150-175 satellites layering additional high capacity over further high demand areas.

This layered method is reinforced with a 'dynamic mesh network', which enables individual terminals to operate as nodes, routing traffic to and from other terminals. The potential to expand the range of direct links to those outside that range, such as ships beyond 5G's reach, will introduce a significant new dimension to networking.

The network named ORCHESTRA was being tested in Singapore, which is known for being one of the container ports, in the world. This location poses challenges due to its weather conditions, including heavy rain and high humidity. The tests involved establishing communication between land based signal towers and ships offshore using Inmarsats technologies across combinations of frequency bands and onboard terminal equipment, on vessels.

Figure 11. Orchestra’s test

The tests demonstrated the effectiveness of the interconnected pathways, in the ORCHESTRA maritime network. These pathways are designed to cover a distance of 10 kilometers (6.2 miles) and provide a speed of 100 megabits per second per connection. The overall network can extend up to 30km (18.6 miles). Beyond, allowing for tasks like downloading an HD movie in 40 seconds. With five stations near Singapore this location alone could provide over 10 gigabits, per second of connectivity.

5.2 Internet of Things

The concept of the Internet of Things (IoT) has perspectives depending on the data generated by connected objects and the technology used. In the stages of implementing IoT the focus was, on identifying objects through radio frequency identification (RFID) tags. However with advancements the vision of IoT has evolved to include various technologies and smart sensors. IoT plays a role in introducing generations of compelling applications and services in areas such as Industrial IoT (IIoT) Industry 4.0 and Society 5.0. Figure 12 displays the technologies that have an impact, on IoT.

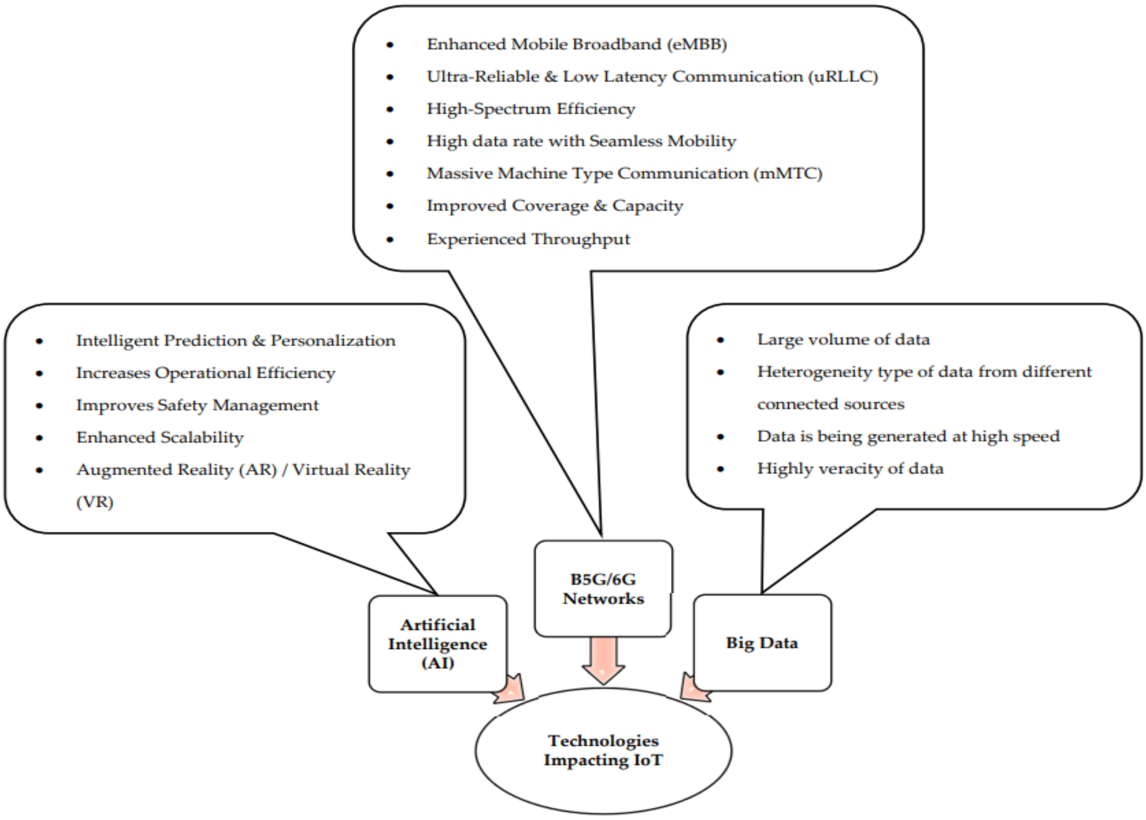

Figure 12. Technologies impacting the IoT.

E-Navigation architecture based on Internet of things

All forms of items within the unrestricted Internet of things are capable of linking together. Application-based communication links are established as per specific needs. The Internet of things is built on a global network that is carefully curated and highly exclusive. Using an open system architecture [13], data is transmitted and received seamlessly. The examination of e-Navigation architecture involves the application of different approaches.

These approaches specifically focus on architecture and are conducted on dry land. Ship end systems, communication links, and communication technology systems were all utilized to improve communication efforts. Management system of goods and route systems that concatenate identification. Each system within a network can exchange and combine to form a vast network. Information is meant to be shared, but it must be approached in a thoughtful way. It's not just about exchanging tidbits of knowledge, but rather about building understanding together. Such an understanding requires an openness and curiosity that can be difficult to foster, but is essential for growth. Learning how to share information effectively takes practice and patience. It's important to be clear and direct, but also receptive to feedback and open to making adjustments. By working together and sharing our experiences, we can generate new insights and deepen our knowledge. So let's make the effort to share more openly and thoughtfully – the rewards will be worth it.

By examining the internet of things [14] the architecture of e Navigation and the concept and technical framework of the Internet of Things we can explore the e Navigation technical architecture from a ship based perspective. This involves combining communication links, with distribution technology and ideas from the Internet of Things. The e Navigation technology architecture is built upon communication means that connect shore based systems, ship end systems and communication links in order to create an integrated navigation system. Additionally the sensor identification system plays a role in the Internet of Things. By incorporating perception systems for goods, channels, navigation aids and other aspects into the e Navigation architecture data acquisition is significantly enhanced. Ultimately this enables information exchange between ships and space based command and control systems as all relevant systems from ship end to space based platforms. Investing in IoT is crucial for enhancing e Navigations framework. As a result a new comprehensive structure system with increased strength, larger capacity higher levels of informatization has been established—an upgrade, to e navigation structure.
The navigation architecture is divided into five categories; connection, WWRS, CMDS, ship and shre based environment. You can refer to Figure 13 for an example..

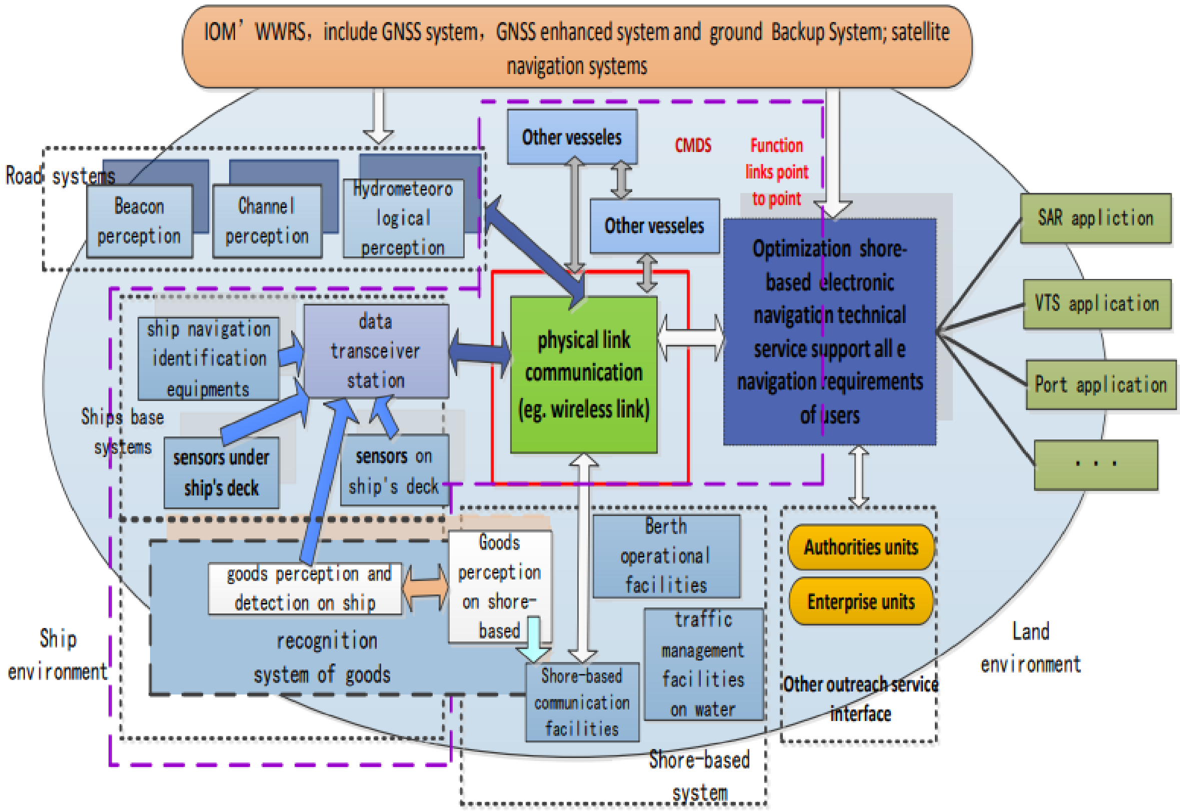

Figure 13. E-navigation architecture based on iot perspective

After comparing figure 12 and figure 13 the new architecture, which is based on an e navigation framework incorporates systems such, as ship based systems, goods identification system and shared based goods identification from the Internet of Things. This integration allows for data collection. Additionally it enhances physical link communication. Improves the transmission of marine data in terrestrial environments.

All processed data can be securely transmitted between subsystems within the structure as per the requirements, for data sharing. The implementation of data acquisition secure transmission protocols and intelligent distribution enables e Navigation to offer comprehensive content, increased reliability and prompt emergency response services to all users including shared based users.

5.3 Maritime Cloud

The Maritime Cloud is defined as:

> *A communication framework enabling efficient, secure, reliable and seamless electronic information exchange between all authorized maritime stakeholders across available communication systems.*

The 'Maritime Cloud' enables the smooth interchange of information between multiple systems and across various communication lines in the Maritime Domain.

The Maritime Cloud is not a'storage cloud' that has all information about every ship and cargo. It also cannot relate to 'cloud computing'. The Maritime Cloud is the realization of the defined communication strategy for e-navigation as described in the IMO MSC85 report (MSC 85-26-Add.1):

> *a communication infrastructure providing authorized seamless information transfer on board ships, between ships, between ship and shore, and between shore authorities and other parties, with numerous associated benefits.*

The Maritime Cloud consists of a set of standards, infrastructure and reference implementations of services. These components, along with governance enable maritime entities to exchange information effectively through interoperable information services. It utilizes interfaces and various communication options to enhance communication related to berth to berth navigation and associated services.

The implementation of the Maritime Cloud does not aim to replace existing infrastructure, methods and systems in one go. Instead it takes an approach by transitioning towards a service oriented architecture for exchanging information. The Maritime Cloud will be used in a manner allowing for increasing levels of cooperation, across business domains. It also ensures that supporting systems can communicate with each other in an standardized way.

According to the aforementioned:

The Maritime Cloud is:

• The implementation of the specified communication strategy for e-navigation.

• An explanation of the complexities of selecting the greatest available communication channel in real time.

• A framework enabling the introduction of enhanced or automated information services enhancing berth to berth navigation and related services for safety and security at sea and protection of the marine environment

The Maritime Cloud is NOT:

• A 'storage cloud' containing all information about every ship or cargo

• 'cloud computing'

• A specific communication link

The Maritime Cloud provides e-navigation over physical communication lines.
Existing and new communication channels may be used to share information via the Maritime Cloud.

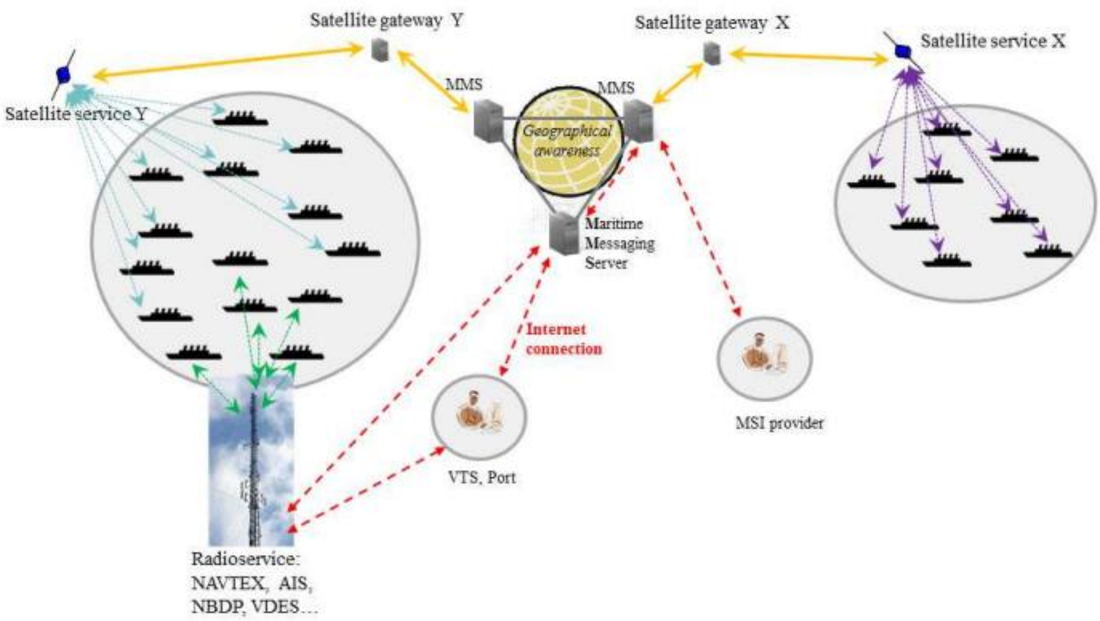

Figure 14. Geographical awareness

Currently the provision of information services, like the MSI service within the GMDSS is done through NAVTEX and SafetyNet communication services. However these technologies based on TELEX do not offer S 100 data distribution that can be displayed on oriented systems. When it comes to representatives interacting with VTS they can use VHF voice communication and AIS. For functions Application Specific Messages over AIS can be. These communication services are provided to ships free of charge.

The Maritime Cloud has the capability to deliver a Geocast MSI Service by utilizing Application Specific Messages via AIS. This can be backed up by commercial datalinks. When two way datalinks are accessible this system will enable an introduction of an MSI service that provides machine visually representable information while assuring automatic quality transmission.

The existing AIS system has limited capacity, in areas where additional data services cannot be introduced. To safeguard the purpose and functionality of AIS, IALA and ITU are working towards allowing the implementation of VDES (VHF Data Exchange System).
The VDES option allows Application Specific Messages originally used on AIS to be transmitted on channels. This helps preserve the capacity and intended purpose of existing AIS while enabling ship, to ship and ship to shore communication with a 10 30 times higher

data capacity than AIS. The VDES system may include a two way communication link making it globally applicable. This service can provide information services based on machine readable formats near VTS centers and ports possibly extending to other areas if the necessary infrastructure is in place – even globally including polar regions if there is a viable business case, for establishing satellite service.

Another technology called NAVDAT has already received ITU authorization. Will undergo testing in the coming years. It aims to create a version of the broadcast system using the frequency band as NAVTEX. By reusing the existing framework NAVDAT could deliver bandwidth broadcasts for an MSI Infrastructure Service using S 100 structured data.

In conclusion, the benefits of the Maritime Cloud include:

- The ability to utilize existing communication systems and seamlessly communicate across systems also facilitating the transition, to technologies and systems.
- Having a communications queue to handle actors efficiently.
- Automatic quality assurance of communication links and information delivery through the use of automatic acknowledgments when using the Maritime Messaging Service.
- Additional service available for verifying the authenticity of the origin and content of information (not generally required).
- Enabling the creation of a communication terminal that can automatically switch between channels to identify and address specific actors.
- Facilitating the development of improved information services based on an open architecture that allows for alternative distribution methods or service points.
- Establishing a framework that enables data exchange, between MRCC, VTS, etc. onshore.

5.4 Artificial Intelligence

The maritime industry is an essential part of global trade, with vessels transporting over 80% of the world's goods. However, the industry faces various challenges, including safety, efficiency, and environmental sustainability. E-navigation is the use of technology to support and enhance maritime navigation, including safety, efficiency, and environmental protection. Artificial Intelligence (AI) has the potential to revolutionize e-navigation by providing real-time situational awareness, enhancing decision-making, and optimizing vessel performance. This article explores how AI supports e-navigation, including its benefits, challenges, and future prospects.

Benefits of AI in E-navigation:

- Improved Safety

Safety is a critical concern for the maritime industry, and the use of AI can help improve safety by identifying and mitigating potential hazards. AI algorithms can analyze data from various sensors and sources, such as Automatic Identification Systems (AIS), radar, weather forecasts, and sea-state information, to provide real-time situational awareness to the crew. This allows the crew to make informed decisions, avoid risks, and take necessary actions to prevent accidents.

For example, AI can be used to identify potential collisions by analyzing vessel trajectories and predicting their future positions. This can help the crew take necessary evasive actions, such as altering course or speed, to avoid a collision. AI can also be used to identify potential grounding risks by analyzing the vessel's speed, course, and water depth. This can help the crew take necessary actions, such as reducing speed or altering course, to prevent grounding. Moreover, AI can help vessels navigate in adverse weather conditions, such as heavy rain, fog, or storms. AI algorithms can analyze weather data, such as wind speed, direction, and precipitation, to provide real-time weather forecasts and situational awareness. This can help the crew make informed decisions, such as altering course or reducing speed, to avoid risks associated with adverse weather conditions.

In addition, AI can help vessels navigate in areas with high traffic density, such as ports or busy shipping lanes. AI algorithms can analyze AIS data to identify potential collision risks and provide situational awareness to the crew. This can help the crew make informed decisions, such as altering course or speed, to avoid collision risks.

- Optimized Route Planning and Decision-making

AI can also be used to optimize route planning and decision-making, thereby enhancing safety and efficiency. AI algorithms can analyze a vast amount of data, including weather, sea conditions, traffic density, and vessel characteristics, to determine the optimal route and speed for a vessel. This can help vessels avoid dangerous areas and reduce the risk of accidents.

For example, AI can be used to optimize route planning by considering various factors, such as weather conditions, sea currents, vessel speed, and fuel consumption. AI algorithms can analyze weather data, such as wind speed and direction, to determine the most fuel-efficient route. This can help vessels reduce fuel consumption, emissions, and operating costs.

Moreover, AI can be used to optimize vessel performance by analyzing performance data, such as engine efficiency, fuel consumption, and speed. AI algorithms can adjust the vessel's settings, such as engine power and speed, to optimize performance and reduce fuel consumption. This can help vessels operate more efficiently and reduce their environmental impact.

Furthermore, AI can support decision-making by providing real-time situational awareness and data analysis. AI algorithms can analyze data from various sensors and sources, such as AIS, radar, and weather forecasts, to provide the crew with real-time information and insights. This can help the crew make informed decisions, such as altering course or reducing speed, to avoid risks and optimize performance.

- Reduced Workload and Increased Efficiency

AI can also be used to automate routine tasks, such as route planning, weather forecasting, and communication. This can reduce the workload on the crew and free up their time to focus on more critical.

5.5 Sensor Technology

Sensors are a type of equipment found on cargo ships. As a result the data they provide is typically comprehensive and accurate. The use of sensor technologies is rapidly expanding, which will bring about regulatory challenges. With the availability of computing components there will be opportunities, for businesses and researchers. These electronic devices will have the ability to gather and analyze data through a network connection to a device. The advancement of wireless sensor technology and the emergence of nanomechanical sensors will play a crucial role in revolutionary advancements, in environmental monitoring and data collection.

5.5.1 Remote Sensing

There will no longer be a need to travel back, to areas for data uploads or sample collection for analysis. This is because data can now be acquired autonomously through a network of sensors that have time communication and data transfer capabilities. To establish a network architecture for the shipping industry these sensors will require certain features such as self calibration fault tolerance, high transmission capabilities, wireless functionality, recyclable materials for easy disposal, durability, ultra low energy consumption, miniaturization the ability to exhibit active behavior and compatibility with network modules (like master slave layouts). All equipment, on board whether critical or non critical will have the ability to monitor, control and regulate its status. [16]

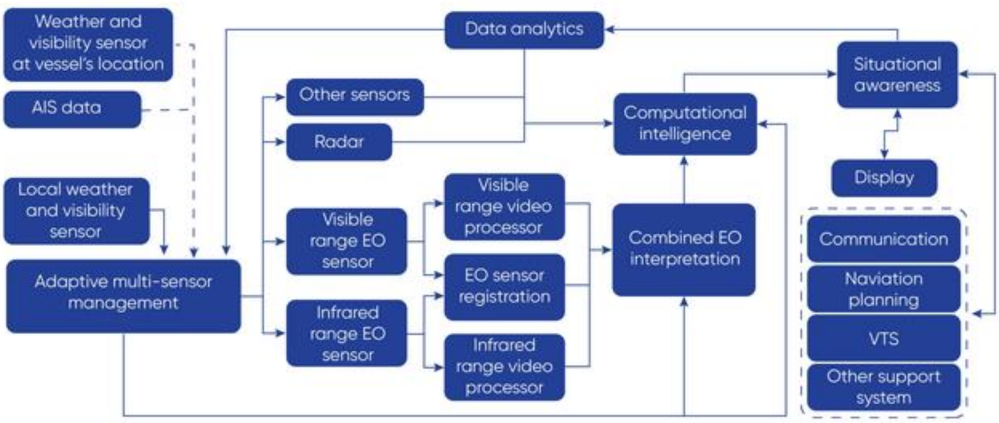

Figure 15. Flowchart of sensors

5.5.2 Integrated Bridge System (IBS)

Bridge navigation equipment encompasses a range of systems that support the efficient navigation and protection of the marine environment. With the increasing integration of sensors, technical systems, displays and advanced decision support systems combined with alerts it is crucial for the bridge crew to maintain awareness.

In response, to these changes in performance standards and technological requirements for bridge equipment, equipment suppliers and integrators have introduced products that go beyond current compliance levels. For instance Kongsberg Maritimes Sensor Fusion has been integrated into their generation of integrated bridge systems (IBSs). This system combines sensors with navigation aids like radar and sonar into a single platform to provide improved situational awareness for bridge personnel. It offers a real time picture of navigation based on data from diverse sensors.

The displays, on Kongsbergs IBS provide information to facilitate vessel navigation enhanced maneuvering capabilities, energy management and increased safety. Additionally Kongsberg has also introduced an autopilot system that integrates autopilot and trackpilot functions with joystick control and dynamic positioning in an unit.

Figure 16. New generation of Integrated Bridge System (IBS)

5.5.3 Forward - looking sonar (FLS)

Active sonar, also referred to as an echo sounder, by the International Maritime Organization (IMO) is utilized by ships to determine the distance between the ships keel and the bottom surface. Forward looking sonar, a type of echo sounder detects features and objects ahead of the ships bow. Despite being available in the sector this technology is not commonly included in a ships navigation sensor system.

Methods for detecting bottom features, objects and soundings involve sending a sonar signal along the vessels trajectory or transmitting a single pulse to capture snapshots of the environment. As the vessel moves along its course it builds up a representation of both the topography and specific targets.

The range of looking sonar can vary from eight to twenty times the depth depending on factors such as bottom conditions and target characteristics. It works effectively when scanning sloping bottoms or when detecting targets composed of hard rock or coral, with distinct acoustic signatures. There are FL sonar products that can provide both two three dimensional visualizations of what lies ahead offering a more accurate depiction of future navigational paths.

To ensure the accurate performance it is essential to mount FL sonar transducers in a hull area that is free, from turbulence caused by objects located in front of the mounting site. For accuracy and usefulness each transducer should have a view both horizontally towards the bow and vertically from the waterline to the bottom.

The Echopilot 3D Forward Looking Sonar utilizes two transducers installed at the midpoint of the hull from the keel. Towards the back third of the vessel. Figure 16a illustrates how these transducers are placed internally within the hull.

The Farsounder 1000 Navigation Sonar uses a transducer positioned on the bow either with a fairing tube integrated into an standard bulb or, as a separate installation. Figure 16b depicts how this transducer is installed externally when viewed from forward of the bow.

Figure 17: FL-Sonar Transducer Installations (1a. Dual EchoPilot Transducers Mounted Athwartships (left) and b. Single FarSounder Bow-Mounted Transducers (centre and right)

5.6 Augmented Reality

Today, mariners on a ship bridge have to exert great efforts to alternate their focus between the separate interfaces on the bridge in order to achieve situational awareness. At the same time, their perceptual awareness of what is happening outside the ship needs to be maintained, which constitutes a crucial aspect of the demand on the mariners during operations. However, ship bridge consoles consisting of fragmented and detached systems force mariners to shift their attention between the separate systems interfaces on the inside of the ship bridge and what is happening on the outside.

Emerging technologies, such as augmented reality (AR), may provide new ways of designing user interfaces for ship bridges that meet the unique needs of mariners to synchronise their personal experience of control with their overall situational awareness, both inside and outside of the vessel.

Augmented Reality (AR) is where computer generated graphics is combined and placed to coexist together with the real physical environment. Azuma defines AR by three main characteristics:

1. Combines real and virtual

2. Is interactive in real time

3. Is registered in three dimensions

One method to achieve this involves utilizing a two overlay of video graphics. In this approach the user observes the actual image captured by a camera merged with an object displayed on a 2D screen. Another approach entails using a Head Mounted Display (HMD). A three dimensional display that aligns with the users line of sight and permits unrestricted head movement and full body mobility. This HMD incorporates combiners positioned in front of the user enabling them to perceive the real physical world, around them including what lies behind it. [15].

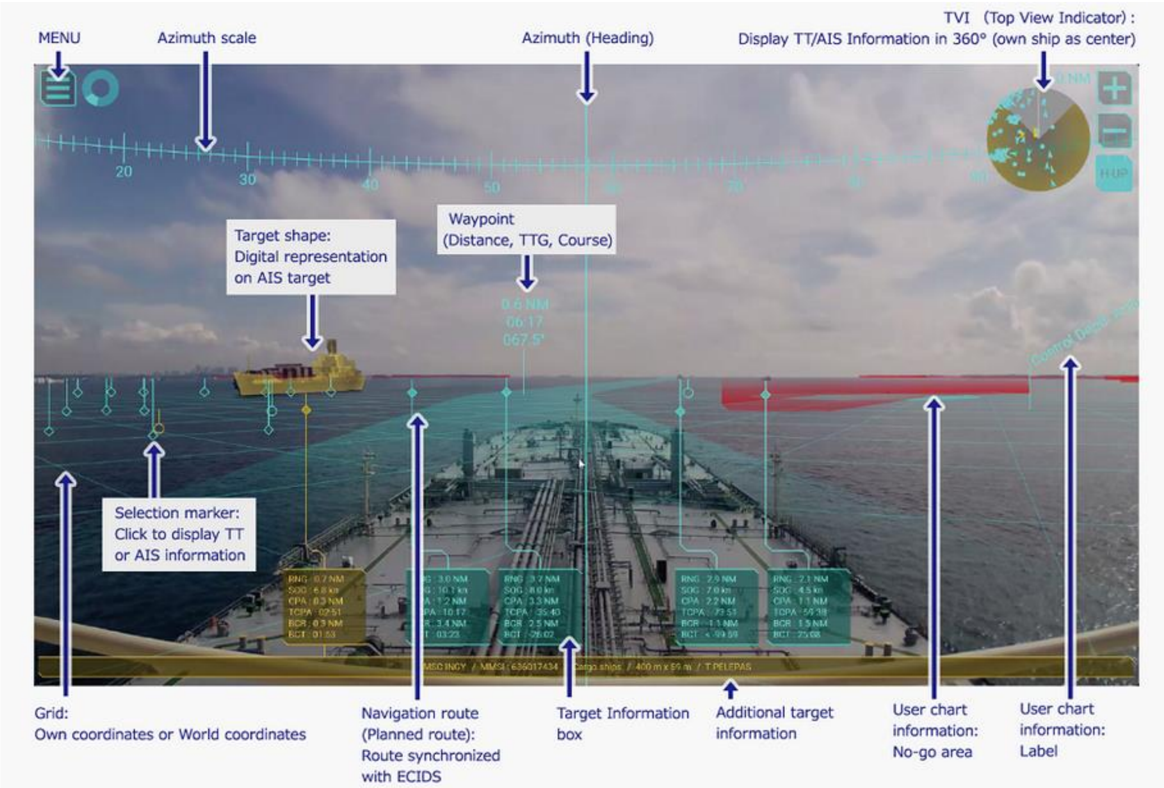

Figure 18. Presentation slide explaining AR Navigation System screen used in the conference in Dubai, 2020 (vessel under way in the Kanmon Straits)

The advantage of adopting augmented reality when building an interactive human-computer system is that it may be developed as a nncmmand interface. This means that the system may comprehend the present context and operate in accordance with it instead of the user's commands. This can benefit the user in three different ways:

1. By decreasing the interaction cost to perform a task.

2. By reducing the user's cognitive load.

3. By combining multiple sources of information and minimizing attention switches.

Other than contextual based interaction modern HMDs also have the capabilities to get input data through eye gaze, gestures and voice.

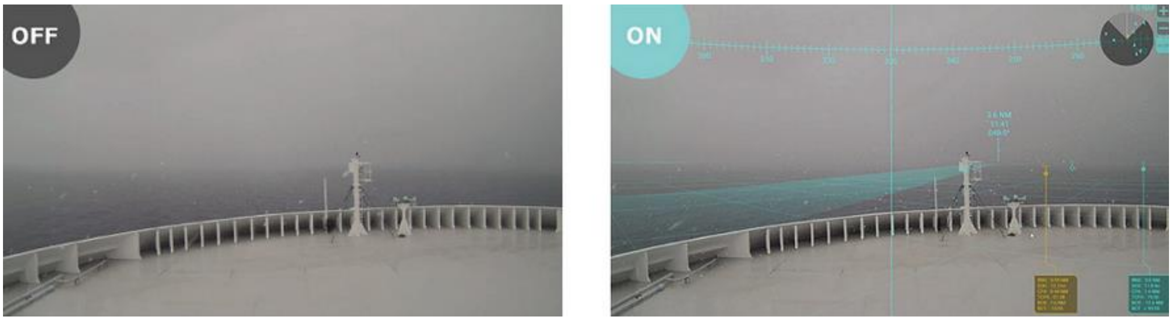

Figure 19. AR Navigation ON/OFF Comparison in bad weather conditions

Figure 20. AR Navigation ON/OFF Comparison during nighttime navigation

The Head Mounted Display (HMD) is similar, to eyeglasses as it includes lenses. These lenses project a video stream of objects with an overlay that doesn't obstruct the users vision. As a result there may be a delay between what the user sees in reality and what is projected.

To create the HMD projection of objects it follows the principle of Integrated Navigation System (INS) by gathering information from bridge navigation resources such as Automatic Identification System (AIS) Radio Detection and Ranging (RADAR) Automatic Radar Plotting Aid (ARPA) Electronic Chart Display and Information System (ECDIS) Gyro Compass, Magnetic Compass among others. It's important to note that this projection relies on the accuracy of those sources or inputs. If the inputs are incorrect or faulty then the displayed information may not be applicable to the view.

Another useful application for this method is utilizing user charts. The Officer of Watch (OOW) can input areas, boundaries for areas Marine Protected Areas (MPAs) environmentally sensitive regions concerning ballast water, sewage discharge, greywater discharge and other related matters specific, to the ship or company procedures.

One of the advantages is the ability to project the familiar "Simulated track prediction." Unlike its version the "Path prediction" that used simplified motion models this prediction tool offers navigators a visual representation of the ships movement and trajectory based on its current rudder and speed settings.

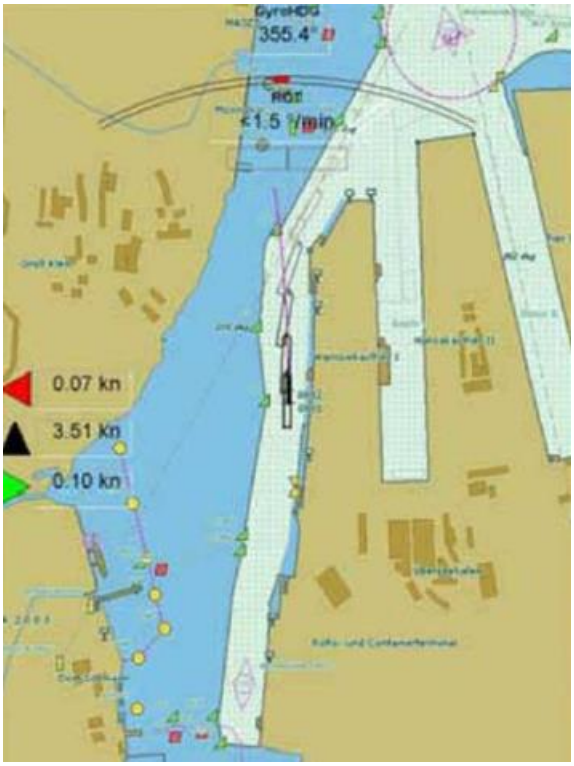

Figure 21. Simulated track prediction on ECDIS

AR navigation systems allow easy access to all relevant electronic information on a single screen. This improves situational awareness, decreases cognitive load, and makes validating and cross-checking navigational information easier than ever. Improved situational awareness leads to a reduction in navigational accidents, safer ships, and inevitable cost savings in repairs and insurance premiums.

6. CONCLUSION

E Navigation refers to an approach that involves the integration of systems and infrastructure guided by a strategic plan approved by the International Maritime Organization (IMO). Various stakeholders, including mariners, pilots, port authorities, port services, governments, at levels, manufacturers, data suppliers, shipbuilders and the IMO itself will be affected by navigation and should be involved in its development.

The objective is for all these parties to collaborate through the IMO to establish and implement an e navigation strategy before MSC 85 convenes, in 2008. The current technological advancements and system integration capabilities offer possibilities for what e navigation could encompass. Hence it is crucial that user demands drive the development of this concept at this stage—referred to as "Goal Based" within the IMOs terminology.
Despite the phenomenon of constant technological changes, the main principles and navigational needs are kept unchanged over time and are included to avoid stranding, avoid damage due to adverse weather conditions and protect the environment. The only changes created over time are modernization of the methods used and the means available to achieve them aforementioned main purposes.

It is critical that the human being is constantly at the center of onboard decision-making.
Machines should be allowed to do what they do best: process large amounts of data / information quickly and accurately. However, if judgment, experience, and 'gut feel' are necessary, the human factor takes precedence. A number of incidents have shown us that the more automation there is, the more people must be educated to accomplish. The human component must have a thorough awareness of the amount of automation and be capable of comprehending automation processes.

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