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ANALYSIS OF THE E-NAVIGATION CONCEPT USING A LOGICAL FRAMEWORK MATRIX AND SWOT ANALYSIS

Mirko Čorić*, Zvonimir Lušić, Miro Petković, Vinko Demicheli

Abstract. e-Navigation is a global initiative designed to transform traditional navigation practices, enhancing the safety and efficiency of maritime operations. Its primary objective is to mitigate the impact of human error on maritime accidents, thereby contributing to environmental protection. As technologies, information, and geopolitical and commercial priorities evolve, e-Navigation should be regarded as a dynamic and adaptive concept. This paper explores and analyzes the e-Navigation framework and its core components. Additionally, the research examines e-Navigation and its relation with emerging Information and Communication Technology (ICT) developments, highlighting potential challenges and risks associated with its implementation and ultimate realization. Finally, as a result of the conducted research, the paper introduces a logical framework matrix and a comprehensive SWOT analysis of the e-Navigation concept. This facilitates structured analysis and strategic planning for the implementation of the e-Navigation concept.

Keywords: e-Navigation; ICT; Logical Framework Matrix; SWOT Analysis.

University of Split, Faculty of Maritime Studies, Split, Ruđera Boškovića 37, Croatia
e-mail: mcoric@pfst.hr; zlusic@pfst.hr; mpetkovic@pfst.hr; vdemichel@pfst.hr

* **Corresponding author:** mcoric@pfst.hr

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1. INTRODUCTION

In general, there is a prevailing trend of leveraging the benefits of cutting-edge technological progress within the realm of maritime technologies (Weintrit, 2007). One approach to accomplishing this objective is through e-Navigation, a concept endorsed by the International Maritime Organization (IMO). It is founded on the integration of maritime navigation systems and related services, with user requirements serving as the primary catalyst for its evolution (IMO, 2006). Its development began in 2006 when the IMO decided to define a strategy to support the seamless incorporation of both new and existing navigation technologies, with the aim of improving ship operation and maritime safety. The incorporation of cutting-edge technologies plays a crucial role in e-Navigation. Currently, e-Navigation is being implemented directly or indirectly through numerous testbed projects within the maritime domain (IALA, 2022). e-Navigation involves the coordinated collection, integration, exchange, display, and analysis of maritime data to enhance navigation and associated services. This approach ultimately aims to enhance maritime safety and contribute to the protection of the marine environment (IMO, 2008). The concept of e-Navigation remains relatively conceptual, as it is still challenging at this stage to precisely define the extent of changes needed to fully achieve its primary goal. The following are some interesting observations. The U.S. Committee on the Marine Transportation System (CMTS) has emphasized that the goal is to harmonize various sources of maritime data and make them accessible to users, enabling better decision-making and safer, more efficient navigation. This approach emphasizes the importance of information sharing and collaboration, rather than just the adoption of specific technologies. (Committee on the Marine Transportation System, 2012). e-Navigation is an idea that aims at properly integrating and utilizing current and emerging technologies to improve navigational safety while ensuring operational efficiency (Weintrit, 2008). Strategy for execution of this global initiative poses a considerable challenge for the industry. Section 2 provides an overview of the key elements of e-Navigation, which are essential for understanding the concept and developing the previously mentioned strategy. Section 3 examines the potential challenges and risks associated with the implementation of e-Navigation, with a focus on new and emerging ICT technologies. Based on the analysis of the e-Navigation concept, Section 4 proposes a logical framework and a SWOT analysis.

2. e-NAVIGATION CONCEPT

It is a fact that advanced and innovative technologies are rapidly evolving, providing seafarers with more technological support systems than ever before. However, maritime accidents related to navigation continue to occur despite the presence of numerous shipborne and shore-based technological systems designed to enhance decision-making and improve seafarers' situational awareness during navigation. These technologies include Global Navigation Satellite Systems (GNSS), Automatic Identification Systems (AIS), Electronic Chart Display and Information Systems (ECDIS), Integrated Bridge Systems (IBS), Integrated Navigation Systems (INS), Long Range Identification and Tracking (LRIT) systems, maritime radars, Automatic Radar Plotting Aids (ARPA), Vessel Traffic Services (VTS), and Global Maritime Distress and Safety Systems (GMDSS) (Patraiko, Wake and Weintrit, 2010). This has created the need to harmonize existing and future technological systems, as many of these systems are neither fully integrated nor aligned with each other, nor with existing systems on other ships and shore-based facilities. Additionally, there is a growing need to standardize these systems, as this is one of the primary objectives of e-Navigation. A list of the objectives that e-Navigation aims to achieve can be found in source (IALA, 2019). At the same time, it has become clear that it is essential to consider the human element, which includes training, competencies, language proficiency, workload, and motivation. Additionally, e-Navigation aims to address issues such as administrative burdens, information overload, and ergonomics (Weintrit, 2016). Several influential organizations, including the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) and the International Hydrographic Organization (IHO), led by the International Maritime Organization (IMO), support the development of e-Navigation within the framework of international maritime regulations. The IMO organization considers the Strategic Plan for the Implementation of e-Navigation, approved in November 2014, as the cornerstone of e-Navigation implementation (IMO, 2014a). The plan outlines a list of tasks required to implement the priority e-Navigation solutions. It is important to emphasize that e-Navigation is an evolutionary and dynamic concept that will continue to evolve in parallel with new user needs and emerging technologies. The key components of the e-Navigation are explained in the following subsections.

2.1. e-Navigation Architecture

To implement the concept of e-Navigation, architecture is an essential step. The architecture should first and foremost fulfill the conceptual requirements of e-Navigation, with technical solutions that most effectively match these specifications being chosen

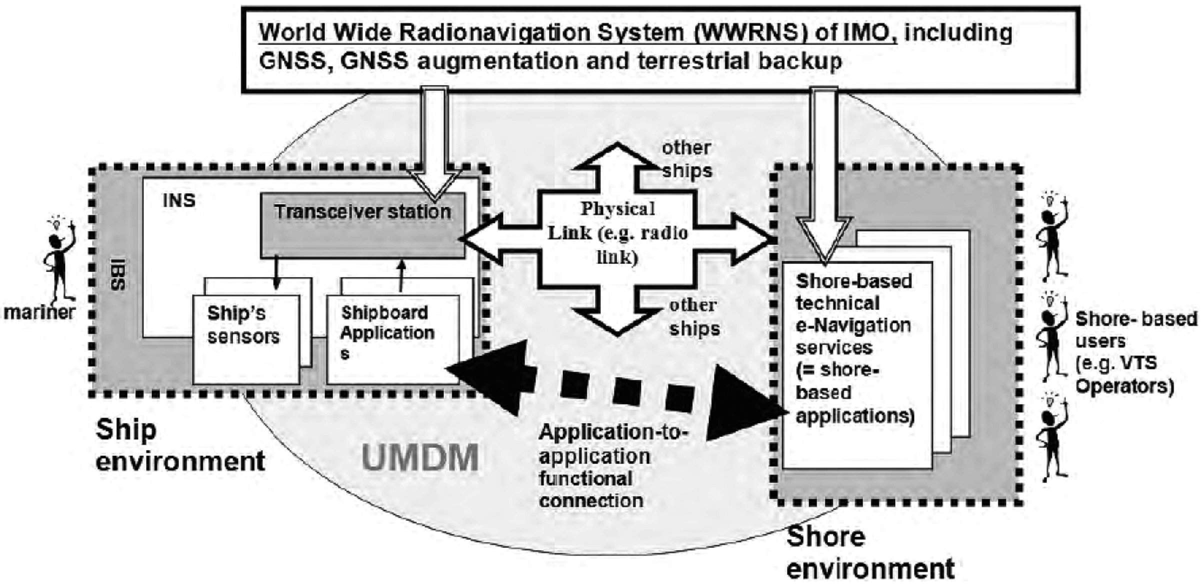

Figure 1. e-Navigation architecture (IALA, 2009).

thereafter (IALA, 2009). The architecture encompasses the hardware, software, data, information, and communication required to fulfill user requirements. It needs to be built on scalable and modular framework (Figure 1).

Figure 1 presents the e-Navigation environment. The figure highlights shipborne entities, shore-based/land-based entities, and the physical and functional connections between these entities (IALA, 2009; Čorić, Gudelj, Lušić and Mandžuka, 2019). The architecture also points out that Universal Maritime Data Model (UMDM) should be a standard for interchange of data between the aforementioned entities, as well as the World Wide Radio Navigation System (WWRNS), which support both shipborne and shore-based/land-based entities. On the left side is the shipborne environment and the relevant devices in this environment that include sensors, transceiver station, applications connected to the transceiver station, INS, and the IBS. Transceiver station(s) is/are connected via a physical link to the corresponding technical services of e-Navigation located on the shore/land. It is planned for UMDM (see Figure 1) to serve as a conceptual model of data appearing within the framework of e-Navigation. For both shore-based operators and onboard personnel, the primary concern is the functional link between user applications on the vessel and those onshore (black arrow in Figure 1). The previously mentioned functional link pertains to the exchange of data between various entities, while the physical connection pertains to the data transmission medium. Global radio navigation systems (WWRNS) are incorporated into the architecture and play a key role in providing positioning and timing information. Global navigation satellite systems (GNSS), including GPS, play a crucial role within this framework.

2.2. e-Navigation Data Representation Standard

In Figure 1, it is clearly observed that the UMDM stands as a core architecture component. Architecture should be viewed from the perspective of data/information flow, with this data being processed in the form of so-called data objects (a concept originating from object-oriented programming) (IALA, 2013). UMDM is a unified representation of data objects and their relationships within the maritime surroundings and is intended to evolve into a widely recognized data model used for e-Navigation. This is regarded as the initial phase in establishing a so called Common Maritime Data Structure (CMDS) which will serve as a data structure element within the framework. UMDM represents just one component of this data structure, which may encompass other different data models as well. The S-100 data model of the International Hydrographic Organization (IHO) has been proposed as an example that could serve as the basis for the implementation of the UMDM data model (IHO, 2010).

2.3. Maritime Cloud

The Maritime Cloud is defined as a communication framework that enables efficient, secure, and reliable exchange of electronic information among all stakeholders in the maritime domain (within the context of e-Navigation) using available communication systems (IHO, 2014). It is important to emphasize that the Maritime Cloud is not a "storage cloud" containing all information about ships and cargo, "cloud computing", or a communication channel. Instead, it represents the implementation of the defined e-Navigation communication strategy, as described in (IMO, 2008): "A communication infrastructure that enables the transfer of information (with numerous advantages) on ships, between ships, between ships and shore, and between shore and other stakeholders". The implementation of the Maritime Cloud is not intended to replace existing infrastructure, procedures, and systems but rather to facilitate an evolutionary transition toward a service-oriented information exchange infrastructure.

3. POSSIBLE CHALLENGES AND RISKS IN THE IMPLEMENTATION OF e-NAVIGATION

e-Navigation (whether on board or shore-based) will support heavily machine-to-machine (M2M) communication (Xia, Wang, Zhang and Wang, 2020). Therefore, operators are expected to possess sufficient technical knowledge, competencies, and training to keep pace with existing and emerging technologies within the e-Navigation framework and to identify problems and respond appropriately. It is essential to highlight that e-Navigation does not eliminate the human element from the system but rather facilitates and supports human involvement both on board and ashore.

The most advanced ICT (Information and Communication Technology) concepts and technologies, such as the Internet of Things (IoT), Cloud Computing, Big Data, and Artificial Intelligence, are of great importance, as their implementation will be an essential component of autonomous ships, which are already starting to materialize (Im ,Shin and Jeong, 2018; Danish Maritime Authority, 2017). A potential challenge lies in the fact that autonomous ships have not been explicitly considered within the e-Navigation concept, although they are not in conflict with its objectives (Burmeister et al., 2014). Some ICT concepts have already been studied within the e-Navigation framework. For example, the architecture of e-Navigation itself has been presented within the IoT concept (Wang and Peng, 2015), which implies the interconnection of all devices, systems, equipment, and ships via the internet. This e-Navigation architecture is fully aligned with the traditional e-Navigation architecture and would primarily enhance the collection and automated delivery of information.

It is currently recognized that not all countries will have the same level of services and technologies required for e-Navigation (Sari, 2017). Variations in the quality of services and information provided to different ships could lead to accidents. In other words, some countries may be unable to afford advanced e-Navigation services, and time will be required to upgrade their existing systems. Furthermore, each country is not obligated to provide all services from the Maritime Services Portfolio (MSP) (IMO, 2014b), and with the existence of both SOLAS and non-SOLAS vessels, the implementation of e-Navigation becomes significantly more challenging. Therefore, traditional navigation methods and e-Navigation-supported methods must be compatible and function in synergy.

Satellite communication will form the foundation for communication within the e-Navigation system. However, data exchange capabilities via satellite vary significantly depending on a ship's communication equipment. Therefore, it is essential to develop e-Navigation services with data requirements that:

- Adapt to the least technologically equipped ships, ensuring that all vessels have access to e-Navigation services,
- Provide services based on the technological capabilities of each ship, while ensuring that certain essential services and information are available to all vessels.

Another potential issue is the loss of traditional seafaring skills, which have been developed and refined over generations (Sari, 2017). E-Navigation aims to alert or warn seafarers in case of task-related omissions. However, this approach poses the risk that seafarers may become overly reliant on automated alert systems, leading to the gradual loss of their traditional navigation skills. The same source also highlights the concern that using e-Navigation systems may cause seafarers to lose situational awareness during navigation, which is a serious problem. It is important to emphasize that e-Navigation does not aim for full automation or the exclusion of human involvement but rather for partial automation, assuming that humans will remain the primary decision-makers in navigation. For example, problems may arise if a seafarer fails to use conventional observation methods, such as visual lookout or radar, to cross-check information provided by e-Navigation systems with the actual situation during navigation.

One of the more serious identified issues concerns cybersecurity and the potential compromise of information and e-Navigation systems (Sari, 2017). Hacking and information manipulation could mislead ships during navigation and cause incidents. It is crucial to develop a high level of cybersecurity, drawing lessons from other relevant industries.

Another risk lies in the development of isolated e-Navigation solutions (particularly shore-based systems) that lack an international character. The goal should be the implementation of harmonized, standardized solutions (Sari, 2017).

Furthermore, it is concerning that e-Navigation is not explicitly mentioned in most major political and strategic initiatives related to the future of maritime transport within the EU, although it is indirectly supported through key EU policy and strategic documents (European Commission, 2007; European Commission, 2009; European Commission, 2011). This indirect support is reflected in the fact that most EU maritime policy and strategy documents emphasize increasing the efficiency of maritime transport while enhancing environmental protection—which aligns with the core objective of e-Navigation. However, e-Navigation focuses on a narrower scope, specifically improving navigational efficiency while simultaneously promoting environmental protection. Given that certain navigational incidents—particularly collisions and groundings—can cause large-scale environmental disasters, greater and more detailed engagement from the European Union on e-Navigation would be essential.

4. LOGICAL MATRIX AND SWOT ANALYSIS OF e-NAVIGATION

Based on the previous analysis and conducted research over e-Navigation concept, the following logical matrix and SWOT analysis are presented.

Table 1. e-Navigation SWOT analysis

Strengths	Weaknesses	Opportunities	Threats
a) e-Navigation concept is supported by IMO, IALA, and IHO, which increases the likelihood of success for this global project due to the influence and recognition of these organizations, b) detailed and long-term implementation of the concept (with analysis starting in 2008) minimizes errors and omissions, highlighting its ongoing nature, c) openness and flexibility of the e-Navigation regarding the use of the latest technologies, d) openness of e-Navigation architecture to the latest technologies, e) objectives of this global concept are of exceptional importance to the entire world and the maritime industry as a whole	a) Excessive level of abstraction in the e-Navigation concept. Namely, it is still not entirely clear how the core objectives of the concept will be realized, b) insufficient number of countries involved in smaller-scale e-Navigation related projects, c) e-Navigation concept does not imply complete automation or the elimination of the human role. This suggests that humans remain the weakest link in the system, as all critical decisions are still made by humans, d) limited efforts in developing e-Navigation solutions for non-SOLAS ships, e) autonomous ships are not explicitly included within e-Navigation concept, f) significant disparities in the technological and economic development of different countries	a) Emergence of new technologies (artificial intelligence, IoT, big data, cloud computing, etc.) that can significantly facilitate the implementation and realization of e-Navigation, b) increasing internet availability and geographic coverage, c) future growth of maritime traffic, increasing the importance of e-navigation, d) promotion of standardization and issuance of directives by the IMO to accelerate and enhance the implementation of e-Navigation, e) detailed vision and inclusion of autonomous ships in the e-Navigation concept	a) Training and education of seafarers for the use of e-Navigation, b) challenges in global implementation of e-Navigation due to significant technological and economic disparities between countries, c) future coexistence of ships within and outside the e-Navigation coverage—with consequences yet to be determined, d) lack of strategic and policy directives that sufficiently support e-Navigation (e.g., the EU does not explicitly mention e-Navigation in any major strategic or policy document), e) global acceptance of the technical and technological standardization introduced by e-Navigation, f) cyber-attacks, g) loss of traditional seafaring skills

Table 2. e-Navigation logical matrix

Matrix elements	Narrative summary	Indicators	Means of verification	Assumptions
Goal	Enhancing maritime safety and environmental protection	Number of maritime and environmental incidents	Statistical data from various organizations, institutions and countries	
Specific goal	a) Reducing the number of collisions and groundings, b) minimizing maritime environmental incidents, c) facilitating navigation, d) focusing on user needs, e) reducing the administrative burden on seafarers	a) Number of ship collisions, groundings, and environmental Incidents, b) feedback from seafarers	a) Statistical data on accidents and incidents in maritime traffic, b) results from seafarer surveys and interviews	Existence of continuous and long-term engagement by IMO, IALA, governments, and other stakeholders
Outputs	a) Harmonization and standardization of equipment, navigation systems, communication methods, and information display, b) unified maritime data model (UMDM) for data exchange, c) utilization of the latest technologies in e-navigation solutions, d) improved connectivity and networking between ships and VTS centers	a) Proportion of ships Included in e-Navigation and number of countries that have accepted and implemented e-Navigation, b) insight into the utilization of the latest ICT technologies in e-Navigation	Insight into the situation based on data from the IMO and other organization	Strong collaboration with other industrial sectors (e.g., IT industry)
Activities	a) Improvement and maintenance of the e-Navigation architecture, b) implementation of the strategic e-Navigation implementation plan steps, c) issuance of IMO directives and strategic guidelines to facilitate e-Navigation implementation, d) execution of smaller-scale e-Navigation related projects, e) clear definition of technologies, software, and hardware as essential, components of e-Navigation, f) upgrades and modifications to technical equipment on ships and shore-based facilities			a) Global acceptance of e-Navigation solutions and the standardization it delivers, b) existence of strategic and policy guidelines from most countries aimed at the realization of e-Navigation

5. CONCLUSION

Given that technologies, information, and political and commercial objectives evolve, e-Navigation and its implementation needs to be observed as a dynamic and evolving idea. This paper explores and analyzes the e-Navigation framework and its key components, identifying its architecture as the cornerstone of the concept and a guiding framework for its development. Additionally, the research examines e-Navigation within the context of emerging ICT technologies (e.g. Artificial Intelligence, Big Data, Internet of Things, Cloud Computing, etc.) recognizing that none of these technologies conflict with e-Navigation's objectives. Machine-to-machine communication is expected to play a crucial role in future e-Navigation solutions, further emphasizing the significance of such technologies. The study also identifies key challenges and risks associated with the implementation of e-Navigation and ICT technologies, including global consistency in the quality of e-Navigation solutions, compatibility with existing maritime systems, the loss of traditional maritime skills and technical proficiency among seafarers, cyber-attack resilience, and inadequate support from political and strategic initiatives. As a final result of this research, the paper introduces a logical framework matrix and a comprehensive SWOT analysis of the e-Navigation concept, providing a structured approach for analysis and strategic planning in its implementation.

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