JURNAL CITA HUKUM (Indonesian Law Journal)
FSH UIN Syarif Hidayatullah Jakarta
Vol.12 No. 3 (2024), pp. 569-586, DOI: 10.15408/jch.v12i3.42268

Legal Framework of Employing Autonomous Navigation Technologies in Maritime Transport Vessels: Challenges and Benefits from Stakeholder Perspectives*

Mahmoud Abd Elgawwad Abdelhady[1]
University of Tabuk, Tabuk, Saudi Arabia

10.15408/jch.v12i3.42268

Abstract
The study aims to explore the challenges of employing autonomous navigation technologies in maritime transport vessels by identifying the main challenges and assessing their relation to the readiness of the legislative framework. The methodology conducted for this study is semi-structured interviews to collect data, and participants were recruited via snowball sampling. This method was a series of one-on-one, open-ended interviews with a variety of stakeholders involved in maritime transportation, including "maritime transport experts, technicians, legal professionals, maritime insurance experts, captains, maritime observers, port officials, officials in maritime transport companies, and crew members of maritime transport vessels, along with experts in control and remote sensing systems." Data was gathered in two stages: the first involved in-person and remote interviews focused on exploring the challenges and benefits of employing autonomous navigation technologies in maritime transport vessels. In the second stage, the main challenges identified in the first round were presented again to the experts to evaluate their impact on the readiness of the legislative framework. The methodology ensured sufficient data collection, reaching a saturation point, which enhanced the reliability of the results. The study's results confirm the strong relationship between overcoming the challenges facing autonomous navigation technologies in maritime transport vessels and utilising these technologies. It also confirms the direct impact of the expansion of autonomous navigation technologies on the legal status of the ship and maritime navigation personnel. This entails the need for innovative standards to ensure safety and determine legal responsibilities in line with the unique risks associated with autonomous navigation technologies. The study offers a distinctive contribution by exploring the challenges of employing autonomous navigation technologies in maritime transport vessels and analysing the challenges and benefits from multiple, realistic perspectives. This contributes to creating a suitable environment for employing autonomous navigation technologies in maritime transport vessels, achieving the benefits of these technologies, and overcoming the challenges.
Keywords: Autonomous Ships; Navigation Technologies; Maritime Transport Ships

* Received: July 22, 2024; revised: July 28, 2024; accepted: August 23, 2024; published December 29, 2024.
[1] Mahmoud Abd Elgawwad Abdelhady, Faculty of Business Administration, University of Tabuk, Tabuk, Saudi Arabia. https://orcid.org/0009-0004-2177-6147 Email: mabdulhadi@ut.edu.sa

A. INTRODUCTION

The utilization of autonomous navigation technologies in maritime transport Ships is greatly affected by various challenges that impede their implementation, along with the existing legal framework and the legal status of the ships and personnel involved. To fully harness these technologies' environmental and economic advantages, it is essential to establish a conducive environment for their widespread use soon. However, introducing these technologies encounters several obstacles that hinder their smooth integration and impact their overall effectiveness and results.

Autonomous ships offer a promising approach to integrating modern technologies in maritime transport, including artificial intelligence, robotic systems, and remote sensing. These Ships enhance operational efficiency, lower costs, reduce human errors, bolster maritime safety, improve risk prediction, and enable quicker, more accurate decision-making for effective naval operations management. A major challenge in implementing autonomous navigation technologies in maritime transport Ships is the inadequacy of the existing legal framework to support this advancement.

National laws and international agreements have effectively regulated maritime transport activities, evolving from the time when wind and human power were the main energy sources for ships to the present, which includes fossil fuels, nuclear energy, and electric power. Throughout these developments, maritime navigation and sea voyage management have relied on human crews for leadership and oversight.

The rise of autonomous navigation technologies marks a new chapter in maritime transport, utilizing modern systems to manage and execute operations. However, this shift significantly challenges the existing legal frameworks governing ship activities. Historically, sailors and captains have never been completely replaced with robotic systems, artificial intelligence, or remote sensing technologies for navigation tasks. As this new era of shipbuilding emerges, driven by advancements in autonomous navigation technologies, there is a pressing need to examine the factors that influence their deployment—both positively and negatively. Successfully addressing these challenges is crucial for widely accepting these technologies in maritime transport.

A key motivation for this study is the lack of a specific legal framework for autonomous navigation technologies in maritime transport Ships that can be widely applied. Both traditional and autonomous ships are categorized under the same legal provisions. For example, Saudi Arabia's new Maritime Commerce

Law of 2022 defines a ship as any floating structure intended for regular maritime navigation, regardless of profit motives. This broad definition raises legal concerns, as current provisions do not adequately accommodate the unique nature of autonomous Ships that rely on modern technologies. Existing laws predominantly apply to traditional ships, a situation mirrored in international conventions ratified by many countries.

This article explores the challenges and benefits of implementing autonomous navigation technologies in maritime transport Ships and their relationship with the legal framework. The use of robotic systems and artificial intelligence to manage sea voyages without onboard crews challenges established legal concepts in maritime law. (Vojković & Milenković, 2020)

The study poses essential questions about the feasibility of modern technologies handling navigation tasks independently, their impact on legal concepts, and how they relate to other challenges. By addressing these questions, we can better understand the primary challenges and anticipated benefits of enabling autonomous navigation technologies in maritime transport, considering the interconnectedness of these issues with the legislative framework.

B. METHODS

A comprehensive research methodology was employed for data collection, utilizing semi-structured interviews with participants selected through a two-stage sampling process. Initially, snowball sampling was used to identify and reach respondents, followed by purposive sampling to confirm their expertise and relevance to the study. In total, 18 experts from various domains were interviewed, including professionals from the maritime transport sector, technicians, legal professionals, maritime insurance experts, captains, maritime observers, port officials, managers of maritime transport companies, crew members of maritime Ships, and experts in control and remote sensing systems.

The interview process adhered to all ethical standards and protocols. Participants were informed via formal letters outlining the objectives and scope of the interviews. The date and time of each interview, whether conducted online or in person, were scheduled according to the participants' convenience. The data collection phase commenced on May 10, 2024, and concluded on September 28, 2024. Interviews were conducted in various formats, including face-to-face meetings and phone calls, to ensure flexibility and facilitate data collection. The semi-structured interviews began with an explanation of the study's objectives, followed by open-ended questions focusing on the future employment of

autonomous navigation technologies in maritime transport ships and the challenges and benefits associated with their use. Each interview lasted approximately 30 minutes.

The interviews were conducted in two rounds. After the first round, the main challenges were identified and presented to the experts for further discussion to assess their interaction with the readiness of the legislative framework. Nearly all participants validated the results, confirming their realism and relevance. This process determined the most significant challenges in deploying autonomous navigation technologies in maritime transport Ships. The methodology ensured sufficient data collection from participating experts, reaching a point of information saturation where no new insights were provided. This saturation enhanced the reliability and validity of the study's findings.

C. RESULTS AND DISCUSSION

1. Legislation as a tool to achieve alignment with the employment of autonomous navigation technologies in maritime transport ships

Legislation must evolve to keep pace with the rapid technological advancements in the maritime transport sector, mainly through the development of existing legal frameworks (Kim et al., 2020) to enable the use of autonomous ships and enhance the integration of autonomous navigation technologies in maritime Ships. This process takes various forms, such as enacting new laws that address the challenges posed by these technologies in the shipbuilding industry. The goal of this legislative approach is to support innovation rather than merely regulate it. (Issa et al., 2022)

To achieve this, legislation must extend beyond drafting new rules or modifying existing legal provisions using traditional concepts and objectives. It must also include adopting necessary constitutional procedures to make legislative processes more efficient, effective, and flexible, enabling the integration of autonomous navigation technologies in maritime Ships and facilitating their application. This can be accomplished by ensuring that legislation's content, issuance, and enforcement are well-suited to the specific activities to which they will be applied. Although there are challenges in deploying autonomous navigation technologies, the anticipated benefits far outweigh the costs, aligning with expert opinions.

Given the economic significance of the maritime transport sector, it is essential to adapt laws and legislative frameworks to accommodate technological advancements and their positive impact on the sector’s activities. However,

legislative frameworks tend to evolve slowly, influenced by factors beyond the control of any single entity. As a vital and global economic activity, maritime transport requires substantial changes and strong external influences to bring about legislative development—similar to what was seen with nuclear ships (Handrlica, 2020), which necessitated specific regulations. Therefore, significant advancements in shipbuilding demand continuously evolving legislative frameworks.

Integrating autonomous navigation technologies in maritime Ships represents a significant leap in shipbuilding. It impacts traditional legal concepts due to its influence on all relationships from the ship's operations. As a result, a legal framework is needed to regulate the responsibilities of all involved parties, including ship operators, owners and developers of autonomous technologies, maritime insurers, and other stakeholders.

For such a framework to be practical, international cooperation and coordination are essential, particularly with organisations like the International Maritime Organization (IMO), to ensure cross-border legal harmonisation. This approach would facilitate the use of autonomous navigation technologies, promote their broader adoption, address related challenges, ensure compliance with established standards, and align with ongoing technological advancements. Ultimately, this would enable the realisation of their full benefits through a deep understanding of the associated challenges and advantages, while establishing a legislative framework that encourages using these technologies, overcomes obstacles, and maximises their potential.

2. Definition of Autonomous Maritime Ships and the Criteria for Their Identification.

A ship remains fundamentally a ship, but the integration of autonomous navigation technologies replaces the physical presence of the captain and crew with systems that manage and execute maritime voyages. This marks a significant advancement in marine transport, as ships have always required a human crew since their inception. (Mallam et al., 2019)

An autonomous ship refers to Ships that utilize artificial intelligence, remote sensing, robotic systems, and communication technologies to perform maritime navigation tasks instead of human crews. These ships can undertake various operations such as navigation, collision avoidance, route planning, and other related tasks Munim (2019). The autonomy of these ships distinguishes them and raises questions about the legal implications of employing such

technologies and the impact on legislative frameworks regarding the benefits and challenges of expanding their use. These technologies manage navigation autonomously through sensors, robotic systems, and artificial intelligence, making decisions without human intervention.

On the other hand, unmanned ships (Yang et al., 2019), though also products of technological progress, are considered more advanced than traditional Ships. They sail without human crews and are remotely controlled by a control centre. Unlike autonomous ships, they may not rely on artificial intelligence systems, as human operators oversee all maritime tasks remotely. Robots may assist with tasks like loading, maintenance, and monitoring. Advanced communication systems link the ship to the control centre, enabling efficient management and rapid decision-making. From a legal perspective, unmanned ships do not raise significant issues because individuals in control centres manage the voyage, similar to a human crew being relocated from the ship to a remote location. This contrasts with autonomous ships, where technologies take control of navigation and decision-making without referring to human operators. ("When is a ship a ship? 2020)

According to expert analysis, a ship's legal classification is based on its function rather than how its voyages are managed or tasks executed. This legal concept remains unchanged regardless of technological advancements in ships' operations, materials used, or propulsion methods. Autonomous ships are surface Ships that rely on autonomous navigation technologies to manage maritime voyages and make decisions independently. The key criterion for classifying a ship as autonomous is its reliance on these technologies rather than human crews to manage and execute voyage tasks (navigation, route planning, handling hazards, etc.). Ships controlled remotely by human operators do not fall under this category. (Chen et al., 2019)

The fact that a ship is autonomous does not alter its fundamental legal status. Autonomous navigation technologies merely shift responsibility from traditional maritime personnel to modern technologies. Liability continues to rest with the shipowners under established legal principles, whether the ship is autonomous or conventional (Mallam et al., 2019). As one expert (A8) stated, "These technologies enhance and streamline maritime transport operations, and a ship remains a ship, regardless of whether it is autonomous or traditional."

3. The Benefits of Replacing Human Crews with Autonomous Navigation Systems in Maritime Transport Ships

The utilisation of modern technologies, robotic systems, and artificial intelligence in place of human crews for navigating maritime transport ships and managing their voyages provides a variety of distinct benefits:

a. Expanding the scope of enabling modern technologies across various sectors.

Ships, as vital means of maritime transport, act as connectors between various industries and sectors, offering services to beneficiaries across diverse fields. The range of beneficiaries utilizing autonomous maritime transport services expands the application of these technologies to multiple sectors, ensuring they remain aligned with advancements in autonomous ship technologies. (Issa et al., 2022)

This technological expansion across sectors aims to achieve both environmental and economic benefits. Innovations are used for loading and unloading, reshaping insurance system concepts, and performing other related activities. As a result, these technologies become more widely adopted, increasing the overall benefits of their use, as noted by experts A1 and A2.

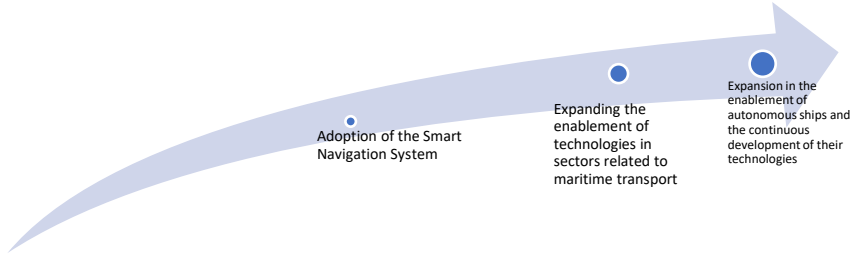

Figure 2: The Impact of Expanding the Employment of Autonomous Navigation Technologies on Related Sectors' Technologies.

b. Environmental Benefits.

Environmental benefits are primarily achieved by reducing human errors and improving route accuracy, which leads to advantages such as reduced fuel consumption (Ahn et al., 2019) and, consequently, lower greenhouse gas emissions (Ahn et al., 2019). In addition to these key environmental benefits of employing autonomous navigation technologies in maritime transport ships, expert A3 highlights that these technologies save on crew living expenses and are more compliant with sustainability standards. (Akter & Department of computer science and engineering, University of Dhaka, Bangladesh, 2024)

c. Economic Benefits:

Expert A4 asserts that relying on modern technologies is more cost-effective than traditional methods (*Georgieva, K. (2024). AI Will Transform the*

Global Economy. Let's Make Sure It Benefits Humanity. IMF Blog (Blog), International Monetary Fund., n.d.). Experts agree on the economic advantages and the potential of these technologies to address specific challenges, such as the shortage of qualified personnel to navigate ships and the reduction of long-term operating costs. (Dařena & Gotter, 2021)

Autonomous ships also help improve the efficiency of global supply chains (Cohen, 2022) by reducing operating costs. They can save up to $357 per day for each container transported, significantly lower energy consumption compared to traditional ships, and reduce operational expenses by approximately $1 million annually (*Maritime Transport Strategic Research Programme Publications*, n.d.), affirming that employing this technology is less costly in the long term. Experts confirm the study's findings: autonomous ships represent the future of the maritime transport industry, offering both economic and environmental benefits. Their technology addresses the challenge of a shortage of qualified personnel for navigating Ships. (Weintrit & Neumann, 2013)

d. Enabling autonomous navigation technologies in maritime transport ships contributes to creating appropriate legislative frameworks.

Implementing autonomous navigation technologies in maritime transport ships relies on the legislative framework's suitability and ability to support this technology on a broader scale in marine transport operations (Ltd, n.d.). Creating an enabling legislative framework for autonomous ship technologies can be approached in two main ways:

The first approach addresses a legislative gap created by expanding autonomous navigation technologies in maritime transport ships. This gap must be resolved as these technologies become more widely deployed and the desire to realise their benefits increases. In this case, creating an appropriate legislative framework would precede the full enablement of these technologies.

The second approach focuses on the desire to capitalise on the benefits of autonomous navigation technologies in maritime transport ships. As a result, a legislative framework is developed to create an environment conducive to implementing these technologies. State legislative strategies are unlikely to deviate from these two scenarios, and this framework can eventually be applied globally.

Expert A11 noted that the Kingdom has undergone a legislative revolution over the past five years, using legislation not only for regulation but also to support innovation. Ports are being constructed to accommodate this type of

ship, as he remarked: 'Modern ports require a legislative framework to streamline operations and will be more compatible with autonomous technologies. (*Oxagon Port Supply Chain and Logistics*, n.d.)

It is important to note that preparing the legislative framework for implementing these technologies in ships takes considerable time, primarily due to the slow adoption of innovative technologies in maritime transport. Several factors largely influence this delay, with economic considerations and the international nature of naval transport activities being the most significant. (Agarwala, 2023)

4. The Main Challenges in Employing Autonomous Navigation Technologies in Maritime Transport Ships.

a. Risks of Employing Autonomous Navigation Technologies in Maritime Transport Ships

The deployment of new technologies introduces unknown and unpredictable risks. Even after achieving a satisfactory level of enabling autonomous navigation technologies in maritime transport Ships, specific tasks cannot be entirely entrusted to robotic systems and artificial intelligence. Expert A12 explained that while allowing technology to perform human tasks introduces new and unknown risks, these tasks should remain under human supervision. Technological malfunctions, cybersecurity threats, and other risks are associated with the latest technologies. Emerging technologies are generally accompanied by undefined risks, which always necessitate developing solutions to mitigate these dangers. (Jovanović & Renn, 2013.

b. Lack of Autonomous Ship Technologies Integration with the Implementing Maritime Piloting Operations Requirements.

Maritime piloting, an essential part of naval transport operations, occurs when ships enter ports and waterways to ensure safe passage and docking and prevent accidents. It involves cooperation between the ship's captain and the port or waterway pilots (Abdelhady, 2024), following technical and legal rules based on international agreements or national regulations.

Generally, these rules do not account for piloting ships that use autonomous navigation technologies. Piloting operations for such ships require new tools and technologies for handling them during maritime piloting. This challenge is compounded by the fact that, according to most regulations, piloting is mandatory for ships in ports and waterways. This requirement highlights the lack of integration between piloting systems and autonomous navigation technologies in maritime transport Ships. Expert A5 emphasised that maritime

piloting for ships employing autonomous navigation technologies demands legal regulations and technical, material, and infrastructural adjustments to enable successful piloting operations.

Expert A6 further points out that ports and waterways differ in infrastructure and compatibility with autonomous navigation technologies. The lack of integration between port infrastructure and these technologies is seen as a negative factor hindering their widespread adoption, leading to disruptions in the smoothness and flexibility of maritime transport operations.

c. The Lack of Readiness of Infrastructure to Support Autonomous Navigation Technologies in Maritime Transport Ships.

Conventional maritime transport Ships are managed by human crews, whereas autonomous Ships rely on autonomous navigation technologies, robotic systems, and artificial intelligence to perform these tasks. Using these technologies in maritime transport Ships requires the development of port infrastructure. (Rødseth et al., 2020)

Port infrastructure has not yet been developed to accommodate autonomous maritime transport technologies, even in the most active ports, as confirmed by expert A5. This challenge presents a significant barrier to the widespread implementation of autonomous navigation technologies in maritime Ships, as infrastructure readiness depends on several factors, the most crucial being economic capabilities and the cost of adopting and deploying modern technologies. This is an issue that cannot be resolved by legislative frameworks alone.

d. Legal Uncertainty in Defining Liabilities Arising from the Employment of Autonomous Navigation Technologies in Maritime Transport Ships.

Autonomous navigation technologies in maritime transport Ships affect the legal positions concerning the vessel's operations. Legislation regulating technology-related matters often lags behind the rapid pace of technological developments. The slow pace of legislative progress and the inability to keep up with technological advancements raise ongoing questions about liability for these emerging technologies, particularly when defining the scope and nature of legal responsibilities.

Traditionally, the captain (Nho et al., n.d.) is legally responsible for technical errors and any resulting damages when negligence is proven, and they are obligated to ensure the vessel's seaworthiness. However, who will be held

responsible when robotic systems take over the captain's role in ensuring the vessel's readiness for sailing?[2]

The inevitable expansion of modern technologies to replace human crews will further increase legal uncertainty. Will these systems have an independent legal personality for establishing liability? Moreover, to what extent will the captain's inherent powers and duties, grounded in maritime law, be altered? Furthermore, the use of these technologies disrupts maritime insurance markets, changes the nature of insurable risks, and raises additional complex issues related to insurance, all of which are linked to the growing use of autonomous technologies in maritime transport Ships.

e. The Impact of Economic Costs on the Employment of Autonomous Navigation Technologies in Maritime Transport Ships

The cost of employing autonomous navigation technologies in maritime transport ships and preparing infrastructure in ports and waterways reduces the impact and effectiveness of the enabling legislative framework. This framework's readiness will not significantly contribute if there are insufficient economic resources to support the implementation of autonomous navigation technologies in maritime transport ships, a phenomenon known as the 'cost of technology barrier' (Jensen & Scheraga, 1998). This barrier aligns with the experts' opinions.

5. The Relationship Between the Readiness of the Legislative Framework and the Challenges of Employing Autonomous Navigation Technologies in Maritime Transport Ships

The legislative framework's readiness alone is insufficient to fully support the implementation of autonomous navigation technologies in maritime transport Ships. Even with the development of legislation and the precise definition of responsibilities and powers, the value of this framework depends on the ability to address other challenges.

This was confirmed during the second round of interviews and data collection, where experts were asked a key question: 'To what extent does the readiness of the legislative framework influence the employment of autonomous navigation technologies in maritime transport Ships on a scale of 1 to 5?' They were then asked to identify two of the main challenges, in addition to the legislative environment, that impact the implementation of these technologies.

[2] -Experts A5 and A6 agree that robotic systems can provide real-time reports on the level of readiness and malfunction reports. Thus, it can be said that technologies are performing the role traditionally carried out by the captain.

The following provides a comprehensive overview of the main challenges, expert evaluations, and the identification of the two most influential challenges, in addition to the readiness of the legislative framework, impacting the implementation of autonomous navigation technologies in maritime transport ships.

a. Main Challenges:

Code	Challenges
B1	Risks of Employing Autonomous Navigation Technologies in Maritime Transport Ships.
B2	Lack of Autonomous Ship Technologies Integration with the Requirements for Implementing Maritime Piloting Operations.
B3	The Lack of Readiness of Infrastructure to Support Autonomous Navigation Technologies in Maritime Transport Ships.
B4	Legal Uncertainty in Defining Liabilities Arising from the Employment of Autonomous Navigation Technologies in Maritime Transport Ships.
B5	The Impact of Economic Costs on the Employment of Autonomous Navigation Technologies in Maritime Transport Ships.

A18	A17	A16	A15	A14	A13	A12	A11	A10	A9	A8	A7	A6	A5	A4	A3	A2	A1	Experts
4	4	4	4	4	4	3	4		4	4	4	5	4	3	4	4	4	The impact of legislative environment readiness on the enablement of autonomous ships

Table 1: Main Challenges and Their Codes.

Experts' Evaluation of the Impact of Legislative Readiness on Enabling Autonomous Ships

Table 2: Experts' Evaluation of the Impact of Legislative Readiness on Implementing Autonomous Navigation Technologies in Maritime Transport Ships**.**

The Two Most Influential Challenges, Alongside Legislative Readiness, in Implementing Autonomous Navigation Technologies in Maritime Transport Ships

A18	A17	A16	A15	A14	A13	A12	A11	A10	A9	A8	A7	A6	A5	A4	A3	A2	A1	Challeng
B1 B5	B1 B5	B1 B2	B2 B3	B2 B3	B4 B5	B1 B2	B3 B5	B1 B5	B4 B5	B3 B5	B1 B5	B1 B2	B5 B2	B2 B3	B2 B1	B3 B5	B1 B2	the Two Most Influential Challenges

Table 2: the Two Most Influential Challenges, Alongside Legislative Readiness, Implementing Autonomous Navigation Technologies in Maritime Transport Ships**.**

Expert = A. Evaluation score = Number Challenge code = B

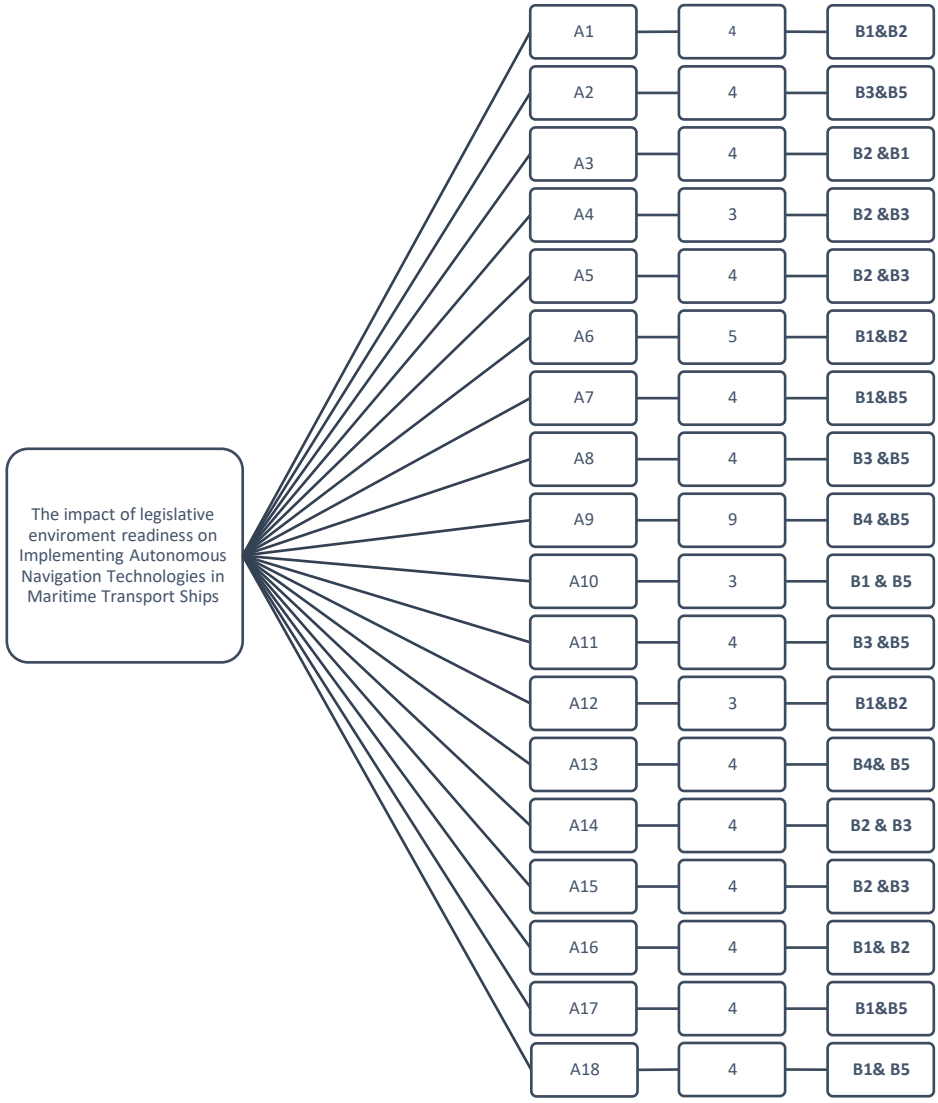

Figure2: Experts' Identification of the Two Most Influential Challenges, Alongside Legislative Readiness, in Implementing Autonomous Navigation Technologies in Maritime Transport Ships**.**

6. The Impact of Autonomous Navigation Technology on Captains, Crews and the Legislative Framework

The study's findings indicate that implementing autonomous navigation technologies in maritime transport Ships will play a significant role in their future development. This technological deployment must be guided by policies that address challenges and facilitate the creation of legislative frameworks to support its successful implementation.

Employing autonomous navigation technologies, advanced technical systems, and artificial intelligence will reduce the need for direct human intervention in navigation and managing maritime voyages, positively and negatively impacting employment opportunities in the maritime sector. The study's results confirm that the use of autonomous navigation technologies will directly affect the responsibilities of the captain and crew, particularly regarding their physical presence aboard maritime transport Ships.

As autonomous navigation technologies expand, the captain will shift from a hands-on commander to a remote supervisor overseeing technical systems from a distance. This transformation fundamentally changes the qualifications required and redefines the concept of a ship's commander, necessitating legislative frameworks that differ from the traditional model governing the primary authority responsible for a maritime voyage.

Limitations:

The limited prevalence of autonomous navigation technologies in maritime transport Ships challenges the objectivity and accuracy of the sample's responses due to the lack of accumulated experience in dealing with these technologies. This may affect the precision of viewpoints regarding the practical application of such technologies.

Additionally, the lack of detailed knowledge about the risks associated with employing autonomous navigation technologies in maritime transport Ships makes it difficult to accurately assess their impact on maritime safety, operational processes, and maritime insurance risks. Furthermore, the scarcity of previous studies addressing the impact of autonomous navigation technologies on the legal status of maritime transport Ships has limited the ability to form a comprehensive understanding of the benefits and challenges of employing these technologies and to propose a legal framework that accurately defines legal liabilities. Moreover, the interplay of economic challenges, insurance risks,

legislative framework readiness, and the risks of employing these technologies complicates the expansion of their use, making it difficult to predict whether they will be widely accepted.

D. CONCLUSION

The study confirms a strong correlation between the various challenges facing the implementation of autonomous navigation technologies in maritime transport Ships and the intertwined effects of these challenges on deploying such technologies. It also provides initial indicators for proposing a legislative framework that can help address the economic influences, infrastructure readiness, and risks associated with employing autonomous navigation technologies in maritime transport. Using these technologies affects the legal status of Ships and the responsibilities and duties of maritime personnel. It necessitates the establishment of standards to ensure safety and security, defining legal liabilities related to changing legal roles, and updating the maritime insurance system to accommodate the unique risks posed by autonomous navigation technologies.

The study's results demonstrate that as autonomous navigation technologies continue to advance, they challenge the adequacy of existing legislative frameworks, which increasingly fail to keep pace. The current situation reveals that technological developments often outstrip the readiness of the legal frameworks meant to regulate them.

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