Systematic Review of Digital Transformation in Maritime Governance in Developing Nations: The Case of Bangladesh

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Abstract

Digitalisation has become a defining lever of efficiency and sustainability in maritime governance, yet its diffusion remains uneven across the Global South. This systematic review examines the current state of knowledge on maritime digital transformation in developing contexts, using Bangladesh as an illustrative lens. Comprehensive searches of Scopus, Web of Science, and Google Scholar yielded 97 peer-reviewed articles that met PRISMA-2020 eligibility criteria; methodological rigour was appraised with the Joanna Briggs Institute critical-review instruments, and thematic patterns were inductively coded in NVivo. The analysis reveals four key interlocking barrier domains: institutional path-dependency, deficient ICT infrastructure, cybersecurity vulnerabilities, and socio-political/governance constraints that collectively hinder the sector's modernisation. Conversely, the literature identifies a nascent enabling environment characterised by expanding national e-governance programmes, incremental improvements in digital connectivity, rising digital literacy, and an emergent regulatory scaffold. Drawing on best practices from digitally advanced countries, this study proposes strategies to guide a sustainable and resilient digital transition aligned with Bangladesh's vision agenda and UN Sustainable Development Goals, offering a transferable template for other developing maritime nations pursuing resilient and inclusive digital transitions

Keywords: *Bangladesh Maritime Sector, Sustainable Development Goals, Maritime Digitalisation, Governance Transformation, Developing Country.*

1. Introduction

The maritime sector plays a crucial role in the economy, facilitating global trade, creating employment opportunities, and contributing significantly to the national GDP. Over 90% of the world's foreign trade occurs via maritime routes, rendering maritime operations a crucial element of economic resilience and

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sustainable growth. The industry in developing countries has several obstacles, including antiquated ports, maritime infrastructure, and insufficient adoption of contemporary technologies, disjointed institutional governance, and a deficit of maritime specialists (Popoola & Akinsanya, 2024). Governments and regulatory bodies in developed nations are integrating advanced technologies, including Artificial Intelligence (AI), blockchain, Internet of Things (IoT), and big data analytics, to improve service delivery, safety, transparency, and environmental compliance (Hirata & Watanabe, 2021; Golgota & Çerma, 2024). These innovations are increasingly viewed as essential instruments for overseeing intricate port logistics and assuring adherence to international standards and sustainable maritime practices (Yuen and Tan, 2022; Pavlinovic et al., 2023).

Bangladesh's maritime sector, which contributes around 7-8% of national GDP (MOFA 2024) presents a compelling case for investigating these issues. The country has committed to international maritime standards as a signatory to major IMO conventions such as SOLAS, MARPOL, STCW, and MLC. However, implementation remains uneven due to fragmented responsibilities among agencies, such as the Ministry of Shipping (MoS), the Department of Shipping (DoS), port authorities, and various law enforcement bodies, as well as outdated laws and manual processes (Bhuiyan et al., 2024). These factors reduce operational efficiency and create barriers to compliance, competitiveness, and sustainable development.

While the literature on maritime digitalisation is expanding, much of it focuses on advanced economies such as Singapore, Norway, and EU member states, where institutional, technological, and financial ecosystems are more mature. Empirical evidence and theoretical frameworks applicable to low-income countries (LICs), such as Bangladesh, remain very limited. Few studies have systematically assessed how digital maritime governance can be implemented in resource-constrained maritime settings or how global best practices might be adapted to local realities (Autsadee & Jeevan, 2023; Reiling, 2019). Therefore, there is a need for tailored transformation strategies for developing countries like Bangladesh, in the context of its current regulatory, infrastructural, and socioeconomic conditions. By studying digitalisation patterns in the maritime industries of developed economies, the researcher aims to address the knowledge gap by examining Bangladesh's digitalisation status, obstacles, and opportunities, and suggests strategic approaches to enhance competitiveness and resilience.

Accordingly, the general objective of this study is to critically examine the role of digitalisation in enhancing maritime governance in developing countries like Bangladesh by identifying key enablers, barriers, governance models, and

strategic pathways to achieve a resilient, sustainable, and competitive maritime industryaims to transform the country into a developed, prosperous nation by 2041, focusing on eliminating poverty and hunger, and becoming a digitally advanced nation. This research seeks to discuss the following specific research objectives:

i.   To examine and evaluate the factors that hinder or enable the digital transformation of the maritime governance ecosystem in Bangladesh (RO 1).
ii.   To identify, contextualize, and analyze digital governance architectures, policy instruments, and capacity-building measures from leading maritime nations to craft a sustainable, resilient, and inclusive digital transition roadmap for Bangladesh and similar developing maritime nations (RO 2).

This study contributes to academic discourse and practical policymaking by proposing context-sensitive strategies aligned with Bangladesh's development vision and the United Nations' Sustainable Development Goals (SDGs).

2. Literature Review

Maritime governance encompasses rules, policies, institutions, and enforcement mechanisms that regulate maritime affairs (Olaniyi et al., 2024). It covers legislative, institutional, and operational dimensions, addressing safety, security, marine environmental protection, port and shipping regulations, and international cooperation. This framework is shaped by global conventions, notably under the International Maritime Organization (IMO), and regional arrangements, such as the European Union's Integrated Maritime Policy and the African Union's 2050 AIM Strategy.

Effective governance ensures safe navigation, sustainable marine resource usage, environmental conservation, and efficient international shipping. However, translating international norms into national practices poses challenges for developing countries due to institutional fragmentation, policy incoherence, inadequate legal harmonisation, and insufficient technical and digital capacity (Bueger & Edmunds, 2024).

International trade is predominantly reliant on marine transport, with around 90 percent of all products using oceanic routes (Hatch, 2013). Effective rules and institutions enhance maritime competitiveness, streamline port operations, and align national practices with global norms (Donner et al., 2018). Bangladesh exemplifies a situation where, despite approximately 90 percent of its international commerce utilizing seaports, congestion, prolonged vessel turnaround times, and elevated operating costs deter investment, which is exacerbated by inadequate governance.

Globalisation and growing environmental pressures, such as marine pollution, overfishing, and habitat loss, demand stronger rules and oversight (Reiling, 2019; Hildebrand & Bellefontaine, 2017). Bangladesh faces pollution from inland waterway traffic, ship-recycling yards, and rising sea levels. Strict enforcement of MARPOL and the broader use of green practices in line with the Sustainable Development Goals are therefore essential.

Security and safety concerns introduce an additional dimension. Piracy, terrorism, and illicit fishing threaten the maritime order (Struett et al., 2013); accidents have a detrimental impact on lives and the economy (Christodoulou & Fernández, 2021). Bangladesh's geographical position renders it susceptible to piracy, drug trafficking, and unregulated fishing; thus, surveillance should depend on risk-based strategies and automated regional intelligence dissemination (Ahmed et al., 2023; Sakita et al., 2024).

Responsibility for maritime governance rests with the Department of Shipping, the Ministry of Shipping, the Port authorities, the Bangladesh Navy, and the Bangladesh Coast Guard. Despite adopting core IMO conventions overlapping mandates, limited coordination, the absence of a central digital-governance unit, and slow regulatory digitalisation keep most services paper-based and reactive (Aktar & Cdcs 2024). The growth of the "blue economy" is also linked to the conservation and sustainable management of ocean resources (Kecskes, 2022). These gaps lower Bangladesh's rank in global maritime indexes and weaken its ability to handle emerging risks such as cyber threats and climate impacts.

Ultimately, robust maritime governance is the hinge on which competitiveness, security, and environmental resilience now turn. Bangladesh must transform its IMO commitments into a well-coordinated, risk-based practice that streamlines agencies, enforces green standards, and unlocks blue economy growth (Bashir, 2022; Bhattacharyya & Rahman, 2019). Closing these gaps will determine whether its maritime institutions thrive or lag in an increasingly volatile maritime arena.

Digitalisation enhances maritime safety by ensuring security, efficient cargo management, and effective maritime traffic control systems. Strong cybersecurity protocols (Golgota and Çerma, 2024). Additionally, digital transformation fosters environmental sustainability by enabling real-time monitoring of environmental impacts and compliance with emissions regulations through data-driven strategies (Karunasena et al., 2022). "Green" technologies integrated into digital initiatives contribute to sustainable development by reducing the environmental footprint of maritime activities (Pavlinovic et al., 2023; Shkurko & Potapovska, 2023). Countries like Singapore and, Netherlands leverage digital technologies to

strengthen shipping competitiveness, enhance port operations, and promote sustainable marine resource management (Margaretha et al., 2024; Winarno et al., 2024). Achieving sustainable development goals, economic robustness, and safety in maritime transport requires digitalisation (Pavlinovic et al., 2023).

However, challenges remain regarding the digital transformation of maritime governance. Poor digital infrastructure, limited technological capability, and regulatory hurdles, particularly in developing regions (Margaretha et al., 2024). Deploying complex digital solutions such as digital twins and integrated data systems demands investment in infrastructure, professional development, and regulatory reforms (Koilo, 2024). Addressing these challenges is essential for successfully transitioning to a digitally empowered maritime governance system.

3. Systematic Review Methodology

This research addresses the research gap by systematically reviewing the academic and policy literature to explore how digital transformation can enhance maritime governance in Bangladesh. It identifies the key enablers, barriers, strategic models, and future research priorities for a sustainable, inclusive, and future-ready maritime governance system.

The Systematic Literature Review (SLR) methodology was employed in accordance with the PRISMA 2020 principles (Page et al., 2021), ensuring a transparent and replicable research process, utilizing Braun and Clarke's (2006) theme analysis framework. The review focused on peer-reviewed journal articles, conference papers, and institutional reports published between 2015 and 2024, using inclusion and exclusion criteria. The articles were written in English and accessible via major academic databases, including Scopus, Web of Science, and Google Scholar. Table 2 presents the literature search framework employed for the two research objectives. A total of 194 studies were initially identified. Following the removal of duplicates and the application of inclusion and exclusion criteria (see Table 1), a total of 97 studies were included in the final analysis. The PRISMA flow diagrams presented in Figure 1 depict the selection process.

Data were extracted with a piloted form and analysed thematically in NVivo. A narrative synthesis grouped findings into barriers, enablers, and recommended strategies. Study-level risk of bias was assessed independently by two reviewers using the Joanna Briggs Institute (JBI) critical appraisal systematic review tools for qualitative research (Joanna Briggs Institute, 2017); any disagreements were resolved by consensus.

**Table 1:** Inclusion and exclusion criteria of sources

Sl No	Inclusion criteria	Exclusion criteria
1	Studies focused on digitalisation in the maritime governance in the public sector.	Non-academic publications (news articles, blogs)
2	Literature published between 2015 and 2024 for RO1, due to the scarcity of literature, and 2020 to 2024 for RO2, to reflect the present development.	Non-English language
3	Article published in a peer-reviewed journal, review article, Book review, conference papers, Policy papers/Government reports.	Studies focused solely on technical ship operations with no governance linkage.
4	Relevance to research objectives, i.e, governance, digital tools, and developing country contexts	Articles without accessible full texts

Source: Author, 2025

Table 2: Framework for literature search

Research Objective	Key Search Terms	Search Strategy	Type of Literature
RO1	Digital transformation, E-governance, ICT adoption, Public administration, Governance, Benefits, Barriers, Challenges, Enablers, Drivers, Bangladesh, developing countries	Boolean	Peer-reviewed journals, conference papers, policy papers, government reports, and empirical studies 2015-2024 in Bangladesh context.
RO2	Maritime digital governance, Maritime administration, Maritime Digital transformation, Digitalisation, E-governance, Smart ports, Maritime ICT, Strategic tools, Digital models, Digital frameworks, Best practices, Developed countries, IMO,EU maritime policy	Boolean	Framework studies, policy models, maritime development strategies (2020-2024) International case studies
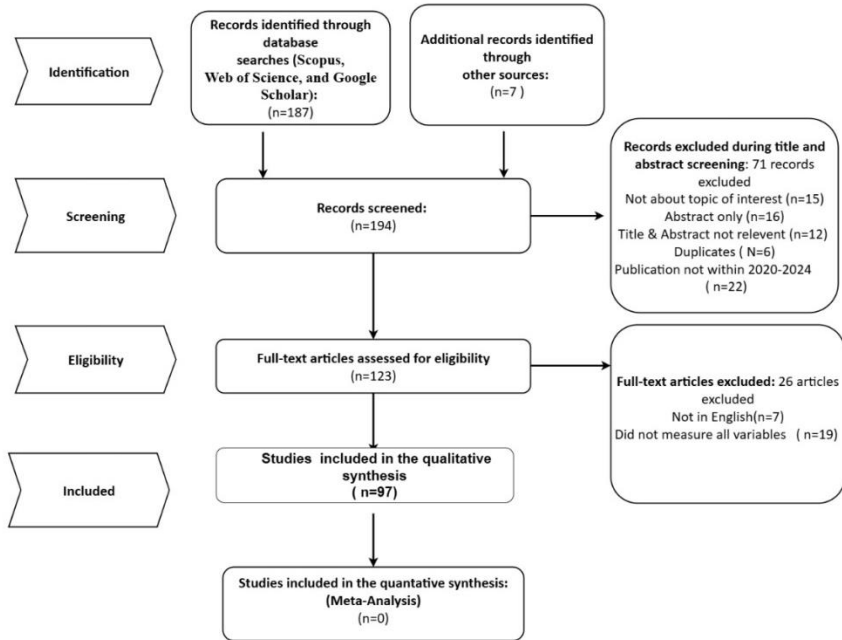
Source: Author, 2025

Figure 1: Prisma flow diagram (Moher et al., 2009)

3.1 Data Analysis

A qualitative thematic content analysis to categorize and quantify textual data derived from 97 high-impact peer-reviewed articles. This study methodically advanced the comprehension of the digital transformation of maritime governance in Bangladesh, utilizing a literature review. Due to the limited number of studies retrieved and their heterogeneity in design and outcome assessment, a narrative synthesis was considered the most appropriate approach to analyze the data. Variables were identified from the reported findings of each study. The variables that had the same pattern were grouped into a specific code. This technique allows identification of relevant categories. The findings were then presented narratively.

To maintain analytical rigor, multiple researchers coded independently but then regularly discussed coding consistency. This approach provided the breadth and depth of literature analysis necessary to identify knowledge gaps and establish the strategic framework proposed in this study.

4. Results and findings

4.1 Barrier variables to Digital transformation in the context of Maritime Administration and Governance in Bangladesh

The thematic analysis of the literature indicates that the impediments to Bangladesh's maritime digitalisation are interdependent rather than discrete. Institutional and regulatory inertia (B1), manifested in overlapping mandates and siloed organisational structures, constrains integrated decision-making . These deficiencies are exacerbated by inadequate digital infrastructure and system interoperability (B2) and underdeveloped cyber-security frameworks (B3), which together diminish system reliability, elevate operational risk, and deter investment. Organisational cultures characterised by risk aversion foster resistance to change (B4), while limited fiscal space (B5) restricts spending on infrastructure upgrades, capacity-building, and cyber-security safeguards. Multi-actor complexity within the maritime domain (B6) fragments initiatives and blurs accountability, amplifying the operational consequences of persistent skills shortages (B7). Finally, weak political sponsorship and predominantly top-down policy processes (B8) limit stakeholder engagement and impede the localisation of national digital strategies. Collectively, these mutually reinforcing barriers suggest that progress will require a coordinated, multi-dimensional reform strategy that addresses regulatory coherence, infrastructure, capacity, and stakeholder alignment in parallel. In this review, the barriers were grouped into eight broad categories Table 3 summarizes category-wise variables in barriers and impacts.

Table 3: Summary of key barriers to digital transformation

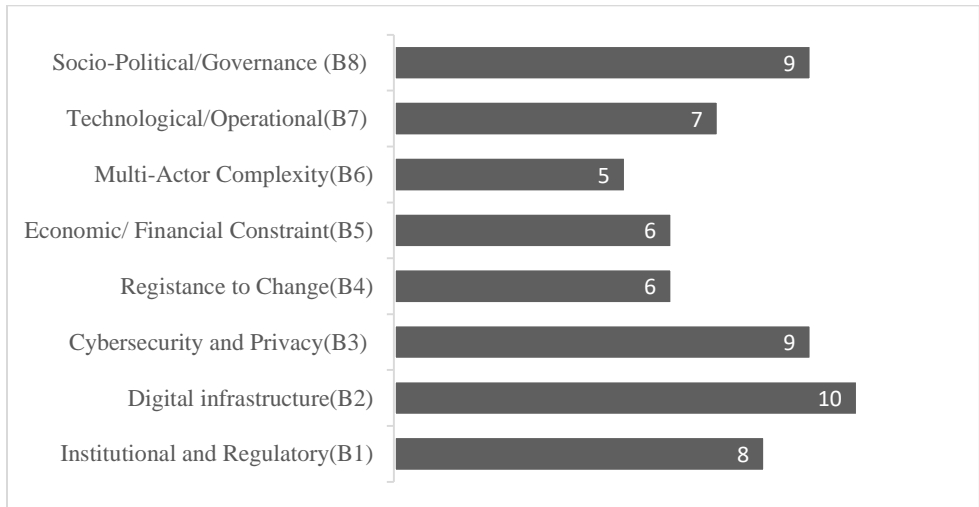| Main category	Sub category	Impact	References
Institutional and Regulatory (B1)	• Governance fragmentation • Institutional rigidity • Overlapping mandates • Siloed operations among various agencies • Outdated regulations	slow decision-making, create confusion in roles and responsibilities, hinder policy implementation, reduce accountability, and obstruct reforms.	(Hasan & Nasrin, 2025; Amin, 2024;Bhuiyan et al., 2024;Amin & Selim, 2022;Hossain, 2022;Hossain, 2024;Islam & Inan, 2021;Rahman & Malik, 2020)

Digital Infrastructure (B2)	• Poor internet connectivity, • Outdated hardware, • Limited digital support systems • System interoperability	Causing delays, inefficiencies, data silos, and security risks, reduces transparency and accountability	(Martinez, 2022; Karim, 2023; Hossen et al., 2017; Rahman & Szabó, 2023;Bhuiyan et al., 2024;Amin & Selim, 2022;Hossain, 2022;Hossain, 2024;Islam & Inan, 2021;Rahman & Malik, 2020)
Cybersecurity and Privacy (B3)	• The absence of robust cybersecurity frameworks, • limited awareness among maritime stakeholders	Expose critical systems to potential cyberattacks	(Nguyen et al., 2022; Hasan & Nasrin, 2025; Mustafa et al., 2023;Bhuiyan et al., 2024:Sakita et al., 2024; Ahmed & Zainordin, 2024;Amin & Selim, 2022;Hossain, 2022;Hossain, 2024)
Resistance to Change (B4)	• Institutional inertia • Fear of job displacement due to automation, • The prevailing culture favours manual processes	Contribute to the slow pace of digital adoption	(Karim, 2023; Huque & Ferdous, 2024; Asmawa et al., 2024; Syed et al., 2022;Hossain, 2022;Hossain, 2024)
Economic/Financial Constraints (B5)	• Investments required for upgrading digital infrastructure, cybersecurity measures, training programs are	Investment required often beyond the allocated budgets	(Zhang et al., 2024; Asmawa et al., 2024; Ahmed et al., 2023; Mazumder & Hossain,

	substantial and		2024;Bhuiyan et al., 2024;Hossain, 2024)
Multi-Actor Complexity (B6)	• Weak coordination among government bodies and private sector stakeholders, and academic institutions	Leads to fragmented efforts and reduced effectiveness of digitalisation initiatives**.**	(Amin & Selim, 2022;Hossain, 2022;Hossain, 2024;Islam & Inan, 2021;Rahman & Malik, 2020)
Technological/Operational (B7)	• Notable shortage of skilled personnel	Skilled manpower is needed to manage and implement digital governance tools effectively	(Martinez, 2022; Abdulnabi, 2024; Uddin & Huang, 2019;Bhuiyan et al., 2024;Hossain, 2022;Islam & Inan, 2021;Zohir, 2023)
Socio-Political/ Governance (B8)	• Inadequate political support and weak institutional capacity to drive digital initiatives. Centralised, top-down decision-making	Fails to engage local stakeholders, causing mismatches between policy initiatives and local needs.	(Huque & Ferdous, 2024; Karim, 2023; Hossen et al., 2017; Asmawa et al., 2024;Bhuiyan et al., 2024;Amin & Selim, 2022;Hossain, 2022;Islam & Inan, 2021;Rahman & Malik, 2020)

Source: *Author, 2025*

Below is the graph (Figure 2) based on the frequency of occurrences of various barrier factors in selected literature from content analysis

Socio-Political/Governance (B8) — 9
Technological/Operational(B7) — 7
Multi-Actor Complexity(B6) — 5
Economic/ Financial Constraint(B5) — 6
Registance to Change(B4) — 6
Cybersecurity and Privacy(B3) — 9
Digital infrastructure(B2) — 10
Institutional and Regulatory(B1) — 8

Source: Author, 2025

Figure 2: Total references in literature of barriers by category

4.2 Key Enablers Variables of Digital Transformation in Bangladesh's Public Administration and Governance

The reviewed literature indicates that Bangladesh already possesses a coherent, if uneven, set of enablers that can underpin maritime digitalisation. High-level e-governance agenda like Digital Bangladesh and Smart Bangladesh (E1) provide the requisite political mandate, while incremental expansion of broadband, mobile, and cloud infrastructure (E2) supplies the technical backbone. Rising digital literacy within public agencies and user communities (E3) is reinforced by updated ICT, data-governance, and cyber-security statutes (E4). Multi-stakeholder collaboration, including donor-funded a2i initiatives (E5), accelerates pilot deployment and knowledge transfer. Technological uptake of AI, blockchain, digital twins, and IoT (E6) is gaining momentum, contingent on parallel cybersecurity safeguards (E7). Equity is addressed through digital-inclusion programmes and data-driven decision-making routines (E8), while emerging innovation ecosystems and start-up support schemes (E9) add entrepreneurial dynamism. These enablers are mutually reinforcing; sustained progress will depend on closing residual gaps and barriers. Table 4 summarises the enablers and their roles in digital transformation.

Table 4: Summary of enablers of digital transformation

Main Category (Enabler)	Sub-Category and Roles in Digital Transformation	References
E-Governance Initiatives (E1)	National e-governance policies, such as "Digital Bangladesh," create a supportive environment for digitalisation initiatives.	(Rahman ,2023; Zhang and Bhattacharjee,2024; Jebunnessa *et al.*, 2024; Rahman and Parvin, 2024; Amin,2024; Ahmed *et al.*,2023; Hasan,2016; Zafarullah and Ferdous, 2021; Sakib *et al.,*2016 ;Hossain, 2022;Hossain, 2024)
Digital Infrastructure Expansion (E2)	High-speed internet, mobile networks, data centres, and cloud services to support digital government services. Improved connectivity and technical infrastructure enable wider access to e-services	(Jebunnessa *et al.,*2024; Rahman and Parvin,2024; Kirmakar, 2023;Hossain, 2024;Hasan *et al.*, 2025; Karim 2023;Hossain, 2022)
Digital Literacy and Awareness (E3)	Stakeholder awareness is growing, with government agencies, private sector actors, and educational institutions increasingly recognising the benefits of maritime digitalisation	(Rahman,2023; Kirmakar,2023; Rahman and Parvin,2024; Zaman *et al.,*2024;Aziz 2020;Hossain, 2022;Hossain;2024)
Policy Frameworks and Regulatory Support(E4)	Establishment of national strategies and policies (e.g., "Digital Bangladesh" Vision, ICT Policy 2018, "Smart Bangladesh" Vision 2041) that set objectives and guidelines for digital transformation. Accompanied by updated laws and regulations (for data, cybersecurity, etc.)	(Rahman and Parvin ,2024; Ahmed *et al.,* 2023; Amin, 2024;Aziz,2020; Hossain, 2022;Hossain,2024;Islam & Inan, 2021)
Stakeholder Collaboration(E5)	Partnerships and coordination among the government, private sector, academia, and civil society to implement digital	(Rahman and Parvin,2024; Rahman *et al.,*2014;Aziz, 2020 ;Hossain, 2022;Hossain, 2024)

	initiatives. International donor support (e.g., UNDP's a2i program) contributes expertise and funding for e-governance reforms.	
Technological Integration and Innovation(E6)	Technological advancements such as blockchain, artificial intelligence, digital twins, and IoT offer opportunities to enhance system resilience and operational efficiency**.**	(Rahman and Parvin, 2024; Ahmed *et al.,* 2023; Ahmed, 2018;Aziz, 2020;Hossain, 2022;Islam & Inan, 2021)
Cybersecurity and Data Privacy(E7)	Implementing cybersecurity measures, including the Digital Security Act, is crucial to protect personal data and maintain public trust in digital systems.	(Rahman and Parvin,2024; Karim, 2023; Ahmed *et al,* 2023;Ahmed & Zainordin, 2024;Hossain, 2024;Islam & Inan, 2021)
Inclusive Governance and Digital Inclusion(E8)	Equal access to digital services for all citizens, including marginalized and rural communities, through community digital centers, affordable access initiatives, and user-friendly service design..	(Rahman,2023; Rahman and Parvin, 2024; Hasan,2016 ; Amin 2024;Hossain, 2024;Islam & Inan, 2021)
Data-Driven Decision-Making(E8)	Data analytics and evidence-based methodologies are utilized in government planning and policymaking, enhancing transparency and effectiveness by enabling real-time monitoring, evaluation, and informed decision-making.	(Rahman and Parvin,2024; Zhang and Bhattacharjee,2024; Ahmed *et al.,* 2023; Aziz, 2020).
Fostering Innovation and Entrepreneurship(E9)	Promoting innovation ecosystems and tech entrepreneurship to drive digital government solutions and economic growth, including government-backed startup funds and collaboration with private innovators.	(Rahman and Parvin,2024; Ahmed *et al.,* 2023; Amin, 2024).

Source: *Author, 2025*

Figure 3 below illustrates the key enabling factors identified across various categories and the corresponding number of references associated with each category.
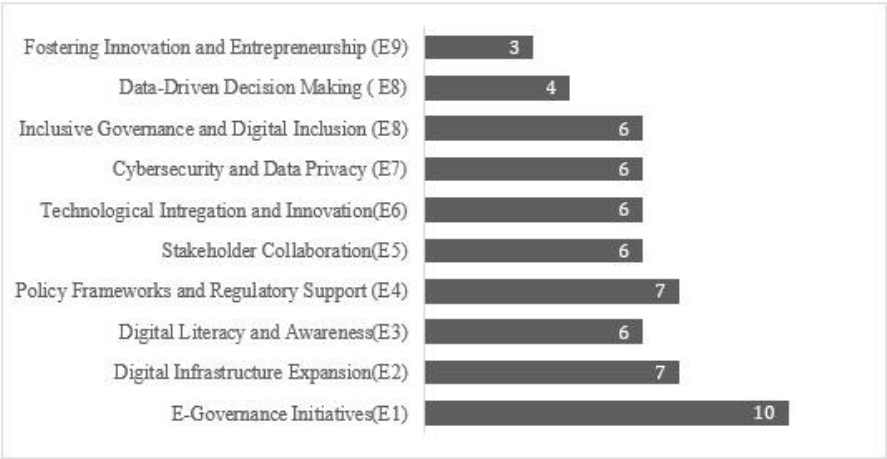
Figure 3: Frequency of references from selected literature for each category

4.3 Strategies and tools for Sustainable and Resilient Digitalization Transformation of Maritime Governance

Sustainable and resilient digital transformation in maritime governance, particularly for Bangladesh and similar developing nations, necessitates a comprehensive strategy that integrates technological innovation, governance reforms, and stakeholder collaboration while addressing identified barriers and leveraging enablers. The thematic analysis outlines interrelated strategies that connect to relevant barriers and enablers, which are essential for a successful digital transformation.

4.3.1. Strategies for Sustainable and Resilient Digitalization Transformation of Maritime Governance

4.3.1.1 Sustainability through modern technology

Modern digital technologies, including digital twin simulations, AI, big data analytics, and blockchain, are crucial for enhancing marine sustainability. These technologies can optimise resource consumption and minimise the environmental impact. For instance, VesselAI has demonstrated how AI-driven analytics can improve vessel performance and reduce emissions (Mouzakitis et al., 2022; Ilias 2023). Blockchain enhances supply chain transparency (Duisenbiyev &

Seitkazieva, 2023), whereas real-time digital twins facilitate predictive maintenance for sustainable port operations (Koilo 2024; Toygar 2024). These innovations support data-informed marine governance by addressing technological and operational challenges (Rahman and Parvin, 2024; Aziz, 2020;Koca & Erdoğan, 2024).

4.3.1.2 Integrating automation with agile governance

Marine governance can be safely, efficiently, and in line with environmental compliance through automation. However, to exploit their full benefits, agile governance is necessary. The IMO supports "smart" regulations, as regulations are usually behind innovation (Olaniyi et al., 2024; Baumann, 2023; Koca & Erdoğan, 2024). For example, modernizing regulatory frameworks can enable automation of port and shipping administration, IoT sensors can be used to optimise logistics and reduce human error (Moldazhanov & Yanitska, 2024; Toygar, 2024; Potamos et al., 2024). Institutional inertia can be overcome only through regulatory flexibility and interoperability (Kaštelan et al., 2024; Aziz, 2020).

4.3.1.3 Improving digital resilience and risk-management skills

The resilience of the maritime sector must be built towards preparedness against disturbances, such as cyberattacks, natural disasters, or maritime emergencies (Gao et al.,2023). Coordinated planning and information sharing can enhance resilience through a network orchestration strategy (Ramstad et al., 2024). Stakeholder connectivity is essential for responding to incidents quickly, and the facility with which this is achieved is through digital platforms. With increased digital dependency, the tools to fight cybersecurity threats include redundant data systems and AI risk monitoring (Kouroupis & Sotiropoulos, 2024; Karaca & Soner, 2023). The collaboration of stakeholders promotes a shared framework of resilience, which considers the complexities of networks involving multiple actors.

4.3.1.4 Encouraging collaboration and engagement among stakeholders

Effective marine digitisation hinges on cooperation among government agencies, port authorities, commercial entities, international partners, and local communities. Baumann (2023) stresses the expanding maritime governance landscape and the need for participatory decision-making to integrate different views. Collaboration between public institutions and IT companies is one of the success stories of EU-funded VesselAI projects (Mouzakitis et al., 2022; Ilias, 2023; Aziz, 2020). Bangladesh's maritime authorities can engage stakeholders in overcoming fragmented networks and institutional silos for knowledge sharing and resource collaboration through digital platforms.

4.3.1.5 Integrating Digital Maturity Models

Marine organisations can leverage the digital transformation maturity model to align digital initiatives toward sustainability and governance objectives. Therefore, such models aid in capability assessment, gap identification, and prioritising improvements. As such, sustainability indicators may be incorporated with digital maturity assessments to enable organisations to develop strategies and improve technology capabilities and resilience (Уґли, 2023; Koca & Erdoğan, 2024). The phased roadmap can address institutional barriers and align with national development visions, such as Bangladesh Vision 2041 (Asmawa et al., 2024).

4.3.1.6 LARG performance model

The LARG performance model (Azevedo et al., 2011) improved the efficiency and sustainability of marine operations. Waste reduction is associated with lean principles and is responsive to the need for change through agile approaches (Narasimha et al., 2022). The resilience of the LARG model is based on risk management, whereas green initiatives focus on reducing emissions and energy efficiency. Strong leadership and commitment to innovation and sustainability are needed to successfully implement LARG (Zhang et al., 2024).

4.3.1.7 Business model innovation

Digital transformation allows maritime companies to innovate business models and propose sustainable value propositions. IoT and blockchain technologies are changing logistics and regulatory service delivery (Larrazábal, 2023). Real-time data centres and predictive analytics enable maritime authorities to facilitate public-private collaboration, attract investment, and overcome institutional resistance while delivering the benefits of innovation (Ahmed et al., 2023).

4.3.1.8 Addressing Implementation Challenges via Capacity Building and Governance Reform

Addressing implementation barriers, such as poor data quality and cybersecurity threats, is critical to ensuring a successful digital transformation. Investing in robust architectures and standards can enhance data-driven decision-making (Wahyu 2024). Strengthening cybersecurity measures and promoting digital literacy through training can mitigate resistance to change (Karim 2023). A systematic approach to tackling these challenges will build a solid foundation for digital transformation, ensuring that technologies and innovations achieve their intended sustainable impact.

4.3.2 Digital Governance Strategic Tools, Techniques, Models, and Best Practices in Maritime Nations

Singapore, the Netherlands, Norway, the UK, and Japan serve as case studies for successful digital transformation in maritime governance. By analysing their strategies, we can identify effective tools and best practices that align with resilient and sustainable digitalisation goals, including enhancing cyber resilience, streamlining operations, and fostering collaboration.

4.3.2.1 Cybersecurity in Maritime Governance

Cybersecurity is crucial for marine digital governance due to escalating threats to ports and shipping infrastructure. In 2024, the Maritime Port Authority (MPA) of Singapore established the Maritime Cyber Assurance and Operations Centre (MCAOC) to provide cyber threat monitoring and consulting services, onboarding 16 organizations (MPA, 2024). Additionally, industrialized nations implement international cybersecurity standards, such as the UR E26 standard of the International Association of Classification Societies (IACS), to bolster ship cyber resilience. Research by Kayisoglu (2024), Ibokette et al. (2024), and Karaca & Soner (2023) on AI-based intrusion detection systems and sophisticated cryptographic protocols has significantly enhanced cyber defenses, ensuring marine systems remain resilient against interruptions.

4.3.2.2 Data Management in Maritime Governance

To enhance the flow of information, advanced nations are setting up integrated data platforms and single-window systems. Such shared situational awareness is also seen with the EU's SafeSeaNet platform, which connects stakeholders among one another to consolidate information from real-time data regarding vessel movements (Ramstad et al., 2024; European Commission, 2020). Maritime Single Window (MSW) systems, such as digitalPORT@SG, are implemented to enhance operational efficiency by reducing administrative delays (IMO, 2024; Du et al., 2023). In addition, Port Community Systems (PCS) are employed to facilitate real-time data exchange among port stakeholders, as evidenced in the Port of Rotterdam's Portable PCS, which encourages other countries (Ramstad et al., 2024; Priya et al., 2024).

4.3.2.3 Smart Port Operations and IoT-Driven Optimization

Currently, leading ports are more inclined to use smart technologies such as IoT and data analytics to improve operational efficiency and sustainability (Hebbar et al., 2024; Su et al. 2024). Digital twins and sensor networks will be used to optimise operations to become the 'first digital port in 2030' (Port of Rotterdam, 2021). Jurong Port in Singapore has launched a GIS-powered digital twin to

control resources better (Bills & Fowler 2024). Furthermore, IoT is utilized for predictive maintenance in Japan and Norway, and an advanced Vessel Traffic Management System (VTMS) in Europe enhances the safety and efficiency of ship movements, as well as the Ship Traffic Management (STM) system (González-Cancelas et al., 2024; Marinova and Zeneli, 2024).

4.3.2.4 Environmental Monitoring and Sustainable Maritime Practices

A sustainability approach was adopted for marine environmental protection through the use of digital governance tools. IoT-based environmental monitoring systems have been implemented in European ports to monitor air and water quality, as well as emissions, in real-time (European Commission, 2020). It helps maintain emission regulations and optimise resource use. Rotterdam's commitment to being a CO_2-neutral port and Japan's focus on energy reduction are initiatives that demonstrate how sustainability can be aligned with digitalization. Thus, the e-navigation systems of developed nations also contribute to environmental benefits by optimizing shipping routes (Arumugam and Parasuraman, 2023).

4.3.2.5 Collaboration, Training, and Governance Framework

Multi-stakeholder collaboration, systematic capacity-building, and fit-for-purpose governance instruments form an interdependent triad that underpins maritime digitalisation. Public–private programmes such as the Netherlands' SmartPort create neutral knowledge-brokering arenas that catalyse the co-creation of digital pilots and demonstrators, while national maritime-education initiatives in Norway and the United Kingdom embed competence standards for data analytics, automation, and cybersecurity (Port of Rotterdam, 2021; Theotokas et al., 2024; Dimitrakiev & Stankov, 2023; Sijabat & Simanjuntak, 2024). Empirical evidence further indicates that cloud-hosted simulators (K-Sim Connect) enhance motivation and performance in remote engine-room courses, algorithm-enabled full-mission bridges (K-Sim Polaris) objectify anti-collision competence audits, immersive virtual-reality fire-fighting and evacuation drills accelerate procedural learning, and AI-driven digital twins generate synthetic emergency scenarios that strengthen joint decision-making across pilot, tug and first-responder teams (Hjellvik & Mallam, 2023; Juszkiewicz & Żukowska, 2023; Vukelic et al., 2023; Wang et al., 2024). Governance tools ranging from digital-maturity matrices to performance frameworks provide ex-ante diagnostics, steer programme portfolios and institutionalise continuous-improvement loops throughout the transformation lifecycle (ўгли, 2023; Narasimha et al., 2022). Collectively, these collaborative structures, technology-rich training modalities, and iterative governance mechanisms create a virtuous

cycle that accelerates safe, efficient, and sustainable maritime digital transformation.

4.3.3 Priority areas of research and policy recommendations

Based on the examination of digital governance enablers/barriers (RO1), transformation strategies, global best practices (RO2), and existing government ICT policies (ICT Division, 2018; ICT Division, 2019; ICT Division, 2021a; ICT Division, 2021b; Japan International Cooperation Agency, 2023), the five clusters presented in Table 5 delineate critical domains where academic research and policymaking must intersect to address existing deficiencies and synchronize national maritime digital initiatives with global innovation pathways.

Table 5: Priority research and policy development areas

Priority Area	Research Direction	Policy Recommendation
Stakeholder Engagement Models	Comparative governance models from developing countries	Maritime Digitalization Council with formal PPP mechanisms
Technology Impact Assessment	Empirical studies on blockchain, AI, PCS, Digital Twin etc.	Technology pilots in ports with built-in Monitoring and evaluation units
National Digital Framework	Frameworks integrating legal, operational, and sustainability goals	National Maritime Digital Strategy aligned with Vision 2041, IMO, and EU frameworks
Digital Skills & Capacity Building	Skills mapping, training impact evaluation	Maritime Digital Skills Academies; STCW digital module integration
Green & Sustainable Digitalization	Modelling emissions savings from digital tools (e.g., JIT, AI-routing)	Green digital indicators; mandatory EIA for digital infrastructure

Source: Author, 2025

5. Discussions and Conclusion

This study explores the digital transformation roadmap in Bangladesh's maritime governance, illuminating formidable challenges and substantial opportunities that lie ahead. Institutional and regulatory rigidity, an inadequate technological infrastructure, and cybersecurity are significant hurdles. However, these challenges are counterbalanced by potential enhancements in operational efficiency, regulatory compliance, and environmental stewardship that digital technologies can facilitate.

Moreover, legislative and policy environments are conducive to digital innovation. This entails revising the existing laws and regulations to facilitate the smooth integration of digital solutions in maritime operations. Enhanced collaboration among government entities, the private sector, and international organisations is crucial to effectively sharing resources, knowledge, and best practices.

The adoption of best practices by global leaders, such as those in Singapore, EU countries, and Norway, offers a valuable blueprint for Bangladesh. These countries have successfully integrated cutting-edge technologies such as AI, blockchain, and IoT to streamline maritime operations and governance. By following these examples, Bangladesh can not only address its current barriers but also leapfrog into a more integrated and efficient management system. This approach aligns well with the Sustainable Development Goals (SDGs), which aim to transform Bangladesh into a digitally empowered society and knowledge economy.

The insights from this study highlight the urgent need for a comprehensive digital strategy that is resilient, inclusive, and aligned with international standards. By adopting a proactive and collaborative approach to digital transformation, Bangladesh can significantly enhance its maritime governance and position itself as a competitive player in the global marine industry. This strategic shift promises improved operational efficiencies and compliance with international standards and ensures the long-term sustainability and resilience of the maritime sector in Bangladesh.

Limited resources exist regarding digitization in Bangladesh's maritime sector. The literature on digitalisation in public administration is extensive, although it hardly addresses the maritime governance framework of Bangladesh. This research employs worldwide case studies to illustrate the advantages and tools of digitalization in global organizations; nevertheless, economic, social, and political factors may restrict its relevance to developing countries such as Bangladesh. This analysis employs secondary data. This reliance may limit the examination of digitalization's impacts and challenges within Bangladesh's maritime sector. A meta-analysis was not conducted due to the limited number of eligible studies identified, which was insufficient to produce a statistically meaningful synthesis. Narrative synthesis was employed to address this gap.

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