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Evaluation of Feasibility and Reality of Smart Port Perspective for Bangladesh

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ABSTRACT

A seaport is a maritime facility equipped with docks, cranes, and storage facilities for international trade, where vessels load and unload cargo, containers, and passengers. In contemporary times, seaports serve as indispensable hubs for global commerce, facilitating the import and export of a wide array of commodities. As the primary interface between nations, ports play a pivotal role in the global economy, with more than 75% of international trade transiting through them. The fundamental functions of seaports encompass operations, surveillance, cargo and container handling, customs procedures, warehousing, transport, ship services, and security measures. Notable ports such as Houston, Los Angeles, Shanghai, PSA, DP World, and Rotterdam manage substantial volumes of goods promptly across the globe. Simultaneously, ports within Bangladesh, including Chattogram, Mongla, Payra, and Matar-Bari, are critical to regional commerce. The efficacy of ports is reflected in their ability to meet defined objectives. Presently, smart ports are markedly efficient, as they incorporate assessments that optimize operational, managerial, and cost-related benefits. Recognizing the potential of smart ports is essential, given that even minor disruptions in cargo movement at major maritime ports can exert far-reaching effects. Furthermore, technological advancements are enhancing maritime navigation and environmental monitoring. This study underscores existing research gaps in Bangladesh's port sector. It aims to evaluate the benefits and challenges of smart ports, as well as strategies for their effective implementation and development.

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Introduction

A notable recent trend in modern port development is the adoption of automation and advanced technologies. This shift is driving ports to upgrade their infrastructure and services to stay competitive and operationally efficient [1]. Automated ports represent a new generation of digital and smart port systems, designed to be more efficient, sustainable, and technologically advanced than traditional ports [2]. These advanced ports utilize innovative technologies like Artificial Intelligence (AI), Machine Learning (ML), Deep Learning (DL), the Internet of Things (IoT), Digital Twin, Big Data, Data Science (DS), and blockchain to improve operational efficiency and reduce environmental effects [3-8]. Just as steam engines, electricity, and computers historically transformed the world, AI emerges as a prominent general-purpose technology with widespread uses across various industries [9]. AI allows machines, especially computer systems, to imitate human intelligence [10]. It is commonly employed in fields like automation, robotics, language translation, image recognition, decision-making, online banking, healthcare, autonomous vehicles, e-commerce, agriculture, and automated port operations [4]. AI systems are built to perceive, comprehend, learn from, and react to their surroundings, playing a vital role in port digital transformation [11]. Machine Learning (ML), which gained prominence in 1959 through Arthur Samuel's work, is a branch of AI focused on developing algorithms that enable systems to learn from data and improve their performance over time without explicit programming. These algorithms are crucial for detecting spam, scams, and phishing by analyzing malicious content [11]. Deep Learning (DL) was introduced to the ML community by Rina Dechter in 1986 and advanced further by Yann LeCun and colleagues in 1989 through the use of back-propagation algorithms [3]. It is a specialized subset of ML [12]. DL uses multi-layered neural networks modeled after the human brain's structure [13]. These networks are computational systems called Artificial Neural Networks (ANNs), which are highly effective for pattern recognition and prediction by modeling relationships among variables [14]. Data Science (DS) is another essential discipline within this ecosystem [4].

Today, ports utilise smart cranes and automated systems, alongside digital technologies, to handle the loading and unloading of containers and bulk goods such as coal, grain, ore, and oil tankers. Well-placed ports are strategically located for optimal access to busy hinterlands [15]. Ports are designed to provide safe navigation and shelter from natural hazards such as cyclones, tsunamis, or rough seas. Many ports are naturally located on estuaries, where shallow waters often require regular dredging to keep them navigable [16]. Some ports also serve military or naval functions [10]. Port types and functions vary globally, with many developed countries favouring public ownership, though some ports are jointly owned by national and municipal authorities [17-19]. To improve port operations, security, and decision-making,

smart ships and advanced technologies such as AI-powered satellite data analysis, passive acoustic systems, and remote sensing are increasingly used for environmental monitoring [20]. These applications utilise IoT, AI, ML, DL, Big Data, and other technologies [21]. Another significant trend is the rise in vessel size, dating back to the 1990s with post-Panamax containerships [22]. Ongoing growth in ship sizes, including container ships, bulk carriers, car carriers, and cruise ships, necessitates specialised port terminals designed for large vessels. Currently, because global trade relies on zero-inventory and just-in-time delivery models, supply chain disruptions can cause shortages at supermarkets and fuel stations within days [23]. The concept of sixth-generation ports aims to develop infrastructure capable of supporting ultra-large vessels with capacities up to 50,000 TEU [24].

A prominent recent trend in modern port development is the increasing adoption of automation and advanced technologies. This change drives ports to upgrade their infrastructure and services to remain competitive and efficient [1]. Automated ports exemplify a new era of digital and smart port systems, designed to surpass traditional ports in efficiency, sustainability, and technological sophistication [2]. These ports utilize state-of-the-art technologies such as Artificial Intelligence (AI), Machine Learning (ML), Deep Learning (DL), the Internet of Things (IoT), Digital Twin, Big Data, Data Science (DS), and blockchain to boost operational performance and reduce environmental impact [3-8]. Just as steam engines, electricity, and computers once transformed society, AI stands out as a versatile technology with widespread industry applications [9]. AI enables machines, especially computer systems, to mimic human intelligence [10]. It is employed in automation, robotics, language translation, image recognition, decision-making, online banking, healthcare, autonomous vehicles, e-commerce, agriculture, and notably, port automation [4]. AI systems can perceive, understand, learn, and react to their surroundings, making them essential to the digital transformation of ports [25]. ML, which gained recognition in 1959 through Arthur Samuel's work, is a subset of AI that uses algorithms to allow systems to learn from data and enhance their performance over time without explicit programming. These algorithms are crucial for identifying spam, scams, and phishing content [11]. It is an interdisciplinary field that combines statistics, computer science, and domain knowledge to extract valuable insights from large datasets [26]. In port operations, big data and Data Science are vital for optimizing logistics, demand forecasting, and decision-making [6]. Overall, the integration of AI, ML, DL, IoT, and big data is transforming smart ports into intelligent, adaptable systems capable of responding efficiently to the needs of global trade and sustainability [27].

DL, introduced to the ML community by Rina Dechter in 1986 and further developed by Yann LeCun and colleagues in 1989 through back-propagation algorithms, is a specialized branch of ML [3,12]. It uses multi-layered neural networks modeled after the human brain [13]. These networks, called Artificial Neural Networks (ANNs), excel at recognizing patterns and predicting by modeling relationships between variables [14]. Data Science (DS) is another essential discipline within this ecosystem [4]. An interdisciplinary field, DS combines statistics, computer science, and domain expertise to extract meaningful insights from large datasets [26]. In port operations, Big Data and DS are crucial for optimizing logistics, forecasting demand, and enhancing decision-making [6]. Overall, AI, ML, DL, IoT, and Big Data are transforming smart ports into intelligent, adaptive systems capable of meeting the demands of global trade and sustainability [27]. Modern seaports should adopt robust change management programs emphasizing transparency and gradual AI integration to gain workforce support. Early staff involvement and clear communication about benefits, such as improved safety and reduced workload, can help overcome resistance. This research will analyze and propose insights on the current state, challenges, recent practices, and advantages of smart technology in Bangladesh's major seaports.

Literature Review and Research Methodology

Ports serve as vital connectors between nations and regions, facilitating smooth international trade. They handle diverse commodities, from raw materials to finished products, supporting global supply chains and various industries. Ports also contribute significantly to employment in sectors like cargo handling, logistics, transportation, and support services. In today's global environment, seaports are recognized as critical infrastructure tied to economic activity. The increasing volume of seaborne trade creates pressure on ports to improve their efficiency, performance, and service quality. Consequently, many ports are transitioning to smart ports, utilizing digitalization and advanced technologies. These ports are becoming more automated, employing sensors, big data analytics, AI, ML, IoT, DL, AR, digital twins, and other sophisticated systems to optimize cargo operations and reduce environmental impact. They also provide enhanced services to stakeholders such as shipping companies, customs, local communities, and others. Additionally, smart ports often include eco-friendly features like renewable energy, electric vehicle charging, onshore power, and smart logistics infrastructure.

Modern ports feature advanced technologies and specialized cargo-handling equipment, including gantry cranes, mobile heavy-lift cranes, straddle carriers, reach stackers, and forklift trucks [25]. Seaports facilitate logistics, including warehousing, customs clearance, and connections to road or rail networks. They also offer ship services like fueling, fresh water, provisions, maintenance, and passenger amenities. Many ports specialize in specific functions: some handle passenger and cruise services, while others concentrate on container cargo, bulk shipments, or general freight. For instance, unlike river ports that serve inland waterway traffic such as barges, coasters, and shallow-draft vessels, Deep-water or deep-sea ports typically accommodate larger ocean-going vessels with deeper drafts. (Shanghai, Matar-Bari) [28]. Additionally, container ports focus on containerized cargo (such as DP World, Chittagong Port), while bulk cargo ports handle bulk cargo (such as Rotterdam and Mongla Port). Inland ports are accessible through rivers and canals. Modern ports function as integrated transport hubs, connecting multiple modes of transportation, including rail, road, sea, air and inland waterways [29]. This multimodal amalgamation enhances supply chain connectivity and logistical efficiency. In today's complex geo-economic and political landscape, specific ports such as PSA, DP World, and CPA hold strategic importance in regional and global trade. For example, Chittagong Port serves as a vital maritime gateway for Bangladesh, affecting both the country's economic growth and geopolitical relationships [11]. Historically, ports served as basic harbors with limited functions. However, today's ports have developed into intricate, multimodal logistics hubs, featuring extensive transport connections by sea, river, rail, road, and air [30,31].

This research adopts an interdisciplinary, multi-scalar approach to investigate the current status of Bangladesh's seaports and their smart port transformation, focusing on both technological and institutional perspectives. While Chittagong and Mongla Port are treated as the primary cases, the findings have broader applicability to other ports in South Asia, particularly across the Global South.

The study seeks to depict the current and future development plans of Bangladesh's seaports. It assesses governance models, stakeholder dynamics, digital policy frameworks, and collaboration mechanisms, including private-public-industry collaboration, that underpin or hinder transformation. It emphasizes the role of inter-agency coordination, regulatory clarity, and enhanced or guided stakeholders' capacity in building a resilient digital and smart infrastructure for maritime trade and the port sector. The research is grounded in Bangladesh's socio-political, technological and economic realities. However, it is designed to depict and inform on the broader aspects of local ports' status, capabilities, and the growth of maritime trade, and to highlight future development plans. Efforts have been made to educate the relevant community about smart port modernization and the economic development plan, as well as related institutional and infrastructural constraints. Here, the Focused Group Discussion (FGD), formal and informal interviews, conversations, idea sharing at conferences, and the author's practical work experience have helped enormously in collecting and analyzing the state of Bangladesh Ports. Additionally, secondary information from electronic, print and social media, along with available literature, has contributed significantly. However, there are many constraints to collecting data and information during the research.

There is a distinct research gap, and a few simple questions need to be answered, as summarized below.

a. What is the present status of sea ports of Bangladesh?
b. What is the growth and future demand for sea port facilities in Bangladesh?
c. What is the concept of smart port and its potential?
d. What are the benefits and challenges of smart ports?
e. How can Bangladesh's major sea ports implement and benefit from smart technology?

In this research work, interviews, formal and informal interactions, and Focus Group Discussions (FGDs) have played a critical role in collecting data and analysis related to community-level insights and local and global maritime ports practice, port operation, safety and security, performance, monitoring, customs formalities, hinterland connectivity, and digital and smart technology integration. These are often underrepresented, even in macro-level policy analysis. However, to gather information, formal and informal online interviews/interactions, FGDs, and involvement of personnel experienced in the respective field were conducted. Interestingly, through the interviews/interactions and FGDs, important information and ground reality were discovered from both local and global seaports. Discussions with FGDs and resource personnel from home and abroad were very useful and helpful for the research. This study employs a mixed-methods design combining primary and secondary data analysis (predicted cargo growth analysis of Bangladesh maritime trade, over 200 both structured and informal stakeholders and related interviews (business owners, traders, local and international shipping lines, off-dock owners, freight forwarders, agencies, maritime traders, port service providers, workers, engineers, regulators, SMEs, NGOs, system architect, managers, foreign experts, economist, dock owners, academician, university professor, consultant, thinkers, different professionals, and many more).

Each FGD involved 6–10 participants and was facilitated by a semi-structured questionnaire. The discussions covered perceptions of optimizing port operations, integrating digital and smart technologies, enhancing service quality, ensuring ESG compliance with port concession licenses, eligibility for public-private investments, SDG performance metrics, and job satisfaction among port workers. Topics also included adopting innovations like AI, ML, digital twins, Big Data, and IoT in port activities, along with developing digital literacy and training programs for port professionals. Additional focus areas included freight and port governance standards, customs procedures, labor safety, port security (including cybersecurity policies), quality assurance, innovation, process standardization, compliance barriers, social livelihood impacts, modernization strategies, and integrating advanced frameworks and technologies. Discussions highlighted the need for manufacturing support, AI- and IoT-based emission tracking systems, environmental dashboards monitoring carbon, noise, and energy, and coordinating digital initiatives across agencies. Emphasis was placed on aligning port digitalization with national development goals, establishing digital legislation, and creating standardized Port Community Systems (PCS) and Terminal Operating Systems (TOS) in local ports. FGDs involved a range of stakeholders, including individuals, agencies, groups, and organizations, to ensure broad participation.

a. Global and Local Shipping lines, ship owners, etc.
b. Shipping agencies and warehouse owners
c. Business people, maritime traders, Insurance workers, bankers, fund providers
d. Port workers, technicians, equipment operators (both skilled and unskilled)
e. Relevant managers, architects, engineers, finance and administrative personnel
f. Government officials working in major sea ports in Bangladesh
g. Digital and smart technological professionals
h. Quality assurance professionals, economists, financial experts, and NGO representatives
i. Related SMEs, journalists, and other organizations
j. Freight forwarders, dock owners, off-dock people, etc.
k. Port executives, operators and other service providers
l. Academics, researchers

The FGDs and informal discussions were held many times (around 20 times) from Feb 2023 to Jul 2026, and more than 300 participants from different levels, both at home and abroad, attended. The FGDs were conducted either in small groups or individually in different places and at different times, at their convenience and within their availability and time constraints. They have attended both individually and in small groups in different places and at different times throughout the study and research work. FGDs and respected personnel with formal and informal interviews/interactions have attended and provided information from many corners of the globe, such as major sea ports of Bangladesh (CPA, MPA, PPA), Global Shipping Lines representatives like Maersk, MSC, CMA CGM, COSCO Shipping Lines, Hapag-Lloyd, Ocean Network Express, etc. Local Shipping Lines representatives like Bangladesh Shipping Corporation (BSC), Maersk Bangladesh Limited and MSC Mediterranean Shipping Company Bangladesh, Akij Shipping Line Ltd, Meghna Group of Industries, Bashundhara Group, etc. Shipping agencies like BSC, Sea King Marine Services Ltd, MGI- Shipping, SR Shipping Ltd, Maersk Bangladesh limited, MSC Mediterranean Shipping Company Bangladesh LTD, PIL Bangladesh Ltd, Cosco Shipping Lines Co., Ltd, Nyk Line (Bangladesh) Ltd, APL Bangladesh Pvt Ltd, etc.

Information was also collected, and sufficient help was taken from many relevant universities and institutes from home and from abroad, with their participants/representatives, such as international organizations. Representatives from different Ministries and officials, along with government organizations and

bodies, Shipyards, industries, and Associations (FBCCI, BGMC, BKMC, BTMC, Bashundhara Group, PHP Industry, Walton, RFL Group, etc.) have been consulted and interviewed formally and informally. Many international universities, such as WMU, Osaka University, University of Yokohama, University of Basel, University of Paris, UNSW, The University of Melbourne, Monash University, CDU, etc., have contributed and guided a lot to explore the global port sector as a whole. Many important participants and representatives attended and participated in the discussion and provided valuable information and suggestions. This research study will evaluate the present status and future development of Bangladeshi seaports, along with smart port solutions, from a global viewpoint. This analytical study will also cover the functional activities and indicators of achievement in the thematic area of key priorities, which guide the implementation of the roadmap and action plan for sustainable seaport development, along with hinterland and transportation improvement in Bangladesh. The author has acknowledged the dedication, positive attitude, and countless help and contributions of all persons, agencies, groups, and organizations from home and abroad.

Status of Bangladesh Sea Ports

Bangladesh's sea ports are currently experiencing a significant modernization and transformation phase, with Chattogram Port handling over 90% of the nation's trade while growing capacity is apparent at Mongla and Payra ports. Key developments also include the Matar-Bari Deep Sea Port and the Bay Terminal aimed at increasing efficiency and reducing congestion. The Chattogram Port is the main gateway for Bangladesh and one of the busiest ports in South Asia, handling 98% of container trade and 90% of total export-import trade. The government has engaged (primarily through Memoranda of Understanding, or MOUs) foreign operators, such as Denmark's APM Terminals and Swiss firm Medlog, for terminal management to improve efficiency. Mongla Port serves as the second-busiest port in the southwestern part of the country. Matar-Bari Deep Sea Port is located in Cox's Bazar and is under development as Bangladesh's first deep-sea port. It is designed to handle large, deep-draft vessels, enhancing Bangladesh's maritime trade capabilities, and is being built with Japanese support. On the other hand, the Payra Port is situated in Patuakhali, and it is being fully developed to ease the burden on Chattogram Port, with major upgrades expected to be fully operational by 2027. However, dream projects like the Bay Terminal (3 container terminals, 13 jetties) aim to reduce congestion, allowing ships with a maximum capacity of 6,000 TEUs (to accommodate more than 12m draught vessels). In Bangladesh, the seaports have historically faced congestion, which has been exacerbated at times by political instability and flooding, leading to supply chain troubles. So, the focus remains on increasing terminal capacity and developing new, deeper ports to support the country's rising maritime trade, especially with the growth in the apparel and other export sectors.

Bangladesh's principal seaport is Chittagong Port, a vital economic engine which handles 92% of the nation's total seaborne trade and roughly 98% of its containerized trade. Operated by the Chattogram Port Authority (CPA) and administered by the Ministry of Shipping (MOS), the Chattogram Port has a rich history dating back to the 4th century BC. The Chattogram Port advanced under British colonial governance through the Port Commissioner's Act of 1887 and subsequently began its modern existence in 1960 as the Chattogram Port Trust. In the post-Liberation War period, it gained semi-autonomous status and was renamed to Chittagong Port Authority in 1976. Given the due importance of the landlocked areas surrounding Bangladesh: North Eastern India, Nepal, Bhutan, and regions of Myanmar and China, with adequate inland connections, the Chattogram Port can be developed to provide a shipping connection link to the wider region and thereafter with the rest of the world. While it is unlikely that the port will become an international hub, due to natural limitations and distance from main international sea routes, the Chattogram Port has the potential to become a major regional hub [32,33]. The Chattogram Port, however, faces capacity constraints and must expand to handle growing volumes of containers and other cargoes to meet foreseeable demand.

Chattogram Port achieved record-breaking numbers during January-December 2025, handling a remarkable 3,409,069 TEUs of containers, 138.15 million metric tons of cargo and 4,273 vessels. As reported by the Chattogram Port Authority (CPA), this feat indicates significant growth in 2024, with container handling rising by 4.07%, vessel handling by 10.5%, and cargo throughput by 11.43% [34]. Even though limited automation, customs halts, strikes, and political unrest slowed down operations, the port managed to stabilize its operations. However, Chattogram port is gradually increasing its operational role and becoming an indispensable part of the national supply chain. This is proven by the 13.2% surge in bulk cargo and a 6.02% rise in container volume, with the port handling 138.15 million metric tons of cargo overall. The growth of Chattogram port didn't falter despite technological limitations and political crises in 2025; rather, it optimized vessel holding durations. During January-November 2025, the port lead time also saw a positive slope as the average vessel turnaround time and average container dwell time underwent massive improvements, with the former being 2.53 days and the latter hovering around 9.44 days. This is a huge step going forward as importers and exporters can trade much more conveniently. Therefore, logistics overheads are anticipated to decline, thus driving export competitiveness, yielding substantial benefits in the Readymade Garments (RMG) sector [34].

The Chattogram Port's continued cargo volume growth mirrors the nation's broader economic expansion, as it is the main maritime gateway. Containerized traffic in the port registered an 11% growth rate while overall port throughput grew at a rate above 8% across the last decade. The port is forecast to see increased container handling, rising from 2.7 million TEUs in 2017-2018 to 10.7 million TEUs by 2043 under baseline economic growth forecasts. Hence, substantial capital investment is essential to increase capacity and optimize operational performance, given its pivotal role and systemic importance in the Bangladesh economy. The statistics of cargo, container and vessel handling by Chittagong Port during 2024 and 2025 have been shown in Table 1, and the growth of cargo, container and vessel handling by Chattogram Port for the last two years is shown in Figure 1 below:

Table 1: Cargo, container and vessel handling by Chattogram Port during 2024 and 2025

Calendar Year	Cargo (In M/Ton)	Difference	Container (In TUEs)	Difference	No. of Vessel	Difference
2024 (Jan-Sep)	91950584	10753675	2441825	121625	2864	297
2025 (Jan-Sep)	102704259		2563450		3161	
Growth (%)	11.70%	-	4.98%	-	10.37%	-

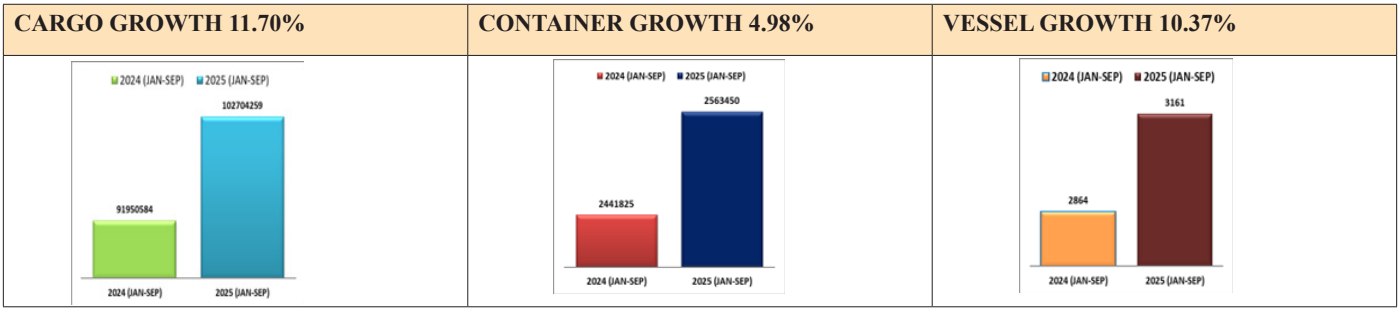

Figure 1: Growth of cargo, container and vessel handling by Chattogram Port over the last two years (2024 and 2025)

Mongla Port, situated at Mongla Upazila in Khulna, is historically recognized as a premier maritime hub of the Bengal Delta. It is the second-largest seaport of Bangladesh, with proximity to the Bay of Bengal. Dedicated to the southwestern region of East Bengal, it was founded in 1950 on the Pashur River in Khulna Division, originally named Chalna Port. With Chittagong port continuing to face congestion issues, several maritime enterprises now prefer Mongla as a strategic alternative, making it more economically lucrative. Coupled with domestic and regional demands, the establishment of the Padma Bridge has largely enhanced its commercial viability. Beyond its commercial duties, Mongla port serves as a hotspot for tourists, providing access to the Sunderbans, a UNESCO World Heritage mangrove forest. It hosts the Mongla Export Processing Zone (MEPZ) and is structured with 11 jetties, 8 warehouses and 12 deep-river swinging moorings. Operating 24 hours a day, it has an unconstrained large anchorage channel capable of accommodating up to 33 ships simultaneously. Moreover, it handles vessels up to 225 meters in length with a maximum draught of 6 meters. The Payra Port was established by an Act of Parliament in 2013 and formally inaugurated in 2016. Its location in Kalapara Upazila of Barisal Division gives it close access to the Bay of Bengal. For deep-sea access to the under-construction Payra Port, the Payra Port Authority (PPA) partnered with Belgium-based dredging company Jan De Nul (JDN) for overseeing the capital and maintenance dredging of its 75-kilometre-long main channel. JDN officially concluded its capital dredging operations in March 2023 and allowed the port access channel to be opened for commercial vessels with a draught of up to 10.5 meters. The project has commenced its maintenance phase, where JDN aims to ensure seamless accessibility by using three trailing suction hopper dredgers, deployed to the Rabnabad Channel to sustain the required navigational depths. This port is crucial for the nation's maritime trade, aiming to be a major economic hub by developing modern terminals, dredging channels for deep-draft vessels, and facilitating cargo handling. Despite challenges with navigability and operational efficiency, authorities are working to resolve these issues through ongoing infrastructure projects and dredging.

Bangladesh's economic prowess is a sight to behold, as it now stands as South Asia's second-largest economy. Characterized by a developing mixed economy, the country now ranks 34th globally in nominal GDP and 25th by purchasing power parity (PPP). It is also a member of the South Asian Free Trade Area and the World Trade Organization (WTO). Bangladesh experienced a macroeconomic deceleration in 2024-2025, registering its slowest GDP growth rate of 3.49%. The post-partition period saw Bangladesh's industrial foundation gain an impressive momentum through labor reforms and industrial diversification [35]. As of recently, by 16 March 2024, Bangladesh has the highest concentration of green garment factories, which came about due to a boom in the 1990s, when the RMG sector emerged as the chief economic driver [36]. Bangladesh is positioned as the only Least Developed Country (LDC) which almost meets its total pharmaceutical demands, as domestic manufacturers supply 98% of local demand. Overall, the pharmaceutical sector goes hand in hand with textiles as a key economic player, maintaining a 12% average annual growth rate [37]. The Bangladeshi diaspora is another source of augmenting foreign exchange reserves through remittances, and the heavily subsidized agriculture sector largely ensures domestic food security. Despite Bangladesh adopting an export-oriented strategy reinforced with digital integration and upgraded infrastructure after the COVID-19 pandemic, some vulnerabilities persist. A low tax-to-GDP ratio of 7.7% is a prime example, while non-performing loans create systemic risks within the banking sector [38]. The Ganges Delta's mild, near-tropical climate, fertile silt-laden soil, and ample water resources, along with ecological diversity, made eastern Bengal a highly prosperous land [39]. So, living standards for the elite largely outpaced those of the other parts of the subcontinent. Bangladesh has somewhat managed to carry forward that legacy by being one of the world's fastest-growing economies.

Prediction Port Service Demand in Bangladesh

The country is currently navigating significant macroeconomic headwinds and slowed growth. Remittance inflows from the diaspora reached approximately $24 billion in FY24, serving as a critical source of foreign exchange. They generate over 50% of GDP and remain a primary driver of employment. Fuel and gas shortages have led to electricity blackouts and disrupted industrial production, with persistently high inflation, declining foreign exchange reserves, and a weakening currency (Taka) pressuring the economy since 2022 [40]. A low tax-to-GDP ratio (around 7.5%–8.3%) limits the government's ability to fund social and infrastructure development. High levels of non-performing loans (over 30% in some estimates) and financial sector vulnerabilities remain a major concern for investors [41]. Nevertheless, RMG is the backbone of the economy, accounting for over 80% of total

exports. Seaports are the prime movers of Bangladesh with regard to the enrichment and transportation of imports and exports. However, none of the ports have achieved the ideal standard of a fully automated smart port in accordance with the international demand of the 21st century. As of early 2026, Bangladesh's sea ports have achieved record-breaking performances. For instance, Chattogram Port, posted its highest-ever cargo and container volumes in 2025, supported by significantly improved efficiency and reduced vessel waiting times besides having a number of limitations and challenges [34]. According to forecasts by the Chattogram Port Authority (CPA), the port needs to be able to handle 8.63 million TEUs annually by 2035 and scale up to 11.41 million TEUs by 2040. Additionally, future upgrades must feature deeper drafts and extended berths for accommodating larger Panamax and post-Panamax vessels. There is a dire need to improve transportation links, digitize systems and include smart technology for refining turnaround time and reducing delays. The upcoming projects and port facilities will be functional soon, with these projects contributing to and enhancing port operations in Bangladesh [42]. In table 2 and figure 2 has been shown below and it projected up to 2040. This is the predicted volumes of TEUs handling in the near future.

Table 2: Prediction of container handling volume (in million TEUs) in Bangladesh projection up to 2040

Year	Total Container Volume of Bangladesh (million TEUs)	Chattogram Port (GCB + CCT + NCT) (million TEUs)	PCT of Chattogram Port (million TEUs)	APM or Laldia Terminal of Chattogram Port (million TEUs)	Bay Terminal of Chattogram Port (million TEUs)	Matar-Bari Port (million TEUs)	Mongla Port (million TEUs)	Pyra Port (million TEUs)
2027	4.97	3.1	0.25	0	-	0.12	0.12	0.08
2030	6.20	3.45	0.40	0.55	1.80	0.29	0.19	0.12
2035	8.63	3.63	0.50	0.90	3.30	0.34	0.35	0.22
2040	11.41	3.85	0.50	1.00	3.60	0.63	0.63	0.39

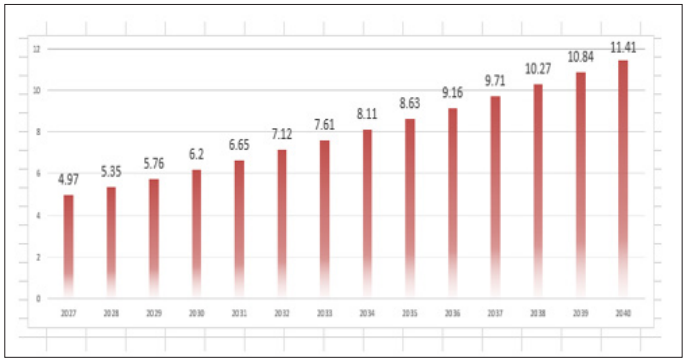

Figure 2: Prediction of container handling growth by volume (in million TEUs) in Bangladesh

As we know, adequate port facilities, export diversification, seamless global trade, developed land connectivity, etc. are prerequisites for the nation's holistic economic growth. Energy, infrastructure, and transportation are the bases and cornerstones to success in the economic field as well as the domains of human development, education, and social progress. In light of this, strategists, planners, policymakers, and bureaucrats need to work together to formulate and prepare a consolidated roadmap towards establishing a sustainable transport mechanism, secure energy supply infrastructure, and purposeful education and skill development programs [43,44]. As we know, Chattogram Port handles 92% of all transported goods. This results in congestion of containers and vessels in the port, which subsequently increases turnaround time. The 9.5-meter draft limitation of Chattogram Port forces Bangladesh to rely on feeder vessels passing through South-East Asian ports like Singapore, Malaysia (Port Klang) and even Sri Lanka (Colombo). Development of port facilities, including the Matar-Bari deep-sea port, is necessary, along with sufficient inclusion of smart port technology in the major sea ports in Bangladesh. This leads to increased transportation costs and escalated transit times. The Bangladesh Single Window aims to integrate the functions of 19 customs-affiliated agencies into a centralized framework in order to streamline and facilitate trade operations. This unified system will expedite and standardize the bureaucratic procedures necessary, including the issuance of permits, licensing, certifications, and customs declarations. By incorporating advanced technologies into import, export, and empty container handling, this system aims to reduce bureaucratic paperwork, alleviate vessel congestion, and noticeably reduce expenses. Adequate port facilities, export diversification, seamless global trade, and developed land connectivity are prerequisites for the nation's holistic economic growth. Energy, infrastructure, and transportation are the bases and cornerstones of success in the economic field, as well as in the domains of human development, education, and social progress. In light of this, strategists, planners, policymakers, and bureaucrats need to work together to formulate and prepare a consolidated roadmap for establishing a sustainable transport mechanism, secure energy supply infrastructure, and purposeful education and skill development programs.

Smart Port Concept and its Future Demand

Smart ports integrate cutting-edge digital technologies like AI, ML, big data, Digital Twin, Internet of Things (IoT), and 5G networks to optimize logistics, efficiency and operations. By connecting terminals, automation, shipping lines, authorities and stakeholders, it minimizes wait times, cuts carbon emissions, enhances efficiency, eases decision-making, and boosts global economic competitiveness. Smart ports are an integral node in the rapidly developing ecosystem of smart cities. Today, such high-end ports utilize technological breakthroughs (blockchain, AI, ML, DL, DS, IoT sensors, computerization, and real-time data analytics, etc.) to provide sustainable solutions to traditional problems and subsequently augment resource efficiency, minimize environmental impact and assist seamless operations—innovations like these support oversight, cargo handling, vessel locomotion in real time and accommodation. Predictive analytics, IoT-enabled sensors, robust communication networks, cybersecurity frameworks, and integrated supply chain platforms are other features smart ports may integrate for seamless connectivity [3,7, 45]. Besides, digital twin technology, augmented reality (AR), virtual reality (VR), and interoperable systems may be used to ensure collaboration among diverse stakeholders [46]. Installing adequate infrastructure for smart ports requires establishing mechanized berths furnished with advanced mooring systems,

along with prioritizing advanced security. Further transformation of smart ports incorporates rigorous assessment of capabilities within port management software, such as yard management, berth scheduling, and terminal operating systems (TOS). Modern maritime port operations greatly rely on energy-efficient technologies to address operational bottlenecks and substantially curb carbon footprints.

Today, effective port facility management emphasizes the smooth operation and maintenance of diverse infrastructure and services to ensure efficient cargo movement, safety, security, and environmental responsibility. The adoption of digital technologies in port operations is increasingly prominent, showcased through initiatives like stakeholder collaboration platforms, digitalization strategies, and port community systems (PCS). These innovations improve coordination and transparency among port users. To boost operational efficiency, smart ports employ automation, IoT sensors, data analytics, and real-time monitoring systems [4,45]. These tools help track cargo handling, infrastructure status, and vessel movements in real time, enhancing productivity and reducing delays. Technologies are also being developed to seamlessly integrate functions such as cargo handling, customs processes, and vessel scheduling to minimize delays. PCS supports better collaboration and data sharing among stakeholders like port authorities, shipping firms, terminal operators, customs, and logistics providers, facilitating smoother cargo flow, transparency, and coordination. Additionally, smart asset management systems use sensors, RFID, and GPS to monitor the location, condition, and performance of key assets, including cranes, containers, vehicles, and infrastructure. These systems enable proactive maintenance, prolong equipment lifespan, and improve asset utilization. Predictive maintenance, driven by advanced algorithms, analyzes sensor data, maintenance history, and equipment performance to detect potential failures early, allowing for timely repairs. This enhances safety and reliability, reduces downtime, and cuts maintenance costs. Moreover, combining data analytics with IoT sensors allows for real-time monitoring of port equipment and infrastructure, enabling immediate responses to emerging issues and further improving operational efficiency [3,7].

Energy-efficient technologies are vital for modern port operations by optimizing electricity use, managing peak demand, and integrating renewable sources like solar and wind. Implementing solutions such as high-efficiency HVAC systems, advanced lighting, and micro-grid technologies can greatly cut carbon emissions, reduce utility costs, and support environmental sustainability. To improve port security, advanced surveillance—including high-definition cameras, perimeter intrusion detection, and sophisticated access control—monitors restricted areas, detects unauthorized activity, and alerts security teams promptly. Video analytics further boost these systems by spotting suspicious behavior and potential threats. RFID tags, GPS trackers, and blockchain enhance cargo, vehicle, and goods tracking, promoting visibility, transparency, and control over inventory, theft prevention, and real-time shipment updates. Traffic management systems help streamline vehicle and cargo flow by managing truck queues, parking, and gate access, using live data on berth availability, traffic patterns, and vehicle movements for dynamic routing to avoid congestion and delays. A centralized port operations platform consolidates data from terminal operators, shipping lines, customs, and logistics providers, improving communication, collaboration, and decision-making for higher productivity and smoother operations.

Smart technologies are vital in emergency preparedness and crisis response. Mobile communication tools, GIS mapping, and automated alert systems allow rapid coordination, safeguard personnel, and support effective incident management during crises. The Bangladesh government should establish a National Smart Port Governance Authority under the Ministry of Shipping (MOS) to oversee inter-agency digital initiatives and policy enforcement for smart technology adoption. This should be integrated with national development frameworks and long-term climate strategies. Bangladesh also needs to develop modern regulations and enact digital and smart legislation to streamline rules, minimize institutional overlaps, and establish cross-agency accountability. PCS is an electronic platform connecting systems run by various port stakeholders, acting as an information provider for supply chains within the port, responsible for data supply, control, distribution, and conversion [47]. Meanwhile, the Terminal Operating System (TOS) provides a comprehensive digital solution for automating (using AI, ML, DL, digital twin, Big Data, and other smart tech) and optimizing terminal operations. TOS efficiently, safely, and securely manages planning, control, and monitoring across all terminal processes, covering not just a single terminal but a network of multimodal terminals supporting storage and transshipment via road, rail, or water. It ensures operators follow all handling and checking steps and accurately place containers based on safety, dwell time, driving distance, and other efficiency parameters [48]. Bangladesh's major ports should standardize PCS and TOS with an interoperable, scalable architecture across all three seaports and selected inland ports. Authorities must ensure seamless cross-platform data exchange, transparency, and interoperability.

Benefits and Challenges of Smart Port Transformation

AI, ML, IoTs, and Big Data hold significant potential to transform operational and administrative functions in seaports and terminals. These technologies can automate decision-making, enhance operational efficiency and security, and provide predictive insights. AI plays a crucial role in modern maritime logistics, especially through robotics, optimizing port and terminal operations. Its success in sectors like healthcare, finance, and pharmaceuticals underscores its transformative power [49]. The push for AI in smart ports is driven by the need to decarbonize supply chains and pursue sustainability [6,50]. AI influences maritime activities such as towage, pilotage, and cargo handling, streamlining these processes. ML predictive models analyze historical data to forecast task durations for specific vessels and services. They refine variables like pilot licensing, tugboat configurations, and pilot deployment, addressing complex scheduling challenges. These measures ensure optimal resource allocation [16-18]. While pilot projects demonstrate AI's value in smart ports, further empirical research is necessary to evaluate practices and guide future directions [51]. AI's potential in maritime management spans multiple areas: optimizing container stacking, crane scheduling, and berth allocation. AI can reduce unnecessary moves, lower fuel use and emissions, and foster sustainability. It also enables real-time operational adjustments through integration with IoT sensors and 5G, providing immediate feedback on equipment, weather, and cargo. This connectivity supports dynamic, data-driven decision-making to boost productivity.

AI models can forecast when equipment is likely to fail, enabling proactive maintenance schedules. This reduces the risk of unplanned downtime and extends the life of critical assets such as cranes, trucks, vessels, and other cargo and container-handling machinery. These AI-driven predictive maintenance solutions are particularly valuable in ports with high equipment utilisation and operational activity. By analysing historical data and usage patterns, together with external factors such as weather conditions, ML models and

big-data analysis can optimise maintenance intervals, reduce costs, and resolve operational issues. AI systems provide a significant edge in decision-making and operational ease, enabling data-driven decisions for route planning, cargo sequencing, safety, and workforce management. These decisions, usually based on real-time data analysis, lead to better-informed strategies. Finally, it streamlines workflows and minimises operational bottlenecks. Furthermore, AI-enabled decision-making supports disaster management by simulating scenarios and identifying the most efficient strategies to recover from disturbances, such as extreme weather events or unexpected supply chain delays. AI plays an important role in enhancing workplace safety and security by identifying potential hazards and automating safety checks. Additionally, it helps ports maintain compliance with increasingly stringent environmental and operational regulations. AI can also support real-time environmental monitoring, helping ports meet sustainability goals. AI contributes to global environmental objectives by tracking emissions, energy consumption, and waste management practices, ensuring that ports operate within regulatory frameworks and promoting sustainability. AI's potential is not limited to operational efficiency; it also extends to administrative processes [52]. Tasks such as invoice processing, claims handling, and customer inquiries can be automated using AI-powered bots, allowing human resources to focus on more complex and strategic tasks.

AI holds great potential for seaports, but several hurdles need to be addressed. These include technological, organizational, environmental, and cultural challenges. Many ports still use outdated systems that are not compatible with AI, and upgrading them can be costly and complicated. Data silos among stakeholders such as port operators, customs, and shipping lines, along with poor and inconsistent data quality, limit AI's effectiveness. Ports must also navigate complex regulations around data privacy and ownership, especially with laws like the EU's AI Act increasing uncertainty. As digitization expands, cybersecurity and safety become major concerns, demanding strong protections. Worker resistance due to fears of job loss can slow progress, and a shortage of skilled professionals in AI, data science, and IT hampers full utilization. Despite these hurdles, the maritime sector can learn from early adopters in aviation, manufacturing, logistics, transportation, and healthcare.

The adoption of AI, ML, IoTs, and Big Data in the port sector is increasingly vital for ports aiming to stay competitive, efficient, and sustainable. AI drives fully autonomous, smart port operations, with many systems centered on AI-driven applications. As international logistics companies focus more on AI, the shipping and maritime industries are also influenced [45,53]. AI and ML algorithms analyze various operational parameters to optimize ship arrival schedules, helping to reduce harbor congestion and cut the carbon footprint of ships idling at port [54]. ML is crucial for berth allocation, considering constraints like vessel size, hull classification, crane availability, and shore power capacity [55]. As the industry turns to renewable energy sources, ships will have diverse service requirements, making efficient berth allocation vital for maintaining port throughput. AI tools enable real-time diagnostics, arrival time predictions, and digital twins—virtual models that enhance oversight of port operations. AI may also be used to analyze aerial imagery to manage traffic and promote environmental sustainability at terminals [56]. Supporting sustainable initiatives like just-in-time arrivals, AI and ML can integrate with congestion prediction models to advise vessels on optimal speeds, reducing fuel costs and environmental impact. These AI systems depend heavily on extensive, high-quality data collected through IoT sensors across ports and shipping networks [57]. To reap full benefits, the industry requires reliable, uncorrupted data from the global supply chain. Automated systems leverage AI to manage freight and oversee terminal activities efficiently [7,11].

Automated guided vehicles (AGVs) facilitate cargo transfer at ports using AI within a centralized management system [58]. While AI enhances the automation of port operations, manual oversight by human operators remains essential. AI has evolved from experimental to a vital component of smart port infrastructure. For example, the AI model Pronto at the Port of Rotterdam improves container throughput by analyzing data streams such as vessel telemetry via Automatic Identification Systems (AIS) and databases, creating self-learning, adaptive models. This has resulted in a 20% reduction in vessel detention times, according to the Rotterdam Port Authority [58]. These models enable better forecasting of vessel arrivals and container processing, boosting port efficiency [59]. Similarly, North American ports like Los Angeles use Port Optimizer. This AI platform employs sensors and predictive analytics to optimize container scheduling and port operations and proactively anticipate demand [60]. In Southeast Asia, Singapore's Maritime Single Window expedites customs and maritime immigration by using natural language processing (NLP) and predictive analytics instead of sensor networks, enhancing transparency and throughput. Additionally, machine learning routines analyze unstructured data from customs documents and shipping records to support macroeconomic port governance [61].

The systematic expansion and integration of AI aim to establish fundamental advancements in maritime operations, bringing numerous benefits to modern ports. Since AI platforms depend heavily on data, port authorities must ensure data availability through data-harvesting pipelines to eliminate errors and gather data streams throughout the supply chain. AI models can identify systemic delays and pinpoint causes to boost terminal productivity. Future AI developments are expected to improve shipping routes, optimize automated cargo handling, and detect illicit activities [62]. Implementing advanced algorithms requires evaluating existing infrastructure, which AI can assist with. Adequate computational resources, storage, and network bandwidth are essential for integrating AI into smart ports. Human-machine co-management is crucial for transitioning from manual to automated systems. Dedicated cross-functional teams are formed to oversee these systems as AI is integrated [61]. Large-scale digital deployment carries financial risks, which AI predictive models can help identify, enabling shareholders to analyze and make informed investments. Collaborative alliances between AI experts enable ports to manage technical complexities while developing on-site expertise [63]. However, smart technology could replace many unskilled and semi-skilled jobs, especially in industry and service sectors. In countries like Bangladesh, this issue is severe, as reported in a national newspaper. Over 7 crore people are employed there, with 85% (around 6 crore) working in the informal sector lacking basic social protections and employment benefits. Bangladesh, despite nearing 2025, shows only slight signs of economic recovery amid factory closures, mass layoffs, weak private investment, and slow growth, which have extended employment challenges across both formal and informal sectors [41,64].

Figure 3: AI will transform the port, and it will make the port a more intelligent and efficient entity [52,65].

Unlike conversational AI, where there is some room for experimentation, the margin for error is virtually zero in maritime safety and operational reliability. To achieve this high level of dependability, AI and ML models must be carefully trained on customized datasets and held to strict performance standards. This process should include a validation or feedback loop that compares projected timelines with each port's actual operational durations [66]. Such a process allows the algorithms to adapt and meet each port's specific needs. This technological precision has become essential due to the dramatic increase in container volumes, which significantly impacts maritime dominance. Historically, European and North American ports held the top global rankings, as seen in data from 2005. However, by 2021, only the Port of Rotterdam remained in the top ten worldwide [67]. The assertion that China is the successor to the West in maritime sectors is supported by data from the Hong Kong Marine Department, highlighting China's success in integrating advanced AI and digital systems into port management [68,69]. Yangshan Port in Shanghai, known as the 'Smart Giant' and 'magic container terminal,' owes much of its technological prowess to an industrial wireless network based on Huawei's pioneering 5.8 GHz LTE technology. Meanwhile, 4.5G LTE, based on 3GPP standards, is increasingly vital for industries aiming to accelerate digital and automation efforts. Authorities expect Yangshan Port to have 130 Automated Guided Vehicles (AGVs), 26 bridge cranes, and 120 rail-mounted gantry cranes for automation. A port worker stated, "You will not find people working in the container terminal area. Everything is automated. For example, quay cranes are operated remotely rather than manually, and container trucks are replaced by AGVs that load, unload, and transport cargo automatically" [70].

In the 21st century, as globalization advances, many countries are investing in the development of smart ports equipped with digital and adaptive systems that drive the Fourth Industrial Revolution (4IR) technologies. Smart technology, such as digital twins, balances efficient logistics with environmental goals by tracking the movement of thousands of ships and millions of tons of cargo annually. Several ports around the world serve as success stories for adopting smart technologies. For instance, Singapore's Port Authority (PSA) has implemented blockchain-based customs, AI-berthing, and real-time dashboards, resulting in a 30–40% reduction in processing times and significant cost savings [71]. Ports in the Netherlands, Australia, and China are adopting fully automated terminals utilizing AGVs, AI-driven cranes, digital twins, IoT, and autonomous drones for monitoring, surveillance, and decision-making. These innovations decrease labor costs, enhance performance, and improve safety and security [72]. China's Yangshan Port, Shanghai, and Australia's Victoria International Container Terminal (VICT) are leading the shift toward Port 4.0. 0, establishing a new roadmap for autonomous port development. VICT has developed a system ensuring that no truck exceeds a 40-minute gate-to-gate turnaround, often achieving an average of 33 minutes, contrasting sharply with other terminals, including nearby Melbourne, primarily due to technological advances [73]. As a result, these ports significantly cut operating costs [74]. Meanwhile, Rotterdam has built a comprehensive digital twin ecosystem- a virtual 4D replica of its port operations- that continuously mirrors current activities and simulates future scenarios using real- time IoT sensors, weather data, and shipping information. These models support predictive cargo flow management, port activity monitoring, and emissions tracking, leading to improved customer service and ecological sustainability [75]. Similarly, Busan Port is undertaking a multi-million-dollar AI-driven transformation to establish itself as a leading smart logistics hub in Asia. By integrating real- time data, IoT, and machine learning across terminal operations and leveraging big data to forecast congestion and optimize routing, the port is moving toward predictive management [76]. Ports like Hamburg and Long Beach also deploy IoT sensors to monitor emissions in real time and utilize AI to reduce them, catering to environmentally sensitive trade routes [77].

Implementation Challenges of Smart Technology in Bangladesh Ports

Chattogram port, located on the Karnaphuli riverbank, has served as Bangladesh's major seaport for over a century. The country's ports, especially those managed by CPA, face increasing pressure to handle rising cargo volumes, satisfy customer demands for quicker turnaround times, and comply with stricter global environmental standards [78]. Reliance on both mechanical and manual systems for berth allocation, customs clearance, cargo documentation, and limited automation has resulted in inefficiencies in Bangladesh's maritime logistics chain [79]. Challenges such as container congestion in port yards and poor multimodal hinterland connectivity hinder operational efficiency. Furthermore, the ports lack systems for monitoring carbon emissions, digital safety compliance, maritime cybersecurity, and sound environmental observation, putting them at a disadvantage in the ESG-focused global market [25,80]. While leading global ports utilize digital dashboards, digital twins, IoT, and AI for cargo tracking, monitoring, and automated customs processing, Chittagong and Mongla ports still rely on paper-based workflows that cause delays, hinder efficiency, and reduce supply chain visibility. Studies indicate that the absence of digital technology limits port capacity and increases operational costs by 10-20% due to duplication, inaccuracies, delays, and repetitive tasks [81]. The COVID-19 pandemic underscored the vital role of digital readiness in ensuring supply chain resilience, emphasizing the need for digitization and smart technologies in port operations and maritime trade management [82]. Additionally, the lack of emissions dashboards and energy efficiency programs raises concerns about vulnerability to carbon-border regulations and ESG-based trade sanctions in Bangladesh's seaports [80].

Bangladesh ports, especially CPA, need to invest in or develop alternative strategies like automation, digital twins, AI or ML-driven analytics, and IoT solutions to boost operational flexibility, ease decision-making, enhance service quality, and increase transparency and accountability. Although CPA has improved its operational capacity and performance, most Bangladesh ports still rely heavily on human-operated cranes with only recent moves toward semi-automation, mostly manual yard planning, and limited digital technology adoption. This reliance hampers their ability to meet international shipping standards. The ports' IT infrastructure is poorly connected, with low interoperability across terminals, customs, stakeholders, and transportation modes, creating data silos and cybersecurity vulnerabilities. As a developing nation, Bangladesh faces constraints such as limited funding, skills gaps, weak institutional mandates, and stakeholder coordination issues. While PPPs, multilateral funding, and donor-led digital programs like those from ADB and the World Bank offer some solutions, overcoming these barriers remains complex. Incremental, culturally tailored technology adoption is more sustainable than extensive imports. Currently, the digital maturity of Bangladesh ports, including CPA and MPA, is in the early stages, limited to basic container tracking, automated berth-scheduling emails, and some pilotage and navigation systems. There is an urgent need for integrated operational dashboards, port control systems (PCS), and port-wide ERP systems. Additionally, policy and operational alignment is essential to support climate adaptation, trade competitiveness, and ecosystem sustainability, helping these ports achieve SDG goals. Major ports must prioritize integrating smart technologies to reduce logistics costs and strengthen supply chain reliability.

The environment surrounding Bangladeshi ports is characterized by fragmented authority, unclear digital mandates, and inadequate investment in digital and smart capacity development, which need careful resolution [81]. Recently, Bangladesh has piloted IoT for tracking and tested blockchain for customs declarations; however, these initiatives often face barriers like limited access, lack of continuity, and insufficient legal, political, and financial support, though they represent positive efforts [72]. Today, integrating smart technologies is central to modern port operations. Bangladesh ports, especially CPA, can leverage digital twins to simulate port activities for scenario planning, energy efficiency, and easier monitoring for quicker decision-making. Advanced technologies like super or quantum computing and 5G-enabled communication for automated guided vehicles (AGVs) and port cranes can offer significant benefits [25,50,81]. CPA and MPA can deploy IoT devices to enable real-time tracking of cargo, equipment status, and environmental factors such as noise and emissions, aligning with global environmental standards [8,69,83]. Additionally, AI can optimize berth scheduling, container yard management, and predictive maintenance using machine learning or deep learning algorithms [6,64]. Blockchain technology can provide secure, tamper-proof documentation for customs, bills of lading, and trade finance, ensuring transparency and accountability [82]. Ports Communication Systems (PCS) and Terminal Operating Systems (TOS) are crucial for real-time coordination among stakeholders like customs, port authorities, freight forwarders, shipping agents, off-dock owners, and shipping lines. The lack of a national PCS in Bangladesh has caused duplicated documentation, conflicting cargo schedules, reduced customer satisfaction, and inefficient customs clearance [84]. Globally, implementing PCS can reduce dwell times by 25–40%, while improving revenue transparency, security, accountability, and customer service [85]. Early integration of effective PCS and TOS by CPA and MPA is essential.

Recommendations and Looking Forward

The Port Authority of all major seaports in Bangladesh should develop and enforce a maritime cybersecurity framework aligned with IMO standards to ensure secure data management, resilience, and auditability. The Ministry of Shipping (MOS) should establish a Port Cyber Resilience Taskforce responsible for threat monitoring, incident response, digital vendor certification, and cybersecurity audits [80]. Bangladesh's ports need to upgrade their digital infrastructure and create an interoperability directive that promotes the use of open APIs and middleware protocols, facilitating smooth cross-platform data exchange, transparency, and accountability. Additionally, all major sea ports are required to develop and implement digital literacy and training programs for port workers, operators, planners, professionals, customs officials, government staff, and freight operators through national maritime academies and relevant institutions. The government should also offer tax incentives and targeted grants to SMEs, related organizations, and logistics operators to adopt digital and smart technologies such as AI, ML, Big Data, Digital Twin, IoT, etc. in port operations [85]. Bangladesh's ports should also introduce AI- or IoT-based emission tracking systems and environmental dashboards to monitor and report on carbon emissions, noise, and energy consumption, supporting ecological balance. Furthermore, ports need to ensure ESG compliance is linked to port concession licenses, eligibility for public-private investments, and SDG performance metrics [86]. Both the Ministry of Shipping and local ports should invest in applied research and pilot projects, collaborating with local institutions (BMU, Bori, BUET, DU, etc.) and international partners (MIT CTL, UNCTAD, ESCAP). Leveraging South-South and Southeast cooperation can help Bangladesh adapt successful smart port models from China, Singapore, UAE, India, Vietnam, and Indonesia, tailored to its socio-economic and governance context [80].

The Chattogram Port is strategically significant and is actively used by India, Nepal, and Bhutan because of its proximity to the ocean. According to World Bank data, Bangladesh's maritime trade faces logistical inefficiencies, with domestic logistics costs ranging from 4.5% to 48%, much higher than neighboring South Asian countries. Implementing short- to medium-term structural reforms could increase national export earnings by 19%. Notably, a 1% reduction in these costs could boost global demand for Bangladeshi exports by up to 7.4% [42]. Bangladesh experiences operational challenges due to rising cargo volumes; in 2023, Chattogram Port handled about 3.05 million TEUs, which increased by 6.8% to 3.26 million TEUs in 2024 [42]. Its poor international operational ranking, at 337th out of 405 in the World Bank's Container Port Performance Index 2023, reflects these issues. The average lead time for RMG supply in Bangladesh is an inefficient 95 days, compared to 60 days in Vietnam and 32.5 days in China. Despite these constraints, Chattogram Port achieved record highs in container, cargo, and vessel handling in 2025, even amidst operational disruptions. The port managed 13.82 crore tons of cargo, up from 12.40 crore in the previous year, with vessel calls increasing to 4,273 from 3,867 in 2024. Container handling grew by 4.07%, cargo by 11.43%, and vessel calls by 10.5% compared to the previous year [87-114]. With the integration of smart port technologies and the completion of port expansion plans, major Bangladeshi ports are expected to realize significant success and impressive results in the near future.

Conclusion

Sea ports significantly shape international trade, handling about 80% by volume and 70% by value, while also safeguarding national security and forming the backbone of the blue economy.

Today, smart ports utilize AI, ML, digital twins, and blockchain to improve reliability, efficiency, and stakeholder trust, thereby enhancing nearly every aspect of port operations. From automating heavy machinery and optimizing berth scheduling to equipment maintenance and workforce training, modern technology offers extensive improvements. Beyond financial and administrative concerns, these ports promote sustainability through renewable energy sources and eco-friendly practices, protecting marine ecosystems and reducing carbon footprints. Their eagerness to adopt innovative, streamlined technologies reflects a strong drive for progress. However, cybersecurity remains a major concern, as cyberattacks on critical systems like power grids could disrupt global economies. To maintain a competitive edge and ensure national stability, Bangladesh must address these security challenges by investing in automation, AI monitoring, and resilient infrastructure. Ports with a clear data strategy, in-house AI, ML, IoT, and Big Data expertise, and a skilled workforce will be better positioned to benefit from AI advancements. The maritime sector is on the brink of transformation; those taking decisive action now will shape the future of global trade. Currently, many smart ports generate renewable energy through rooftop solar panels, wind turbines, geothermal systems, and hydroelectric power, utilizing wind and water flow as well as organic waste like biomass. Despite these advancements, Bangladeshi ports are still underprepared for the transition to smart ports. This study highlights the urgent need for their digital transformation and emphasizes the importance of developing and implementing comprehensive strategies and policies to meet these challenges.

The move towards smart ports in Bangladesh faces challenges such as the digital divide, a shortage of skilled personnel, limited investment, and the need for a thorough understanding of relevant technologies and the current port status. Ensuring maritime security and resource utilization is vital to unlock the full potential of Bangladesh's seas. Strategic ports like Bay Terminal and Matar-Bari will support these efforts. In today's globalized world, naval strength is essential to protect these economic hubs, prompting the Bangladesh Navy to expand its presence around existing and upcoming maritime projects. Deep-sea ports, paired with infrastructure like roads and modern communication systems, will enhance regional trade with neighbors and the Middle East. Launching Matar-Bari and Bay Terminal will address bottlenecks by accommodating large vessels, significantly lowering import/export costs. This progress will boost living standards through economic growth, employment, and better connectivity. Ports must adopt smart systems quickly—not just for improvement but as a necessity. They should assess AI, ML, IoT, Big Data, and PCS/TOS technologies for efficiency, safety, and security, and consider blockchain for customs transparency and digital trade financing. Simulation models can optimize operations such as berth scheduling, yard management, and routing, improving safety and reducing costs. Transitioning to smart ports involves overcoming the digital gap, skill shortages, and investment limits, requiring a clear understanding of available technologies and precise assessment of current conditions. It is crucial to act now, as even small disruptions in major ports can have widespread impacts. Additionally, advancements in maritime navigation and environmental monitoring should be prioritized, with efforts to promote digitalization and smart technologies across Bangladesh's ports to facilitate this transition effectively.

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