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Evaluation of Bangladesh Sea Port Outlook and Suggestions for Development as a Smart Port in the Context of the Global Present

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ABSTRACT

In the present global context, seaports are recognized as essential capital infrastructure, closely linked to a wide range of economic activities. Today, the continuously growing volume of seaborne trade is a global phenomenon, placing pressure on most seaports to continually enhance their operations, performance, productivity, and service quality. As a result, most seaports are increasingly transitioning to smart ports that rely on digitalization and advanced technologies. Smart ports are gradually transitioning into automated facilities, leveraging advanced digital technologies to optimize operational efficiency, transparency, sustainability, and overall competitiveness. Now, smart and automated seaports integrate tools like sensors, big data analytics, artificial intelligence (AI), machine learning (ML), Internet of Things (IoTs), deep learning (DL), augmented reality (AR), digital twins, and various reliable and sophisticated systems to restructure cargo movement and minimize environmental impact. Besides, these ports offer upgraded services to stakeholders including shipping companies, customs agencies, local communities, and other relevant parties. Furthermore, smart ports often incorporate eco-friendly features like renewable energy sources, electric vehicle charging stations, onshore power supply, and smart logistics infrastructure. The objective of this research study is to examine the evolution of the effectiveness of smart seaports, analyzed in the context of how cutting-edge technologies are being used to enhance efficiency, optimize operations, and maximize profitability. This research study will also evaluate the present status and future development of Bangladeshi seaports, along with smart port solutions, from a global perspective. This study will depict the distinct research gaps that remain in Bangladeshi seaports. The findings/suggestions will contribute to and guide the development of a foundational roadmap and the future development of the maritime trade and transport sector.

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Introduction

Today, seaports serve as vital hubs for global trade, facilitating the import and export of a wide spectrum of commodities. As the primary interface between nations, ports are indispensable to the global economy, with over 75% of global trade passing through them. Ports act as a bridge between nations and regions, ensuring the seamless movement of goods across international borders. Ports manage a variety of commodities, from raw materials to finished goods, supporting global trade networks and a wide range of industries. Additionally, ports play a significant role in generating employment across sectors such as cargo handling, logistics, transportation, and various support services. A seaport is a maritime facility featuring docks, cranes, and storage for international trade, where ships load or unload cargo, containers, and passengers. Key functions of seaports include customs, warehousing, and ship services, with major ports like Shanghai, PSA, DP World or Rotterdam handling massive volumes of goods around the globe. On the other hand, sea ports in Bangladesh (Chittagong, Mongla, Payra) are vital for regional commerce. Nowadays, ports ensure loading and unloading of containers

and bulk goods like coal, grain, ore, oil tankers by using cranes and automated systems. Contemporary ports are also equipped with cutting-edge technologies and specialized cargo-handling machinery, such as gantry cranes, mobile heavy-lift cranes, straddle carriers, reach stackers, and forklift trucks [1,2]. Sea ports also assure logistics like warehousing, customs clearance, and connection to road or railway networks. Moreover, ports provide ship services like fueling, fresh water, provision, maintenance, and passenger services.

Ports often specialize in particular functions: some are dedicated to passenger services and cruise operations, others focus on containerized cargo, bulk shipments, or general freight. For example, unlike river ports which serve inland waterway traffic such as barges, coasters, and other shallow-draft ships, deep-water or deep-sea ports usually handle larger, ocean-going vessels with deeper drafts (Shanghai, Matar-Bari) [3]. In addition, container ports specialize in containerized cargo (DP World, Chittagong Port) whereas bulk cargo ports deal with raw materials (Rotterdam, Mongla Port). Inland ports are accessible via rivers and canals (Hamburg, Pangaon). Modern ports function as integrated transport hubs, connecting multiple modes of transportation, including rail, road, sea, air and inland waterways [4]. This

multimodal amalgamation enhances supply chain connectivity and logistical efficiency. In current global geo-economic and political arena, certain ports possess strategic importance in both regional and global trade landscapes like PSA, DP World, CPA, etc. For instance, Chittagong Port is a key maritime gateway for Bangladesh, influencing economic development and geopolitical relations [1].

Historically, ports were simple harbors with restrained functions while modern ports have evolved into complex, multimodal logistics centers, with extensive transport links via sea, river, rail, road, and even air [5,6]. Effective ports are usually located to ensure optimal access to an active hinterland, and are designed to offer safe navigation and shelter from natural hazards like cyclones, tsunamis, or rough seas [7]. Usually, many ports are naturally situated on estuaries, where shallow waters require regular dredging to maintain navigability. Additionally, certain ports serve military or naval purposes [8,9]. Just as ports differ in types and functions, ownership models for ports vary globally, too. Public ownership is prevalent in many developed countries although it is not uncommon to find ports jointly owned by national governments and municipal authorities [10-12].

Effectiveness is the capability of producing or achieving a coveted result or the ability to produce desired output. Port effectiveness embodies the degree to which ports achieve the goals or objectives they have decided upon. Presently, smart ports are very effective as they can identify the assessments that offer the greatest benefits in relation to their cost. A defining characteristic of smart ports is their high level of computerization and intelligent systems, which enable round-the-clock operations with minimal or no human intervention [1,2]. This not only enhances operational efficiency but also significantly reduces labor and operation costs [13]. The effective use of data is core to optimizing resource allocation and streamlining port operations [14]. These ports are increasingly integrated with surrounding logistics and industrial systems, utilizing advanced technologies to ensure a seamless flow of goods and information between ships, cargo terminals, and the broader supply chain [15]. It is high time to actualize the concept of smart ports as even minor disruptions in cargo movement at major maritime ports can lead to widespread consequences. For instance, due to the reliance on zero-inventory and just-in-time delivery models that underpin global trade, supermarket shelves and fuel stations could experience shortages within days of a supply chain disruption [16]. Technological advancements are also extending to maritime navigation and environmental monitoring. Smart ships now patrol the oceans, and technologies such as AI-powered satellite data analysis, passive acoustic systems, and remote sensing are being successfully employed for environmental surveillance [17]. These applications leverage IoT, AI, ML, DL, DS, etc. to enhance accuracy and decision-making [18,19]. Another notable trend is the increase in vessel size, a major technological shift that began in the 1990s with the introduction of post Panamax containerships [20]. The continued growth in ship dimensions across various types including container ships, bulk carriers, car carriers, and cruise vessels necessitates the development of specialized port terminals capable of accommodating them. The concept of sixth-generation ports envisions infrastructure that can support ultra-large vessels with capacities of up to 50,000 TEU. This study will focus on the efficiency of smart ports and the significant benefits they offer in terms of efficiency, sustainability, and global trade facilitation along with capabilities. This analytical investigation will also discuss about the future development of sea port of Bangladesh particular to Chattogram Port.

Literature Review, Research Methodology and Questions

A recent and significant trend in modern port development is the integration of automation and advanced technologies. This shift is placing increasing pressure on ports to upgrade their infrastructure and services to remain competitive and efficient [21]. Automated ports represent a new generation of digital and smart port systems, designed to be more efficient, sustainable, and technologically advanced compared to traditional ports [22]. These smart and modern ports leverage cutting-edge 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 enhance operational performance and minimize environmental impacts [18, 23-27]. Similar to how steam engines, electricity, or computers once revolutionized the world, AI is a standout general-purpose technology with broad applications across industries [28]. AI enables machines, particularly computer systems, to simulate human intelligence [9]. It is widely used in areas such as automation, robotics, language translation, image recognition, decision-making, online banking, healthcare, autonomous vehicles, e-commerce, agriculture, and, of course, automated port operations [24]. AI systems are designed to perceive, understand, learn from, and respond to their environment, making them a critical component in the digital transformation of ports [1]. ML, gaining prominence in 1959 through the work of Arthur Samuel, is a subfield of AI which involves algorithms that enable systems to learn from data and improve their performance over time without being explicitly programmed. These algorithms are instrumental in detecting spam, scams, and phishing attempts by analyzing and identifying malicious content [29]. DL, 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, is a specialized subset of ML [23, 30]. DL involves the use of multi-layered neural networks computational systems inspired by the structure of the human brain [31]. These networks are computational systems, known as Artificial Neural Networks (ANNs) and are powerful tools for recognizing patterns and making predictions by modeling relationships between variables [32]. DS is another key discipline in this ecosystem [24]. It is an interdisciplinary field that combines techniques from statistics, computer science, and domain-specific knowledge to extract meaningful insights and knowledge from large volumes of data [33]. In the context of port operations, Big-data and DS plays a vital role in optimizing logistics, forecasting demand, and improving decision-making processes [26]. Overall, the convergence of AI, ML, DL, IoT, and DS is reshaping smart ports, turning them into intelligent and adaptive systems capable of responding efficiently to the demands of global trade and sustainability [34].

This research takes an interdisciplinary and multi-scalar approach to investigate the present status of Bangladesh sea ports along with smart port transformation, focusing on both technological and institutional perspectives. While Chittagong and Mongla Port has considered the primary case, the findings have broader applicability to other ports in South Asia particularly and the Global South as a whole. An effort has been taken to depict the picture of contemporary and future development plan of the sea ports of Bangladesh. Technologically, the study explores the deployment potential of digital enablers, AI users, policy makers and those who implement the technology to get its benefits. As example AI, ML or IoT for real-time asset tracking, environmental monitoring and decision making. AI, ML, DL or Big-data can be used for vessel scheduling and predictive maintenance. Digital twins can be used for simulating operational

scenarios and optimizing resource flows. However, this study assesses governance models, stakeholder dynamics, digital policy frameworks, collaboration mechanisms among private-public-industry collaboration, which underpin or hinder transformation. It emphasizes the role of inter-agency coordination, regulatory clarity, and enhanced or guide stakeholders' capacity in building a resilient digital and smart infrastructure in maritime trade and port sector. The research is beached in Bangladesh's socio-political, technological and economic realisms. However, it designed to depict and inform broader aspect of local ports status, capability, growth of maritime trade and highlight future development plan. Effort has been made to educate the relevant community about smart port modernization and economics development plan along with similar institutional and infrastructural constraints. Here Focused Group Discussion (FGD), formal and informal interviews, conversation, idea shearing in the conferences and practical work experience of the author has help enormously to collection and analyses the state of Bangladesh Ports. Additionally, secondary information from electronic, print and social media along with available literatures have contributed a lot. But there is many constrain to collect data and information during the research. However, there are few distinct research questions as summarized as mention below will be explore.

- What is the present status of sea ports of Bangladesh?
- What is the growth analysis of sea ports of Bangladesh?
- What is the scope of future development of sea ports of Bangladesh?
- What is smart port and key factors of smart port development?
- What are the advantages of smart ports?
- What are the challenges and solutions of smart ports?
- How to adopt and implement of smart technologies in modern sea ports?
- What is the performance assessment of Chattogram port?
- What are the challenges and suggestions of Bangladesh sea port to implement smart technology?

Focus Group Discussions (FGDs)

In this research work FGDs aim to capture community-level insights and local and global maritime ports practice, port operation, safety and security, performance, monitoring, custom formalities, hinterland connectivity, digital and smart technology integration; which are often underrepresented even macro level policy analysis. However, for gathering information, an online Focus Group Discussion (FGD), involving personnel experienced in the respective field, was held. Interesting to know that, through the FGD, important information and ground reality have been discovered from both local and from global sea ports. The discussion with FGD and resource personnel from home and abroad was 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 100 both structured and informal stakeholders and related interviews (business owners, maritime traders, port service providers, workers, engineers, regulators, NGOs, system architect, managers, foreign experts, economist, local and international shipping lines, off-dock owners, freight forwarders, off-dock owners, academician, university professor, consultant, thinkers, different professionals, and many more). Each FGD has involved 6–10 participants and has been guided by a semi-structured questionnaire. Themes include perceptions of port operation optimization; digital and smart technology inclusions; optimization of service provide; ESG compliance to port concession licenses; public-private investment eligibility and SDG-related performance metrics; job satisfaction of port workers, logistics

operators, adopting smart technologies like AI, ML, Digital-twin, Big-data, or IoT in port operations; develop and implement digital literacy and training programs for port professionals; freight operators standard; port governance standard; customs officials; labour and workplace safety; port security including cyber security policy; quality assurance, creativity, process and standardization; barriers to compliance; social livelihood implications; views on modernization; inclusion of modern framework and cutting-edge technology; manufacturing process needs; Implement AI and IoT-based emission tracking systems and environmental dashboards to baseline; monitoring and report on carbon, noise, and energy footprints; coordination of inter-agency digital initiatives and policy implementation; integration of port digitalization with predominant national development frameworks; develop, organize and implement digital legislation to streamline regulatory mandates; develop and introduce standardized Port Community Systems (PCS) and Terminal Operating Systems (TOS) in local sea ports. To incorporate all stakeholder perspectives, a series of focus group discussions (FGDs) were planned and has conducted with:

- Related service providers of ports
- Service and support takers of ports
- Global and Local Shipping lines, ship owners, etc.
- Shipping agencies, warehouse owners, etc.
- Business people, maritime traders, Insurance workers, bankers, fund providers
- Port workers, technician, equipment operators (both skilled and unskilled)
- Relevant managers, architects, engineers, finance and administrative personnel
- Government officials working in major sea ports in Bangladesh
- Digital and smart technological and professionals
- Members and experts of the classification society, quality assurance professionals, economists, financial experts, and NGO representatives
- Local and international expertise in this sector
- Ports executives, operators and other service providers
- Environmental and labour rights activists
- Freight forwarders, dock owners, off-dock people, etc.

The FGD and informal discussion was held many times (more than 20 times) from Mar 2024 to May 2026 and 369 participants in different level from home and abroad. From home like major sea port 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. Ministries and Officials (MOS, MOE, MOD, MOI, MOE, MOF, MOFA, MOP, DoE, DoL, DoS, etc.), government organization and bodies (EPZ, Army, Navy, Airforce, BGB, Coast Guard, etc.), Shipyards (ASSL, WMSL, KSSL, KSY Ltd, DEW Ltd, CDDL, BN Dockyard, etc.), Industries and Associations (FBCCI, BGMC, BKMC, BTMC Bashundhara Group, PHP Industry, Walton, RFL Group, etc), Universities and institutes (DU, BUET, CUET, KUET, KU, NSU, SAU, BMU, BUP, MIST, IUT, Barisal University, Brack University, Daffodil University, Marine Academies, etc.) and from abroad with their participants/representatives like international organization (IMO,

UNDP, WB, JICA, ADB, EU, OECD, ABS, CCS, IRS, NKK, BV, CISC, CSDDC, CSSC, Wuchang Shipyards Ltd, Dalian Shipyard Ltd, Ardent Marine Singapore, Mitsubishi, etc.) and international universities (WMU, Osaka University, University of Yokohama, University of Basel, University of Paris, UNSW, The University of Melbourne, Monash University, CDU, etc.) Many important participants and representatives have attended and participated in the discussion and has given valuable information and suggestions. The FDG has conducted either in small group or in individually in different place and time in their convenient

due their availability, situation and time constraints. They have attended both individually and small group in different place and different time throughout the study and research work from Mar 2024 to May 2026. Table 1 shown below describes the respondent categories along with a demographic and summary profile of FGDs and respected personnel whose formal and informal interviews/interactions have been taken. On the other hand, the port standard and performance assessment questions, forms for different respondent categories have given in annexures A to C with this paper.

Table 1: Respondent categories and summary profile of FGDs and respected personnel

Respondent Type	No	Age Range	Gender (M/F)	Typical Role/Qualification	Location
Related service providers of ports	30	18–60	25/5	Operation, supervision, maintenance, management	Dhaka, Chattogram, Khulna, Barisal
Global and Local Shipping lines, ship owners, etc.	20	35–65	18/2	Operation, business, trade, policy	Home and abroad Both online and offline
Shipping agencies and warehouse owners	15	25–65	14/1	Operation, business, trade, policy	Home and abroad Both online and offline
Business people, maritime traders, Insurance people, bankers, fund providers	30	30–70	23/7	Operation, business, trade, policy	Home and abroad Both on and offline
Port workers, technicians, equipment operators (both skilled and unskilled)	40	25–55	32/8	operation, environmental and labour-rights activists	Dhaka, Chattogram, Khulna, Barisal, Foreign
Academics, researchers	41	30–80	29/12	Professors, policy researchers	Home and abroad Both on and offline
Foreign Experts	23	35–80	19/4	Specialist Consultants, Professors, Experts	Dhaka, Chattogram, Khulna, Remote, online
Relevant managers, architects, engineers, finance and administrative personnel	33	30–60	20/13	Operation, supervision, management	Dhaka, Khulna, Chattogram
Government officials working in major sea ports in Bangladesh	24	30–60	20/4	Management, standard, policy	Dhaka, Chattogram, Khulna, Barisal
Digital and smart technological professionals	15	25–50	13/2	Operation, supervision, standard maintenance	Dhaka, Chattogram, Khulna, Barisal
Members and experts of the classification society, quality assurance professionals, economists, financial experts, and NGO representatives	15	35–65	12/3	supervision, standard, policy, advice	Dhaka, Chattogram, Khulna, Barisal
Related SMEs and other organizations	16	25–60	13/3	Support, operation, maintenance	Dhaka, Chattogram, Khulna, Barisal
Freight forwarders, dock owners, off-dock people, etc.	25	35–70	20/5	Support, operation, maintenance	Dhaka, Chattogram, Khulna, Barisal
Ports executives, operators and other service providers	20	30–55	15/5	Support, operation, maintenance	Dhaka, Chattogram, Khulna, Barisal
Environmental and labour rights activists	10	35–65	8/2	Support, operation, service, admin, standard	Dhaka, Chattogram, Khulna, Barisal
Journalist	12	25–55	10/2	Support, policy, standard	Dhaka, Chattogram, Khulna, Barisal
Total	369				

State of Bangladesh Sea Port

Bangladesh's sea ports are currently experiencing a significant modernization and transformation phase, with Chittagong 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 Chittagong 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 (by Memorandum of Understanding or MOU primarily) foreign operators,

such as Denmark's APM Terminals and Swiss firm Medlog for terminal management to improve efficiency. The Mongla Port is serving as the second busiest port in the southwestern part of the country. Again, Matar-Bari Deep Sea Port is located in Cox's Bazar and it 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 within 2027. However, the 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 12 metre draught vessel). Actually, in Bangladesh the sea-ports have historically faced congestion, which has been exacerbated at times by political instability and flooding, leading to troubles in the supply chain. 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 Chittagong Port Authority (CPA) and administered by the Ministry of Shipping (MOS), the Chittagong Port has a rich history going as far back as the 4th century BC. The port advanced through British colonial governance under the Port Commissioner's Act of 1887 and subsequently began its modern existence in 1960 as the Chittagong Port Trust. In the post Liberation War period, it gained semi-autonomous status and 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 Port of Chittagong can be developed so as 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 Chittagong Port has the potential to become a major regional hub [35,36]. The Port of Chittagong, however, faces a capacity issue and must expand to handle growing volumes of containers and other cargoes to meet the foreseeable demand.

Chittagong 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 Chittagong Port Authority (CPA), this feat indicates a significant growth from 2024, with container handling rising by 4.07%, vessel handling by 10.5% and cargo throughput by 11.43% [37]. Even though limited automation, customs halts, strikes and political unrests slowed down operations, the port managed to stabilize its operations. The 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 Chittagong port didn't falter despite technological limitations and political crises in 2025, rather they 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 [37].



Figure 1: Geographical locations of existing sea ports of Bangladesh [38]

Growth Analysis and Require Development of Bangladesh Port Facilities

The Chittagong 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 forecasted to undergo an increase in container handling, evolving 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 for increasing its capacity and optimizing 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 has been shown in table 2 and the growth of cargo, container and vessel handling by Chittagong Port for the last two years in figure 2 below:

Table 2: Cargo, container and vessel handling by Chittagong 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%	-

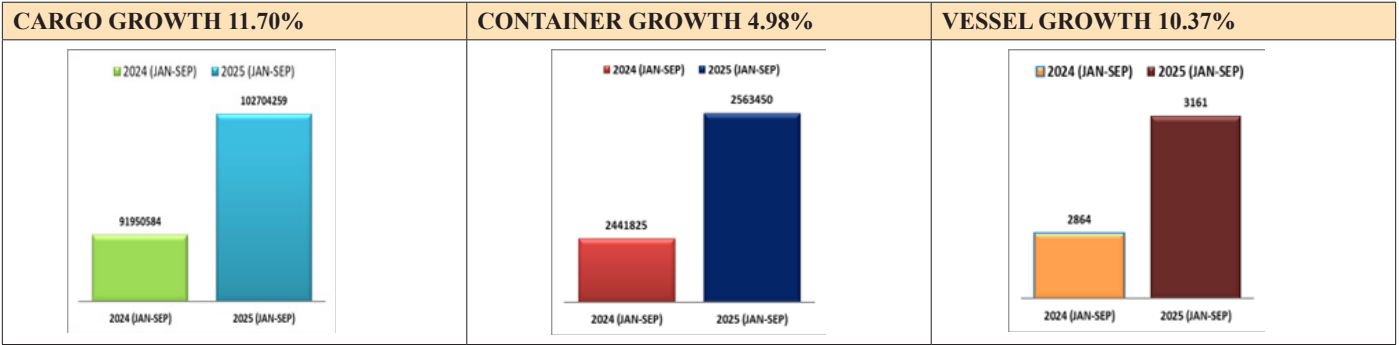


Figure 2: Growth of cargo, container and vessel handling by Chittagong Port last two years (2024 and 2025)

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 a close proximity to the Bay of Bengal. Dedicated to the southwestern region of East Bengal, it was founded in 1950 on the Pashur river of Khulna Division, being 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 for 24 hours all week, it has an unconstrained large channel for anchorage which is 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 had its legislative establishment in 2013 by an Act of Parliament and then 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 to 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 facing challenges with navigability and operational efficiency, authorities are actively working to resolve this problem 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) and 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 [39]. 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 where the RMG sector emerged as the chief economic driver [40]. Bangladesh is positioned as the only Least Developing 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 [41]. The Bangladeshi diaspora is another source of augmenting foreign exchange reserves through remittance 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 still persist. An unfortunately low tax-to-GDP ratio of 7.7% is a prime example while non-performing loans create systemic risks within the banking sector [42].

Historically advantaged by the Ganges Delta's mild, near tropical climate, fertile silt-laden soil and ample water resources added with ecological diversity, eastern Bengal was always a highly prosperous land [43]. So, living standards for the elite largely outpaced that 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. However, 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. It generates over 50% of GDP and remains a primary driver of employment. Shortages of fuel and gas have led to electricity blackouts and disrupted industrial production with persistent high inflation, declining foreign exchange reserves, and a weakening currency (Taka) pressuring the economy since 2022 [44]. 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 [45]. Nevertheless, RMG is the backbone of the economy, accounting for over 80% of total exports.

Sea-ports are the prime movers of Bangladesh as regards 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 [37]. According to forecasts by the Chattogram Port Authority, 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 and enhancing port operations of Bangladesh [46]. This will also increase the volumes of TEUs handling in the near future (projection up to 2040) which has been shown in table 3 and figure 3 below:

Table 3: Predicted of container handling volume (in million TEUs) in Bangladesh projection up to 2040

Year	Total Container Volume of Bangladesh (million TEUs)	Chittagong Port (GCB + CCT + NCT) (million TEUs)	PCT of Chittagong Port (million TEUs)	APM or Laldia Terminal of Chittagong Port (million TEUs)	Bay Terminal of Chittagong 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

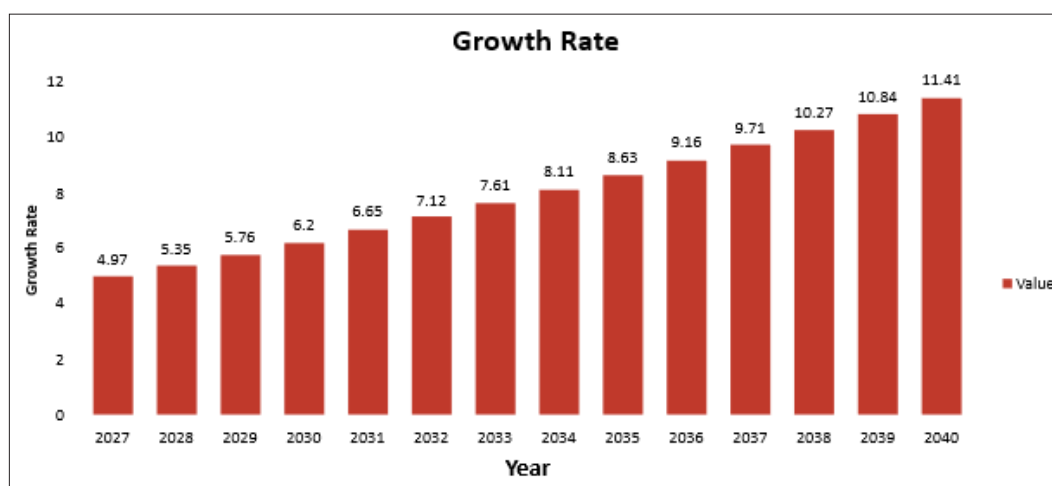


Figure 3: Prediction of container handling growth by volume (in million TEUs) in Bangladesh

Current and Future Development Project and Plan for Bangladesh Ports Facilities

In the age of globalization, efficient infrastructure and capacity enhancement is a key factor to success. In the context of Bangladesh, ports and the shipping sector are very critical for our country's sustainable economic development and growth. Bangladesh's government has recognized our country's great economic potential as well as the growing demand for a strong port infrastructure. After Chittagong, Mongla, and Payra port, Matar-Bari will be the country's 4th seaport and first deep seaport. The project's goal is to create a reliable and low-cost logistic infrastructure for seaborne cargo handling and transport services to keep the Bangladeshi products competitive in the international market. Except Matar-Bari, none of the deep seaport locations in the Bay of Bengal have the capacity to serve the larger hinterland region. Bangladesh is located in a strategic geographic location, with the Bay of Bengal playing a noteworthy role in regional affairs. The country is positioned in a strategic, maritime hotspot where it can play a key role as a nodal point, connecting nations worldwide by offering the most efficient overland transit routes to deep-water ports. Thus, it can substantially limit operational costs and transit times [47,48]. The deep seaport at Matar-Bari may also be used as a transit port for neighbors like Bhutan, Nepal, China, and India's seven sisters. Choosing Matar-Bari for the deep-sea port location is influenced by a number of compelling geopolitical and diplomatic

considerations. Matar-Bari deep seaport is expected to become a transshipment port like Colombo, Singapore, and Hong Kong since it has the sufficient depth to handle larger vessels. The plans of the Bangladesh government regarding the Chattogram port were clarified by Shipping Minister Shaikh Rabiul Alam. He stated that the ministry has no plans to cede full control of the port to foreign entities. Rather both domestic and global enterprises are eligible to compete for terminal operator roles. He added that terminal management would follow a formal and structured framework where public-private partnerships (PPP) and government-approved models will be utilized to leverage foreign expertise [49]. Let's talk about the ongoing and forthcoming projects and facilities which will be activated and contribute soon.

Current State and Future Development of PCT

The current state of Patenga Container Terminal (PCT) project is ready to operate. Annual throughput capacity of PCT is 0.5 million TEUs. It has two Jetties with 600m Length. It may be operated by Red Sea Gateway Terminal (RSGT), Saudi Arabia through PPP G2G Agreement in future. As a part of expanding maritime capacity, the establishment of the PCT was completely funded by the CPA which amounted to BDT 12.30 bn (USD 100.8 million). Subsequently, the CPA signed a 22-year Memorandum of Understanding (MOU) in December 2023 with Red Sea Gateway, Saudi Arabia, aimed at scaling the container handling capacity from 250,000 TEUS

to 600,000 TEUS. Complimenting this initiative, an ADB funded project looks to renovate the 11.5-kilometer long Chattogram Port Access Road, linking the Dhaka-Chattogram highway to the port, into multi-lane configurations and an additional service road. It may be operated by Red Sea Gateway Terminal (RSGT), Saudi Arab; through PPP G2G Agreement in future.

Present State and Future Development of NCT

The New-Mooring Container Terminal (NCT) has constructed in 2007 with 950m length. 5 Ships (with 10m draft and 190 length) take berth simultaneously. This terminal equipped with 14 Quay Gantry Crane (QGC), 30 Rubber Tiered Gantry Crane (RTG) and other handling equipment. Annual throughput capacity of PCT is 1.3 million TEUs. At present, NCT is operated by the supervision by CDDL management. There is a possibility to operate by DP World, UAE; through PPP G2G Agreement in future.

Matar-Bari Sea Port

It is considered as the 1st Deep Sea Port of Bangladesh. Its channel length is 14.3 km from sea coast with 350m width, and 16m depth (CDL). It has protected by two breakwater named North Breakwater with 2150m and South Breakwater with 670 m long respectively. Project construction has started in December 2020 and expected to Complete in 2028. This mega project has financed through JICA Loan and the project is running very satisfactorily. In parallel, the Matar-Bari deep-sea port mega-project, slated for completion by 2029, needs a capital investment of USD 2 billion (BDT 243,81 billion). The major financier of this project is JICA, funding USD 1.06 bn (Tk 128.93 billion), while the government and the Port Authority is supposed to co-finance the remainder of the investment. The existing limited threshold of only 20,000 to 30,000 metric tons will be elevated and reach 80,000 to 100,000 metric tons, thus drastically improving bulk cargo dynamics. This deep-sea port is expected to manage 1.4 to 4.2 million TEU containers, aiming to reach this target by 2041. Matar-Bari is projected to compress transit times to the US from 45 days to a mere 23 days, alongside establishing trade corridors with Europe. Data from the Chattogram Port Authority indicates that these projects could be economically successful and hosting these larger, deeper-draft vessels could probably reduce overall freight transportation costs by 15% [46].

Plans to Develop Laldia Terminal

The develop plan of Laldia Terminal is to going to start with the development of land area (Block C: 32 Acres and Block B: 07 Acres in first phase; and Block A: 10 Acres in 2nd phase in future). The Jetty length of the Laldia Terminal will be 600m. There is possibility to develop and operate this terminal by APM Terminals (A.P. Moller-Maersk, a major Danish multinational conglomerate) through PPP G2G Agreement (BV-Maersk Group) in future.

Plans to Develop Bay Terminal

The future CPA will be flourish with the dream project name "Bay Terminal." The Bay Terminal project has budgeted at Taka 149.1 billion (or USD 1.22 billion) approximately. The project is expected to complete by 2030, and that has designed to double the (CPA) port's overall handling capacity and plan to solve the port congestion problem fully. As an upgrade of berthing parameters, vessels with a 12-meter depth and 280-meter length can be accommodated comfortably. This is a major progression from the current/existing capacity of vessels with a 10-meter depth and 200-meter length in Chittagong Port. With an existing threshold of around 2,000 containers, the Bay Terminal project would allow berthing ships thrice the capacity (6,000 containers)

[37]. However, the development plan of Bay Terminal has described below.

- The marine infrastructure (breakwater and access channel) and developing connecting transportation infrastructure (Roads and Railway) will be financed by CPA; (6 KM Access channel and 6.2 KM Breakwater). This will be financed by WB Loan.
- The development and operation of Container Terminal 1 is expected to be undertaken by Singapore Port Authority (PSA) Consortium under a long-term concession through a direct G2G PPP agreement. Terminal size: 1225MX750M. Primary MOU has done and there is a possibility to operate by PSA, Singapore through PPP G2G Agreement in future.
- The development and operation of Container Terminal 2 is expected to be undertaken by DP World under a long-term concession through a direct G2G PPP agreement. Terminal size: 1225MX750M. Primary MOU has done there is a possibility to operate by DP World through PPP G2G Agreement in future.
- The development and operation of Multipurpose Terminal is expected to be carried out by an international terminal operator under a long-term concession through a PPP open tendering process. Terminal size: 1500MX750M. The terminal operator will be chosen through a tendering process in the near future.

Adequate port facilities, export diversification, seamless global trade, developed land connectivity etc. are the prerequisites when aiming for holistic economic growth. Energy, infrastructure, and transportation are the cornerstones to success in the economic field as well as the domains of human development, education, and social progress. In light of this, Bangladeshi policymakers and bureaucrats are working towards establishing a sustainable transport mechanism and secure energy supply infrastructure [50]. Among the three seaports (Chittagong, Mongla and Payra), Chittagong port handles 92% of all transported goods. This results in congestion of containers and vessels in the port which subsequently increases turnout time. The 9.5-meter draft limitation of Chittagong Port forces Bangladesh to rely on feeder vessels passing through South-East Asian ports like Singapore, Malaysia (Port Klang) and even Sri Lanka (Colombo). This leads to increased transportation costs and escalated transit times. Deep-sea ports have become a strategic imperative for Bangladesh to stay relevant in the global competition and direct foreign investment. Bangladesh can go beyond domestic demands and generate substantial foreign currency by providing maritime access to its landlocked neighbors (Nepal, Bhutan). Besides, logistical corridors to China and Northeast India can also be maintained. These connecting corridors, if properly implemented, along with a deep-sea port can significantly enhance Bangladesh's GDP. Bangladesh is geographically located in a region which is severely vulnerable to environmental degradation and natural catastrophes [51]. During port development and expansion projects (Bay Terminal and Matarbari deep-sea port), the project coordinators and policy makers should think ahead with a contingency plan reinforced with sustainable management to address any natural calamities so that the project on a whole and the livelihoods of the people in the vicinity are not drastically affected [52].

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 which includes the issuance of permits, licensing, certifications and customs declarations. By the incorporation of

advanced technologies into import, export and empty container handling, this system aims to omit bureaucratic paperwork, alleviate vessel congestion and reduce expenses. The Chittagong Port is being actively utilized by India, Nepal and Bhutan due to its strategic significance and close proximity to the ocean. World Bank data acknowledges the logistical inefficiencies that plague Bangladesh's maritime trade as the data states that domestic logistics costs fluctuate between 4.5% and 48%. This is much more than the countries in the South Asian vicinity. Nevertheless, introducing short-to-medium-term structural reforms could catalyze national export earnings by 19%. It is notable that only a 1% reduction of costs in this sector can expedite global demand for Bangladeshi exports by up to 7.4% [46]. Bangladesh faces operational fatigue due to cargo volumes, as Chittagong Port handled about 3.05 million TEUs in 2023, which rose by 6.8% to 3.26 million TEUs in 2024 [46]. Its poor operational performance is reflected internationally as the World Bank's Container Port Performance Index 2023 ranked it 337th out of 405. Mean RMG supply lead time of Bangladesh stands at an inefficient 95 days, which is unfortunate when compared to Vietnam (60 days) and China (32.5 days).

As a part of expanding maritime capacity, the establishment of the The Patenga Container Terminal was completely funded by the CPA which amounted to BDT 12.30 bn (USD 100.8 million). Subsequently, the CPA signed a 22-year Memorandum of Understanding (MOU) in December 2023 with Red Sea Gateway, Saudi Arabia, aimed at scaling the container handling capacity from 250,000 TEUs to 600,000 TEUs. Complimenting this initiative, an ADB funded project looks to renovate the 11.5-kilometer long Chattogram Port Access Road, linking the Dhaka-Chattogram highway to the port, into multi-lane configurations and an additional service road. Similarly, the Bay Terminal project, budgeted at BDT 149.1 billion (USD 1.22 billion) and completed by 2030, is designed to double the port's overall handling capacity and alleviate port congestion. As an upgrade of berthing parameters, vessels with a 12-meter depth and 280-meter length can be accommodated. This is a major progression from the current existing capacity of vessels with a 10-meter depth and 200-meter length [37]. With an existing threshold of around 2,000 containers, the Bay Terminal project would allow berthing ships thrice the capacity (6,000 containers). In parallel, the Matarbari deep-sea port mega-project, slated for completion by 2029, needs a capital investment of USD 2 billion (BDT 243.81 billion). The major financier of this project is JICA, funding USD 1.06 bn (Tk 128.93 billion), while the government and the Port Authority is supposed to co-finance the remainder of the investment. The existing limited threshold of only 20,000 to 30,000 metric tons will be elevated and reach 80,000 to 100,000 metric tons, thus drastically improving bulk cargo dynamics. This deep-sea port is expected to manage 1.4 to 4.2 million TEU containers, aiming to reach this target by 2041. Matarbari is projected to compress transit times to the US from 45 days to a mere 23 days, alongside establishing trade corridors with Europe. Data from the Chattogram Port Authority indicates that these projects could be economically successful and hosting these larger, deeper-draft vessels could probably reduce overall freight transportation costs by 15% [46].

Smart Port Concept and their Efficiency

Smart ports integrate cutting-edge digital technologies like AI, ML, Big-data, Digital Twin, Internet of Things (IoT), 5G networks, to optimize logistics, efficiency and operations. By connecting terminals, automation, shipping lines, authorities and

stake-holders, it minimizes wait times, cuts carbon emissions, enhanced efficiency, ease 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, DS, and real-time data analytics etc.) for providing 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 (Hossain, 2023b, f, g) are some of the other features smart ports may integrate for flawless connectivity [18,19,23]. Besides, digital twin technology, augmented reality (AR), virtual reality (VR), and interoperable systems may be used to ensure collaboration among diverse stakeholders [53]. Installing adequate infrastructure for smart ports requires the establishment of mechanized berths furnished with advanced mooring systems along with prioritizing advanced security. Further transformation of smart ports incorporates the rigorous assessment of capabilities which are a part of the 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 focuses on the smooth operation and maintenance of various infrastructure elements and services to ensure efficient cargo flow, safety, security, and environmental sustainability. The integration of digital technologies in port operations is increasingly evident through initiatives like stakeholder collaboration platforms, digitalization strategies, and the implementation of port community systems (PCS). These innovations facilitate better coordination and transparency among port users. To enhance operational efficiency, smart ports are leveraging technologies such as automation, IoT sensors, data analytics, and real-time monitoring systems [19,24]. These tools are used to track cargo handling, infrastructure conditions, and vessel movements in real time, thereby improving overall productivity and minimizing delays across the port environment. For augmenting overall efficiency and reducing operational delays, technologies are being developed to smoothly integrate various port functions, including cargo handling, customs processing, and vessel scheduling. Port Community System (PCS) facilitates smoother collaboration and information sharing among key stakeholders such as port authorities, shipping companies, terminal operators, customs agencies, and logistics providers. It also enhances the flow of goods through the port, promotes transparency, and improves the coordination of port activities. Additionally, smart asset management systems utilize sensors, RFID technology, and GPS tracking to monitor the location, condition, and performance of critical port assets including cranes, containers, vehicles, and infrastructure. These intelligent systems support proactive maintenance, extend the service life of essential equipment and ensure optimal asset utilization. Predictive maintenance, powered by advanced algorithms, analyzes sensor data, maintenance history, and equipment performance to identify potential failures in advance and hence schedules timely interventions. This approach boosts the reliability and safety of port operations while minimizing downtime and reducing maintenance costs. Furthermore, the use of data analytics combined with IoT sensors enables real-time monitoring of port

equipment and infrastructure conditions, allowing for immediate responses to emerging issues and further refining operational efficiency [18,23].

Energy efficient technologies are essential in modern port operations, as they help optimize electricity usage, manage peak demand, and incorporate renewable sources like solar and wind power. Implementing energy-saving solutions such as high-efficiency HVAC (Heating, Ventilation, and Air Conditioning) systems, advanced lighting, and micro-grid technologies within port facilities can significantly reduce carbon emissions, lower utility expenses, and promote environmental sustainability. To strengthen port security, advanced surveillance systems including high-definition video cameras, perimeter intrusion detection systems, and sophisticated access control technologies are deployed to monitor restricted zones, detect unauthorized activities, and alert security personnel in real time. Intelligent video analytics further enhances these systems by identifying suspicious behavior and potential security threats. Tracking cargo, vehicles, and goods across the port premises is made more effective with the use of RFID tags, GPS trackers, and blockchain technology [54]. These tools improve visibility and transparency across the supply chain, enabling better inventory control, reducing theft and loss, and offering real-time insights into the location, condition, and status of shipments. Intelligent traffic management systems are also employed to optimize the flow of vehicles and cargo within the port area. These systems manage truck queues, parking assignments, and gate access while using live data on berth availability, traffic patterns, and vehicle movements to support dynamic scheduling and routing, thus minimizing congestion and delays. A centralized, integrated port operations platform aggregates data from multiple stakeholders, including terminal operators, shipping lines, customs authorities, and logistics providers. This unified system enhances communication, facilitates collaboration, and supports efficient decision-making, ultimately boosting productivity and streamlining operations. Smart technologies also play a critical role in emergency preparedness and crisis response. Mobile communication platforms, GIS mapping, and automated alert systems enable quick coordination, help ensure the safety of personnel, and provide effective incident management during emergencies.

Key Components and Smart Ports Infrastructure

Traditional supply chain management systems often struggle with fragmented data sources, making it difficult for management and operation systems including managers to gain an inclusive view of logistics, procurement, and inventory status. Interactive dashboards consolidate data from various sources, including enterprise resource planning (ERP) systems, IoT sensors, AI, ML, and supplier databases, big data systems, into a unified interface that enables managers to track supply chain movements in real-time. Traditional demand forecasting methods often rely on historical sales data and static models, which may fail to capture dynamic market conditions and seasonal variations [19,55]. The data management mechanism and system including the operational modalities and data management requirements of port operations are analyzed. The data model consists of four components like, data storage, data interaction, data visualization, and data security. The system achieves synchronous mapping of operational processes, integrated data management, and integration with other systems. For prospective clients interested in adopting automated port solutions, the initial step involves launching a structured program. This typically includes preparing a Request for Proposal (RFP), selecting a suitable technology vendor, and

overseeing the development of a pilot project. Additionally, a Request for Information (RFI) can be issued to assess market capabilities and gather insights into the specifications, services, and end-to-end solutions that providers can deliver. Smart ports operation encompasses the following components [18,27,29].

Smart ports utilize advanced automation to enhance the performance of port machinery and operations. This includes remote-controlled cranes, automated guided vehicles (AGVs), smart mooring systems, and robotic container handling technologies. Managing labor relations remains complex, with challenges surrounding wage negotiations, working conditions, and concerns about job displacement due to automation. Port managers must carefully balance technological advancement with the interests of the workforce. Smart ports are required to follow a wide range of regulations concerning safety, security, environmental standards, and customs. Staying compliant and up to date with regulatory changes can be demanding for port operators. Today, as key nodes in the global supply chain, ports must synchronize operations with other logistics functions such as warehousing, distribution, and transportation. However, differences in technologies and processes among stakeholders can complicate seamless integration. Smart ports are increasingly adopting automation to enhance efficiency, reduce labor expenses, and improve safety. Technologies include robotic container handling, AGVs, and automated stacking cranes. Those are promoting collaboration among port authorities, shipping companies, logistics firms, and other partners is vital for sharing information, optimizing workflows, and driving innovation within the maritime industry. Smart port initiatives must ensure adherence to applicable legal, environmental, and cybersecurity regulations, including those related to data privacy and operational safety. Cutting-edge technologies like fencing systems, biometric access controls, surveillance networks, and cyber defenses are used to safeguard personnel, assets, and operations. Real-time monitoring and proactive risk management improve incident prevention and legal compliance. These systems oversee the full lifecycle of critical port infrastructure including terminals, cranes, warehouses, and berths. Features include asset tracking, maintenance scheduling, and performance analytics to ensure optimal usage and upkeep. These tools allow centralized monitoring and management of port assets, providing real-time operational data, supporting remote diagnostics, and enabling safe and efficient remote equipment operation.

Smart ports are increasingly utilizing sensors to monitor various operational components such as security, traffic flow, environmental parameters, and cargo movement. These sensors generate real-time data that supports improved decision making and enhances productivity. To process and interpret the vast amount of information gathered from sources like shipping manifests, customs documentation, and sensor networks, automated ports rely on advanced data analytics. These insights help identify trends, uncover inefficiencies, and highlight opportunities for optimization. Smart technologies including robotics, drones, and autonomous vehicles are often employed to boost the accuracy and efficiency of tasks such as cargo handling, inspections, and monitoring. Additionally, by integrating digital tools like cloud computing, blockchain, digital twin systems, and the IoT, smart ports can foster greater collaboration and transparency among diverse stakeholders [1,18,56]. Furthermore, in an effort to minimize the environmental footprint of port operations, automated ports promote the adoption of eco-friendly technologies, such as electric vehicles and renewable energy solutions. Besides, smart ports can implement various energy-saving measures to

reduce energy consumption and greenhouse gas emissions, such as using energy efficient equipment and LED lighting. They can also generate renewable energy by installing solar panels on rooftops, parking areas, and other suitable locations alongside installing wind turbines either onshore or offshore to harness wind energy. Additionally, geothermal systems, which tap into the Earth's internal heat, can be used to generate electricity and provide heating for port facilities. Similarly, ports located near rivers or coastal areas can utilize hydroelectric power by capturing energy from flowing water. Moreover, automated ports can generate energy from biomass sources like agricultural waste or wood chips through processes like anaerobic digestion or combustion.

Advantages and Challenges of Transformation into Smart Port

AI, ML, IoTs and Big-data have the required potential to revolutionize both operational and administrative functions within sea ports and terminals. The transformative potential of these technologies lies in their ability to automate decision-making, improve operational efficiency, security, decision-making, and provide predictive insights. AI has a pivotal role in contemporary maritime logistics, optimizing smart port and terminal operations especially through robotics. AI has proven its transformative capacity in fields like healthcare, finance and pharmaceuticals; its inclusion in smart ports is driven by the urgent call to decarbonize global supply chains and aim for sustainability [13,26,57]. Maritime operations like towage, pilotage, cargo movement are heavily influenced by AI which further streamlines operations. ML predictive models are a critical mechanism of this operation as they analyze historical data and accurately forecast task durations specific to certain vessels and service requirements. Variables like vessel-specific pilot licensing, optimal tugboat configurations and the logistical deployment of pilot transit to boarding stations are refined through these predictive insights as complex scheduling problems make operations difficult. Critical port resources are properly allocated using these measures [8,10,11]. Even though the proliferation of experimental programs and pilot projects makes the contribution of AI in smart ports evident, further empirical research is a must to analyze practices and chart future trajectories [58]. The profound potential that AI holds to revolutionize maritime management is organized around many dimensions. AI-driven tools can significantly optimize key operations such as container stacking, crane scheduling, and berth allocation. For example, AI can reduce unproductive moves, cut fuel consumption, and lower emissions, leading to more sustainable port operations. AI can further enhance real-time operational adjustments. By integrating AI with IoT sensors and 5G connectivity, ports can gain immediate feedback on equipment performance, weather conditions, and cargo movements. This connectivity allows for dynamic, data-driven adjustments that enhance productivity.

AI models can forecast when equipment is likely to fail, and that allowing for proactive maintenance schedules. This reduces the risk of unplanned downtime and extends the life of critical assets like cranes, trucks, vessels and other cargo/container handling machineries. These AI-driven predictive maintenance solutions are particularly valuable in ports with high equipment use and operation. By investigating historical data and usage patterns, joint with external factors like weather conditions, ML models, Big-data analysis, etc. can optimize maintenance intervals, reduce costs and solve operational troubles. AI systems provide a significant edge in decision-making, ease of operation, enabling data-driven decisions for route planning, cargo sequencing, ensure safety, and workforce management. These decisions, usually based on real-time data analysis, and that lead to better-informed strategies. Finally, those streamline workflows and minimize operational bottlenecks.

Furthermore, AI-enabled decision-making supports disaster management by simulating various scenarios and recognizing the most efficient strategies to recover from disturbances, like extreme weather events or unexpected delays in the supply chain. AI plays an important role in enhancing workplace safety and security by identifying potential hazards and automating safety checks. Additionally, it assists ports in maintaining compliance with progressively stringent environmental and operational regulations. AI can also be installed for real-time environmental monitoring, helping ports and can meet sustainability goals. AI contributes to global environmental objectives, ensuring that ports operate within regulatory frameworks and promoting sustainability by tracking emissions, energy consumption, and waste management practices. AI's potential is not limited to operational efficiency; however, it extends to administrative processes [59]. Responsibilities like invoice processing, claim handling, and customer inquiries can be automated using AI-powered bots, allowing human resources to focus on more complex and strategic tasks and assignments.

The potential for AI in the sea ports are massive, several challenges and obstacles to adoption must be overwhelmed. These challenges range from technological limitations to organizational, environmental and cultural issues. Many ports rely on outdated systems that lack the compatibility required for AI integration. Retrofitting or replacing these systems is a major financial, technical and operational challenge. The maritime industry and trade frequently suffer from siloed data stored across various stakeholders, both within organization like departments/sections and outside the organization like port operators, customs, shipping lines, stake-holders, etc. Moreover, the quality of data is frequently incomplete and inconsistent, making it difficult for AI models to function optimally and effectively. Modern sea ports must navigate a complex regulatory environment, predominantly with regard to data protection and ownership. The embryonic landscape of data privacy and AI laws, like the EU's AI Act, or similar local roles and regulations adds further complexity, and that leaving many hesitant of how to use data within legal limitations. With increasing digitization, AI adoption brings heightened cybersecurity and other safety concerns. Sea ports must protect sensitive data and operational systems from cyber threats and digital complexity. AI-driven automation often faces resistance from workers who fear that their roles may be at risk. The transition to AI requires cautious modification management to ensure employees feel empowered, not vulnerable. Finally, the biggest barriers to AI adoption are the shortage of skilled professionals in AI, data science, and advanced IT systems [59]. The maritime industry and concern struggle to attract young talent in these areas, and making it difficult to fully leverage AI. However, as the maritime industry discovers the adoption of AI, ML, IoTs and other smart technologies, treasured lessons can be taken from early adopters in other industries, like aviation, manufacturing, logistics, transport, healthcare, etc.

The integration of AI, ML, IoTs, Big-data, in the port industry is no longer a distant vision but a growing necessity for ports aiming to stay competitive, efficient, and sustainable. AI serves as the foundation of fully autonomous smart ports operations, as the structural framework of these ports largely revolve around AI-based applications. As global logistics enterprises shift their focus on AI, shipping and maritime sectors are largely influenced by it [19,55]. Using AI and the pervasive deployment of ML algorithms, various operational variables can be analyzed and thus improve ship arrival sequences. This organized framework increasingly solves the harbor congestion problem and also reduces the carbon footprint of idling ships [60]. ML has a significant contribution in the domain of berth allocation, which is a highly complex constraint matrix that includes several

dimensions like vessel size, hull classifications, ship-to-shore crane availability, and shore power infrastructure capacities [61]. As the maritime industry leans towards renewable energy, ships arriving at the ports will have diversely specific servicing requirements, thus urging the need for computationally efficient berth allocation to sustain port throughput.



Figure 4: AI will transform port and AI will make port more intelligent [59,62]

AI technologies help in real-time performance diagnostics, forecasting estimated times of arrival and constructing high-fidelity digital twins which are virtual replicas of port operations to enhance oversight and supervisory control. Analyzing aerial imagery may soon be possible with the use of AI to supervise and predict traffic congestion at terminals while keeping environmental sustainability in mind [63]. AI and ML, which support sustainable maritime initiatives like just-in-time arrivals, can work in tandem with predictive congestion modeling to dynamically advise incoming vessel to manage their speeds. This reduces fuel expenses while mitigating environmental degradation issues. Modern AI-driven software platforms heavily rely on extensive datasets accumulated from IoT sensors deployed across ports and the overall shipping industry [64]. To obtain the maximum productivity from AI, ML and DL architectures, top-tier and uncorrupted data should be provided by the global supply chain. Automated systems heavily utilize AI, using it to manage horizontal freight and govern terminal operating systems [18,29]. Automated guided vehicles (AGVs) improve cargo movement through the port with the help of AI under a centralized management [65]. Even though the autonomous and mechanized control of port operations might be streamlined with the increased integration of AI, manual or human operators will remain imperative to supervise these operational systems.

AI has gone from being an experimental framework to a critical node in the establishment of smart ports. For instance, pronto is an AI model used in the Port of Rotterdam which enhances the synchronization of container throughput by analyzing various data streams like real-time vessel telemetry using Automatic Identification Systems (AIS) and port authority databases and creates self-learning, adaptive models. A 20% decrease in vessel detention periods is evident through data collected from the Rotterdam Port Authority [65]. Through these self-learning models, pronto leverages machine learning models which enhance forecasting of vessel arrival times and container processing intervals, thus heightening the efficiency of port logistics and operations [66]. In tandem with Europe, North American logistics hubs like the port of Los Angeles have deployed a similar predictive AI platform called Port Optimizer. This utilizes sensor networks and predictive measures to streamline container scheduling and other port orchestrations to anticipate future demand and ensure proactive management [67]. The South East Asian counterpart of this is the Maritime Single Window in Singapore which expedites customs and maritime immigration clearances. Instead of leveraging sensor networks, this uses natural language processing (NLP) along with predictive analytics to optimize transparency and throughput speed. To support macroeconomic port governance, the ML subroutines categorize and translate unstructured data from customs documentation and shipping [68].

The organized expansion and integration of AI serve to produce foundational achievements in maritime operations and provide many benefits to modern ports. Since AI-driven platforms rely heavily on their underlying data, port authorities are obliged to ensure availability of data through data-harvesting pipelines to eliminate flaws and capture data streams from across the supply chain. AI models can diagnose systemic latencies and highlight the catalysts to increase terminal productivity. Future editions of AI are projected to refine maritime shipping routes, optimize automated cargo handling and identify illicit activities [69]. Deploying advanced algorithms requires a thorough evaluation of existing infrastructure which AI can help to conduct. Existing computational assets, storage and network bandwidth need to be adequate for integrating AI into smart ports. Human-machine co-management is essential for the transition of manually operated systems into automated ones. Dedicated cross-functional teams for managing these systems are formed as a result of AI integration [68]. Large-scale digital deployment comes with financial risks, which can be pinpointed by AI predictive models. Thus, shareholders can analyze and invest accordingly. Collaborative alliances between expert AI firms allow ports to manage technicalities which integrate more software while developing onsite proficiency [70].

The integration of AI into the smart port ecosystem requires rigorous planning, evaluation and systematic evaluation because not all AI platforms are equally effective. Much like the human brain, AI uses advanced algorithms to analyze the immense amount of data that is generated from port operations [1,25]. AI has enabled automated port operations through various mechanized technologies like autonomous cranes and trucks in the Port of Los Angeles and AI-powered operations in the Port of Rotterdam. AI-driven predictive analytics have gone a great extent in accurately predicting a ship's Estimated Time of Arrival (ETA), which is a milestone in smart port development as many ships currently arrive much later than estimated. Without AI intervention, a severe unpredictability confronts the maritime sector. This was highlighted by a 2020 report by the Danish firm, Sea-Intelligence wherein it was evident that carrier on-time reliability across 34 global trade routes had plummeted to 50.1%. Such logistical chaos is on par with the assumption of half of all commercial flight arrivals being delayed by 24 hours. Retrofitting port infrastructure enhances logistical visibility by incorporating AI-driven software is optimal as it lets stakeholders analyze complex datasets to improve schedule and cargo handling along with managing freight movement [1]. Nevertheless, integrating AI into daily port operations is a complex process due to the deeply embedded industry practices, a heavy dependence on data quality and a lack of technical standards. This forces AI models to be customized in accordance with specific port requirements [2,25,55]. Collaboration between port authorities and AI professionals is a prerequisite to develop standardized and

adaptable measures which address the entirety of the maritime network.

There are several other instances of premier shipping enterprises revolutionizing the maritime landscape using AI, ML, DL etc. Maersk is one of the industry pioneers who have developed Captain Peter, an AI model to optimize fuel economy while addressing sustainability concerns [71]. Likewise, CMA CGM has introduced Smart Containers, which creates transparency and a client-friendly interface as it permits customers to track the precise location of their containers along with other environmental conditions [72]. Other industrial giants like Hapag-Lloyd and MSC aren't lagging behind either, as the former engages AI to filter out the most cost-effective maritime route basing on meteorological and traffic data. On the other hand, MSC's 'Safeguard' uses ML and data from various streams to broadcast safety alerts and help prevent unwanted circumstances [73,74]. Complimenting these technological advancements, Evergreen Line's predictive maintenance devices anticipate equipment errors before mechanical failure can occur. Besides, it has also developed a standard frictionless tracking interface which can provide instantaneous information about the location of cargo to the customers if provided with the necessary shipping credentials (Booking reference, Master Bill of Lading etc.) [75,76].

Unlike conversational AI use where there is a slight scope for experimentation, the margin for error is virtually nonexistent when it comes to maritime safety and operational fidelity. To reach this pinnacle of reliability, AI and ML models must be meticulously trained using tailored datasets and rigorous performance benchmarks. This should be in accordance with a validation or feedback loop which contrasts projected timelines with each port's actual operational durations [77]. This process helps the algorithms to evolve and tailor themselves to each port's specific requirements. Such an upgrade and technological precision has become necessary due to the dramatic surge in container volumes which largely influences maritime dominance. Historically, European and North American ports have commanded the top positions of global shipping as proven by data from 2005. However, by 2021 only the Port of Rotterdam clung to a top ten spot globally [78]. The claim that the successor to the West in the maritime sector is China is supported by data from the Hong Kong marine department as they set a new standard in modern shipping through the successful assimilation of advanced AI and digital infrastructure into its ports' administrative and operational activities [47,48].

Adoption and Implementations of Smart Technologies in Modern Sea Ports

As the port industry adopts AI and ML technologies, significant shifts are expected in the roles, responsibilities, and required skillsets of the workforce. While AI promises to improve operational efficiency, security and decision-making, it also poses challenges related to job displacement, and the need for upskilling, and the cultural transition towards data-driven decision-making. Understanding and managing these implications is crucial for ensuring a smooth transition to more automated, smart and AI-augmented operations. Smart technologies like AI, ML, DS, IoTs, Digital-twin, Bid-data, etc. will increasingly automate routine, repetitive tasks traditionally handled by port workers, such as data entry, administrative processing, and predictive decision-making in areas like container stacking and equipment scheduling. Such shift means that human workers will move away from performing manual tasks and instead take on more supervisory roles. For

instance, while AI systems may handle crane operations or truck scheduling, humans will still be required to monitor these systems and intervene in complex, unpredictable scenarios [79]. As smart technologies taking over operational decisions, the workforce will need to be retrained and upskilled to manage and supervise AI-driven processes. Future ports workers will need to learn how to interact with AI systems, interpret data outputs, and make high-level, contextual decisions based on AI recommendations. This will require training in both technical skills like data literacy, AI system management and soft skills, such as critical thinking and problem-solving in complex situations. As smart technologies systems take over these functions, the industry will see a move toward more data-informed decisions. AI's ability to process vast amounts of real-time data means that workers will be required to trust and rely more on these insights, potentially reducing the reliance on human intuition in day-to-day operations. In future many employees may feel uncomfortable with AI taking over tasks that were previously based on their judgment or experience [80]. Ports will need to implement robust change management programs, focusing on transparency and gradual integration of AI, to ensure workforce buy-in. Early involvement of staff in AI deployment, as well as clear communication about the benefits (e.g., improved safety, reduced workload), can help mitigate resistance.

Smart technologies implementation, particularly in administrative and operational roles, will lead to workforce reductions in some areas. Automation of administrative processes, such as invoice handling, claims processing, and customer support through AI-powered chatbots, will reduce the need for clerical staff. Similarly, predictive maintenance and AI-optimized equipment management will decrease the reliance on manual interventions and routine inspections. In future ports will need to address the potential job losses caused by smart technology or AI-driven automation. One approach is to gradually reduce the workforce through natural attrition (e.g., retirements) rather than abrupt layoffs. Additionally, ports should focus on redeploying affected workers to other areas, such as system supervision, customer relations, or logistics optimization, after proper retraining. This gradual shift can help avoid abrupt transitions that might generate resistance or insecurity among the workforce. In future while AI will displace some traditional roles, it will also create new opportunities. The maritime industry will see the emergence of new roles focused on AI system management, data analysis, and IT security. For example, data scientists, AI specialists, and cybersecurity professionals will be critical in ensuring that AI systems run smoothly, that data is accurately interpreted, and that port operations are protected from cyber threats. The challenge for ports will be to attract and retain skilled professionals in these emerging roles. Historically, the maritime industry has struggled to attract young, tech-savvy talent. To overcome this, ports should focus on fostering an innovative culture that emphasizes technology, sustainability, and data-driven operations. Partnering with academic institutions and offering apprenticeships or on-the-job training can also help build a pipeline of qualified candidates. In future as more decisions are delegated to AI systems, the role of human workers will shift from direct decision-makers to collaborators with AI. For example, planning departments may move from making detailed operational plans to overseeing AI-generated plans, focusing on exceptions or complex scenarios that AI may not be equipped to handle. However, in future the balance between human expertise and AI-generated insights will be crucial. While AI can optimize many decisions, it lacks the contextual awareness and experience that humans bring to the table, especially in unexpected or emergency situations

[81]. Ports must, therefore, ensure that AI systems are designed to complement human decision-making rather than replace it entirely. The success of smart port programs depends on policy coherence, especially in digital governance, data interoperability, and cybersecurity.

The adoption of smart technologies like AI, ML, DS, IoTs, Digital-twin, Bid-data, etc in the port industry will lead to significant changes in the workforce. While automation will reduce the need for certain roles. Moreover, it will also create new opportunities and shift the focus toward supervisory and high-level decision-making tasks. Ports that proactively address these workforce changes by upskilling, retraining, and change management; they will be better positioned to integrate AI successfully and maintain workforce morale. However, by fostering a culture of innovation and collaboration between human workers and AI systems, the port industry can yoke the full potential of AI while ensuring that employees are not left behind in the transition. The integration of AI, ML, IoTs, Big-data, etc. in the port industry is no longer a distant vision but a growing necessity for ports aiming to stay competitive, efficient, and sustainable. While there are significant challenges, which ranging from legacy systems and fragmented data to workforce resistance and these barriers can be overcome with strategic planning, incremental adoption, and a focus on collaboration and talent development. As more ports embrace AI and other smart technologies, the industry will likely change into a highly automated, data-driven ecosystem; where operational efficiency, safety, security, decision-making, and sustainability are improved. AI will become a keystone of future port operations, but human mistake and domain expertise will remain critical, particularly in managing complex, us usual and unpredictable scenarios. Future smart ports that have a clear data strategy and right vision, invest in building in-house AI, ML, IoTs, Big-data expertise and upskill their workforce will be better positioned to secure the benefits of AI [82]. The maritime industry is on the tip of a transformation, and those who act decisively now will lead the way in shaping the future of global trade. Global best ports practices promote for layered cybersecurity policies, including encrypted data flows, third-party risk management, and ISO 27001 compliance frameworks around the world. Vietnam's national digital logistics strategy has targeted to make the sector contribute 6–8% of GDP by 2030, driven by AI, smart warehouses, IoTs instigation, and 4PL platforms. Such national digital logistics roadmaps with defined KPIs and cross-ministerial accountability give the nation in high punch and help development. The World Bank Group highlights that setting up these interagency coordinating bodies is vital to reducing overall logistics costs [83].

In 21st century, in the era of globalization many countries are shifting toward the development of smart ports digitally enabled with smart system and adaptive systems that influence Fourth Industrial Revolution (4IR) technologies. Smart technology the digital twin balances high-utility logistics with progressive environmental goals tracking the movement of thousands of ships and millions of tons of cargo yearly. We can share few great examples of success story of smart technology adaption in few contemporary ports around the globe. Singapore's Port Authority (PSA) has instigated blockchain-based customs, tools, AI-berthing and real-time port dashboards, and which contributing as 30–40% reduction in processing time and distinct amount of cost reduction

[84]. Ports in the Netherlands, Australia and China are adopting fully automated terminals using AGVs, AI cranes, digital-twin, IoTs and autonomous drones for monitoring, surveillance and effective decision-making. These smart innovations and technology adaptation in ports have reduced labor costs, enhance performance and improved safety and security standards [85]. China's Yangshan Port Yangshan, and Australia's Victoria International Container Terminal VICT are spearheading the conversion to "Port 4.0" and that is a new roadmap for the sector will guide moves on autonomous port. As a result, these ports significantly reduce operating expenses [86]. On the other hand, Rotterdam has successfully established a full-scale digital twin ecosystem and which acts as a virtual, 4D replica of its entire port operations. This advanced infrastructure integrates real-time IoT sensors, weather statistics, and shipping data to continuously mirror reality and simulate future scenarios. However, there digital twin models for predictive cargo flows, monitoring port activities and emission tracking and which result improvement of customers service and ecological refinement [87]. At the same time, Busan Port is implementing a major, multi-million-dollar AI port transformation to begin itself as a global smart logistics hub in Asia. By integrating real-time data, IoT, and ML across terminal operations and uses big data to forecast congestion patterns and optimize routing the port actively shifts towards predictive operations [88]. Ports like Hamburg and Long Beach deploy IoT sensors to measure emissions in real time and use AI to adjust operations for emissions reduction. Such practices are increasingly demanded by eco-sensitive trade routes [89].

Descriptive Analysis and Performance Survey of Chattogram Port
The respondent categories and summary profiles of FGDs as mention above and the respective personnel, whose formal and informal interviews/interactions have been conducted are described, and the sample port standard and performance assessment form for different respondent categories is shown Annexure A to C. Twenty-two determinants have been considered to assess the port standard and performance of Chattogram Port. A survey was conducted among 17 categories of people from home and abroad. Those categories are: A: Port Service Provider, B: Port Service Taker/Receiver, C: Global and Local Shipping Lines/ Ship Owners, D: Shipping Agencies, and Warehouse Owners, E: Business People, Maritime Traders, Insurance Workers, Bankers, Fund Providers, F: Port Workers, Technician, Equipment Operators (Both Skilled and Unskilled), G: Relevant Managers, Architects, Engineers, Finance and Administrative Personnel, H: Government Officials Working in Major Sea Ports in Bangladesh, I: Digital and Smart Technological and Professionals, J: Members and Experts of The Classification Society, Quality Assurance Professionals, Economists, Financial Experts, and NGO Representatives, K: Related SMEs and Other Organizations, L: Freight Forwarders, Dock Owners, Off-Dock People, Etc., M: Local and International Experts and Specialist, N: Ports Executives, Operators and other Service Providers, O: Environmental and Labor Rights Activists, P: Academics, Researchers, Q: Journalist. The weightage of parameter/scale and easy interpretation of assessment has been shown below. The summary of assessment and results have been shown in Table 4 below. The brief description of performance result of Chattogram Port has been given in Annexure D with this report.

Table 4: Finding and assessment result or descriptive statistics

Determinant	Mean	Interpretation
Container Handling	4.80	Excellent
Basic & Conventional Security	4.70	Excellent
Ensuring Safety	4.50	Very Good
Compliance with Standards & Regulations	4.50	Very Good
Labour Law Practices	4.50	Very Good
Berth & Infrastructure Management	4.10	Very Good
Ship Movement Operational	3.80	Good
Cargo Management	3.60	Good
Tariff, Billing & Revenue Collection	3.60	Good
Reporting & Decision Support	3.50	Good
Resource Optimization	3.40	Good
Inventory Management	3.40	Good
Transport Services	3.40	Good
Cargo & Terminal Supervision	3.20	Good
Digitization	3.00	Good
Berth Allocation	2.90	Fair
Real-time Monitoring	2.70	Fair
Gate & Landside Management	2.60	Fair
Accountability, Responsibility & Transparency	2.50	Fair
Good Governance	2.50	Fair
Financial Support & Funding	2.50	Fair
Documentation & Customer Service	2.30	Fair
Supply Chain Integration	2.20	Fair
Cyber Security Implementation	1.90	Poor
Automation	1.40	Poor

Descriptive Analysis

The descriptive analysis was conducted to examine respondents' perceptions regarding the determinants of port standard and performance. A five-point Likert scale was used, where 5 = Excellent, 4 = Very Good, 3 = Good, 2 = Fair, and 1 = Poor. The results indicate that respondents rated several operational and regulatory dimensions positively, while technological integration, governance, and automation received comparatively lower ratings. Among the 22 determinants, Container Handling achieved the highest mean score ($M = 4.80$), indicating excellent operational efficiency in handling cargo containers. Likewise, Basic and Conventional Security ($M = 4.70$), Ensuring Safety ($M = 4.50$), Compliance with Standards, Rules and Regulations ($M = 4.50$), and Labour Law Practices ($M = 4.50$) were also rated at a very high level, suggesting that respondents have strong confidence in port safety, security, and regulatory compliance.

Operational functions such as Berth and Infrastructure Management ($M = 4.10$), Ship Movement Operations ($M = 3.80$), Cargo Management ($M = 3.60$), Tariff, Billing and Revenue Collection ($M = 3.60$), Reporting and Decision Support ($M = 3.50$), Resource Optimization ($M = 3.40$), Inventory Management ($M = 3.40$), Transport Services ($M = 3.40$), and Cargo and Terminal Supervision ($M = 3.20$) were rated as good to very good, indicating that the port performs satisfactorily in its core operational activities. Conversely, several determinants received relatively lower evaluations. Real-time Monitoring ($M = 2.70$), Gate and Landside Management ($M = 2.60$), Accountability, Responsibility and Transparency ($M = 2.50$), Good Governance ($M = 2.50$), Financial Support and Funding ($M = 2.50$), Documentation and Reporting/Customer Service ($M = 2.30$), Integration with Supply Chain Systems ($M = 2.20$), Cyber Security ($M = 1.90$), and Automation ($M = 1.40$) indicate that respondents perceive weaknesses in digital transformation, governance, technological infrastructure, and automation. Overall, the findings suggest that while the port has developed strong operational capabilities, safety measures, and regulatory compliance, significant improvements are required in digital technologies, cyber security, governance, customer service, automation, and supply chain integration to achieve a modern smart-port environment.

Overall Agreement ^{a,b}						
	Kappa	Asymptotic			Asymptotic 95% Confidence Interval	
Overall Agreement	.285	.009	31.327	<.001	.267	.303
a. Sample data contains 26 effective determinates and 17 raters.						
b. Rating category values are case sensitive.						

Table Interpretation

Statistic	Value	Interpretation
Kappa	0.285	Fair agreement
Standard Error	0.009	Very small standard error, indicating a precise estimate
z-value	31.327	Strong evidence that agreement exceeds chance
p-value	< 0.001	Agreement is statistically significant
95% Confidence Interval	0.267–0.303	The true population Kappa is likely within this range

The inter-rater reliability analysis produced an overall Fleiss' Kappa coefficient of 0.285, indicating fair agreement among the 17 expert raters who evaluated the 26 subjects. According to the commonly used benchmarks proposed by Landis and Koch (1977). The obtained Kappa value of 0.285 falls within the fair agreement category. This suggests that although the raters agreed more often than would be expected by chance, there was still considerable variation in their assessments. The z-statistic of 31.327 with a p-value less than 0.001 indicates that the observed agreement is statistically significant, meaning the agreement among raters is substantially greater than chance alone. Furthermore, the 95% confidence interval (0.267–0.303) is relatively narrow, indicating that the estimated Kappa is precise and stable across the sample.

Kappa Value	Interpretation
< 0.00	Poor
0.00–0.20	Slight
0.21–0.40	Fair
0.41–0.60	Moderate
0.61–0.80	Substantial
0.81–1.00	Almost perfect

Reliability Interpretation

The results indicate that the ratings exhibit statistically significant but only fair inter-rater reliability. The low-to-moderate level of agreement suggests that respondents from different stakeholder groups may have differing perceptions of the determinants of port standards and performance. This is not unusual in studies involving diverse experts (e.g., port authorities, shipping companies, government officials, academics, and logistics professionals), as each group may evaluate port performance from its own professional perspective as per their choice. The inter-rater reliability of the assessment was evaluated using Fleiss' Kappa because the study involved multiple raters (17 raters) evaluating the same set of subjects (26 effective subjects). The analysis produced an overall Kappa coefficient of 0.285, indicating fair agreement among the raters based on the classification of Landis and Koch (1977). The agreement was statistically significant ($z = 31.327$, $p < 0.001$), demonstrating that the level of agreement exceeded what would be expected by chance. The narrow 95% confidence interval (0.267–0.303) suggests that the estimate is moderately stable and reliable. Although the agreement among raters is statistically significant, the relatively low Kappa value indicates differences in perceptions among stakeholder groups, reflecting the diversity of expertise and professional backgrounds represented in the study. Consequently, while the ratings provide meaningful evidence for evaluating port standards and performance, the findings should be interpreted with consideration of the variability in stakeholder opinions. Respondents/port users and service provider sometime do not fully understand the determinants and that's why they response casually.

Findings

The findings indicate that although the port performs well in core operational activities such as container and cargo handling, safety, security, and infrastructure management, several critical weaknesses continue to hinder overall port standard and performance. These problems affect operational efficiency, customers/port users' satisfaction, and the port's competitiveness in international trade. However, after completion of ongoing development project related to infrastructures, port efficiency and port user satisfaction will improve intensely. The excellent performance in container handling reflects the availability of appropriate container and cargo-handling equipment, effective terminal operations, and a skilled workforce capable of managing increasing container traffic. This excellent result on basic and conventional security suggests that respondents have a very high level of confidence in the port's basic security measures and their efficacy in safeguarding port facilities, cargo, vessels, personnel, and other critical assets.

The findings indicate that safety is integrated into the port's daily operations through compliance with established safety standards and continuous monitoring of operational activities. The findings indicate that employees and stakeholders believe the port provides a relatively fair working environment through the application of

labour standards related to wages, working hours, occupational health and safety, and employee welfare. The very good rating suggests that the port has effective mechanisms in place to ensure compliance with relevant regulations related to port operations, container and cargo handling, cargo management, safety, security, and environmental protection. The positive assessment of resource optimization reflects the port's capability to allocate labour, equipment, and infrastructure resources in a manner that supports cargo handling, vessel operations, and terminal activities. The rating compared with the highest-performing dimensions suggests that the port can enhance resource optimization through the adoption of advanced planning systems, predictive maintenance of equipment, data-driven resource allocation, and greater use of digital and smart technologies [47,48].

The findings also indicate that, the absence of fully digitization and automated systems increases cargo handling time, reduces operational efficiency, raises labor costs, and increases the likelihood of human error. However limited digitization and semi-automated systems make easier for monitoring and operations. Limited investment in cyber security infrastructure exposes the port to cyber-attacks, data breaches, and operational disruptions. After automation of the port the investment in this sector will be enhanced and will improve the performance. The low score for supply chain integration suggests inadequate coordination between the port, shipping lines, customs authorities, freight forwarders, transport operators, and warehouse managers. Poor information sharing results in delays, increased logistics costs, and inefficient cargo movement. City and metropolitan discipline, ecosystem, practice hamper supply chain integration. Fully digitization and automation system can help in this regard. The findings indicate that the paper-based documentation, lengthy approval processes, and insufficient customer support contribute to cargo clearance delays and reduce stakeholders' satisfaction. Fully digitization and automation, mindset of port users, service providers, professionals, and others as well as cooperations among the stake holders can enhanced the performance.

The relatively low ratings for accountability, responsibility, transparency, and good governance indicate concerns regarding administrative efficiency and decision-making processes, along with other sector's status (nation discipline, punctuality, law acceptance mindset) not found at global standard. So, port along cannot achieve global standard with help of related sector's upgradation. The findings indicate that weak governance may reduce stakeholder confidence and create opportunities for delays and inefficiencies. This indicates that respondents have concerns regarding transparency in administrative processes, clarity of responsibilities among different port-related organizations, and the effectiveness of institutional coordination. Inadequate funding and financial support slow the implementation of modernization initiatives including digitization and automation, which is essential elements to improve port performance. Foreign direct investment (FDI) is must to develop the infrastructure, modern port facilities, and others.

The findings also indicate that inefficient gate operations contribute to truck congestion, long waiting times, and delays in cargo delivery. Implementation of fully digitization and automation can enhance the system. Weak coordination between port operations and inland transportation networks further reduces logistics efficiency. River navigability, maintenance, dressing, and discipline in inland waterways need to improve. The findings indicate that the absence of comprehensive real-time monitoring systems with

smart technology limits the port's ability to track cargo, equipment, vessel movements, and operational performance. Implementation of fully digitization and automation can improve the system distinctly [18-19,23-26,29]. Now port has lack of integrated digital and automated platforms and has constrain to prevents seamless information exchange among port users and stakeholders. After fully digitization, automation implementation along with smart technology inclusion, the overall operational and management efficiency will improve dramatically [47,48]. The relatively low score for berth allocation indicates scheduling inefficiencies that may lead to vessel waiting time, berth congestion, and lower utilization of available facilities. Other expansion plan of port facilities when come to use (Mathr Bari, Bay Terminal, Laldia, etc.). This problem will automatically solve. After the successful implementation of all on-going port expansion plan, port facilities and service will enhance exponentially.

Recommendation for Chattogram Port Based on Survey

The results of Chattogram port assessment suggest that the principal challenges facing port standard and performance are associated with digital transformation, smart technology inclusion, good governance, technological infrastructure adaptation, modernization of equipment, and stakeholder integration rather than traditional operational activities. While respondents rated container handling, safety, regulatory compliance, and infrastructure management highly appreciated. On the other hand, deficiencies in automation, fully digitization, cyber security, supply chain integration, customer service, and governance continue to limit the port's overall efficiency and competitiveness. The completion of ongoing infrastructure and port facility enhancement projects and future port development strategic plan will solve many constrains and problems. Overcoming the performance barriers at Chattogram Port requires a combination of infrastructure investment, operational reform, digitalization, smart technology inclusion and better governance. The port development strategic plan needs to apply in Bangladesh, where Chattogram Port is vibrant in leading this, because of its financial strength and long-time experience in port management. This research reports consistently identify the following priorities to improve port performance, management should prioritize.

Higher crane productivity and better yard management reduce vessel turnaround time. Modern and AI operated/digital ship-to-shore cranes, smart rubber-tired gantry cranes (RTGs), automated stacking systems, better berth allocation software, and predictive maintenance for equipment, foreign investments and integrated expertise initiative will improve the containers and cargo handling performance. And that can reduce ship waiting time and improve cargo/container management efficiency. Smart-port technologies can improve operational and monitoring efficiency. Recent initiatives (digital/semi-automation) indicate progress toward more paperless and real-time operations. Establish a Comprehensive Cyber Security Framework is essential. Full automation and digitization can reduce the likelihood of cyber-attacks and unauthorized access. Chattogram port may focus on adopting an internationally recognized cyber security framework, such as ISO/IEC 27001 or the NIST Cyber security Framework, to guide information security governance and risk management. It could review user accounts regularly and promptly remove inactive or unauthorized accounts. It needs to implement centralized log management and a Security Information and Event Management (SIEM) solution, providing Cyber Security Awareness training include phishing simulations and role-specific security training for personnel handling critical systems. Online methods might

be introduced in the operations of the port and customs house in place of the present manual or semi-digital/automated system. This would lead to enhanced coordination between the customs and port authorities. Fully online banking facilities may be deployed to reduce hassles faced by importers, exporters, and other port service receivers.

Chattogram port need to focus on developing integrated digital or automated port community systems. A committee might be formed comprising of service recipients, service-providers and specialists; the number of layers for import and export might be reduced on the basis of its recommendations. It needs to be improved documentation and customer service processes. However, port service takers can assess and raise their requirement. The auditing function in the port and customs need to be strengthened. Joint auditing ventures need to be undertaken for observing the present state of those commodities, which have not been released despite noting in the bill of entry or where duties have not been realized despite their imposition, or where noting has not been done at all. It can give importance on enhancing transparency and governance practices. Accelerate mega-projects including the Bay Terminal and Matarbari Deep Sea Port to handle larger vessels (Panamax/post-Panamax) and which can increase volumes projected through 2040. Fully deploy the Bangladesh Single Window to merge regulatory activities of multiple agencies and cut clearance paperwork. There is a scope to improve better inter-ministerial synchronization between customs, port authorities, and transport providers. Partner with global operators (like DP World, AP Moller-Maersk, PSA, Gate Sea World, etc.) for advanced logistics infrastructure and terminal management might be chosen to attract foreign investment and for enhance performance, better port operation and competitions among different terminals.

Challenges and Suggestions of Bangladesh Sea Port to Implement Smart Technology

Bangladesh ports particularly CPA are under increasing pressure to manage growing cargo volumes, meet customer desires and demands for faster turnaround, along with comply with firmer environmental and ecological global mandates and standard [90]. The mixture of mechanical and manual systems in Bangladesh Ports straddling berth allocation, customs clearance, cargo documentation and minimum introduction of automation has ingrained inadequacies in Bangladesh's maritime logistics chain [91]. Problem like container congestion in port yards and a lack of multimodal hinterland connectivity are the main challenges of local port operation and achieve efficiency. Additionally, there is an absence of carbon emissions monitoring, sound observation, digital safety compliance, and maritime cybersecurity frameworks, making the major ports at a disadvantage in the evolving ESG-driven global trade environment [83]. Unlike leading global ports that operate digital dashboards, digital-twin, IoTs, and AI (very recently) for cargo tracking, monitoring, and automated customs synchronization, Chittagong or Mongla ports relies on paper-based workflows that delay processing times, create hinderance, and reduce supply chain perceptibility. These studies suggest that the lack of digital and smart technology integration not only limits port throughput capacity but also increases operating time and costs by up to 10 to 20% due to duplication, inaccuracy, inefficiency, time delay and repetition of work/task [92]. The COVID-19 pandemic highlighted and demonstrated the importance of digital and smart readiness in maintaining supply chain continuity, and shown the requirement of digitization and smart technology inclusion initiatives in the port operation and maritime trade management [93]. The absence of emissions dashboards and energy efficiency

programs in Bangladesh sea ports increases its susceptibility to carbon-border regulations and ESG-driven trade sanctions [83]. Bangladesh ports particularly CPA need to invest or to develop alternative plan in automation, digital twins, AI or ML-driven analytics, IoTs solutions to increase operational suppleness, ease of decision making, improve service, perceptibility and accountability. However, CPA has improved its operational capability and enhanced its performance.

Bangladesh ports particularly CPA continues to rely on human-operated cranes with some exception (semi-automation has found in very recent time), almost manual yard planning, lack of digitization and inclusion of smart technology limiting local port's capacity and efficiency to meet international shipping standards and operational performances [94]. Bangladesh ports IT architecture is not sufficiently connected (there are complain of disjointness), lacking interoperability across terminals, customs, stake-holders, road and rail transport. This disintegration obstructs data-driven coordination, compilation, joint-coordinated effort and which creates cybersecurity weaknesses. Bangladesh as developing nations is facing frequent many constraints like limited financing, skills gaps, scrawny institutional mandates, and lack of stakeholder public-private orientation, honesty, attitude, and many more [95]. However, PPPs model, multilateral funding, donor-led digital transformation programs like ADB and World Bank initiatives are also found easy, rather complicated to overcoming these barricades [85]. However, incremental adoption, tailored to local operational culture and regulatory capacity, is more sustainable than wholesale technology imports. The digital maturity of Bangladesh ports particularly CPA and MPA remains in its initial stages [96]. Digital and smart port systems are mainly limited to basic container tracking, automated emails for berth scheduling and some extend to pilotage and navigation system [91]. Integrated operational dashboards, PCS, and port-wide ERP systems need to be introduced and should be considered as necessity. Additionally, Bangladesh Ports have an urgent need for policy-operational alignment in line with climate adaptation, trade competitiveness goals and balanced ecosystem provision to fulfil the SDG goals.

The official environment surrounding Bangladeshi ports is manifest by little uneven authority, unclear digital mandates, and insufficient investment in digital and smart capacity-building and that need to be solved carefully [92]. Recently, Bangladesh has piloted IoT for tracking and tested blockchain in customs declarations, and these efforts are not always inaccessible and lack continuity due to insufficient legal frameworks, intention, and funding mechanisms; it was a good effort anyway [85]. Today the merging of smart technologies forms the core of modern ports

functionality. Bangladesh ports particularly CPA can take the help and adopt digital twins to enable simulation of port operations for scenario planning, energy efficiency modeling and ease of monitoring the port activities and quick decision-making. Superiority or quantum computing and 5G supported communication for automated guided vehicles (AGVs) and modern port cranes can contribute tremendously [13,97,98]. CPA and MPA can introduce IoT devices and which can allow real-time tracking of cargo, equipment status, and environmental metrics like noise and emissions and that can fulfil the requirement of global port standard in respect of environment and ecological balanced [27,48,99]. Finally, AI facilitates berth planning, container yard optimization, and predictive maintenance through ML or DL algorithms, Blockchain can be used for secure, tamper-proof

documentation in customs, bills of lading, and trade finance and that can ensure transparency and accountability [18, 26,93,100]. As we know that, PCS and TOS act as crucial in synchronizing real-time communication among relevant stakeholders like customs, port authorities, freight forwarders, shipping agent, off-dock owners, and shipping lines. In Bangladesh, the absence of a national PCS has led to duplicated documentation, conflicting cargo schedules, along with limited customer satisfaction and a lack of synchronized customs clearance [101]. Globally, PCS implementation has been linked to a 25–40% reduction in dwell times and enhanced revenue transparency, accountability, security and effective customer service [102]. CPA and MPA need to integrate effective PCS and TOS as early possible.

Bangladesh government need to establish a National Smart Port Governance Authority under the Ministry of Shipping (MOS) to coordinate inter-agency digital initiatives and policy implementation to adopt smart technology. Integrate port digitalization with predominant national development frameworks with long term vision and the national climate strategy. Bangladesh needs to formulate contemporary regulation and enact digital and smart legislation to streamline regulatory mandates, reduce institutional overlaps, and ratify cross-agency accountability mechanisms. Organize and implement standardized Port Community Systems (PCS) and Terminal Operating Systems (TOS) with interoperable, scalable architecture across all three sea ports including selected inland ports. Authority needs to ensure seamless cross-platform data exchange, transparency, and interoperability. Authority needs to develop and enforce a maritime cybersecurity framework aligned with IMO MSC.428(98) to ensure secure data handling, resilience, and auditability. MOS need to organize and launch a Port Cyber Resilience Taskforce to oversee threat monitoring, incident response, digital vendor certification, cybersecurity audits [83]. Bangladesh ports need to digital infrastructure and interoperability directive to the use of open APIs and middleware protocols to ensure seamless cross-platform exchange, transparency and accountability. Develop, organize and inclusion of digital literacy and training programs for port workers, operators, planners, professionals, customs officials, government official, and freight operators through national maritime academies and relevant institutions. Government needs to implement tax incentives and targeted grants for SMEs, related organizations, and logistics operators to adopting digital and smart technologies like AI, ML, Big-data, Digital-twin, IoT, etc. in port operations [102]. Bangladesh sea ports need to introduce AI or IoT-based emission tracking systems and environmental dashboards to baseline, monitor, and report on carbon, noise, and energy footprints to maintaining ecological balance. Bangladesh sea ports need to ensure link ESG compliance to port concession licenses, public-private investment eligibility, and SDG-related performance metrics [103]. MOS and local sea ports need to invest in applied research and technology pilot programs in collaboration both with local institutions (BMU, Bori, BUET, DU, etc.) and with global institutions (like MIT CTL, UNCTAD, ESCAP) [104–109]. Leverage South-South and South-East cooperation to adapt successful smart port models from China, Singapore, UAE, India, Vietnam, and Indonesia to Bangladesh's socio-economic and governance [83].

Limitations of the Research and Acknowledgement Limitations and Future Research

This study has certain limitations. First, data were collected cross-sectional from different stakeholders at Chattogram seaport. A longitudinal study involving data collection from various sources

would provide deeper insights and broader generalizability. The focus group were not much interested to provide information as most of the respondents are not well aware of the actual performance standard of the Chattogram sea port and the performance of it. Second, the study focuses solely on one seaport. Investigating the same issues at other seaports would help generalize the factors causing congestion. Third, the sample selection could be expanded to include other seaport management teams and use focus groups to explore the sources of congestion from a management perspective. Triangulating these arguments would provide a more comprehensive view of the realities related to congestion at Chattogram seaport. Selection of very few interviews, participants, FGDs of port users, service providers, different stakeholders and small number of local and foreign expert is considered a limitation. To get the accurate and perfect result it needs genuine and elaborate quantitative assessment. No fund allocation and no big team of data collection and other support was limited in nature to get the in depth and real observation of the Chattogram port. As this port is very busy and diversified stakeholders who are not ready to give the actual pictures and views in general. During data collection, cooperation from them was minimum and it is always a constrain. At future a project may be taken with some funds and group of dedicated researchers and information collectors and which can evaluate the real status and consequence of these issues. Additionally, future research should explore the sustainability of seaports concerning the triple bottom-line paradigm.

Acknowledgement Statement

The authors would like to give thanks and regards to all participants (Focus Group Discussion; FGD, internal port users, port service takers, workers, government officials, foreign experts, shipping lines, and service providers) who helped a lot in depth discussion. However, from their observations, views, opinions, and the experts' suggestions both from national and from international, authors are highly boosted and recognized their contributions and helps significantly. The different stakeholders related to port survey, who provided different information, data and opinions has contributed a lot to survey the status and performance of this busy major port of nation and which help to depicts the overall scenario and the performance of Chattogram Port as well as maritime sector of Bangladesh. We appreciate everybody and we feel highly blessed.

Conclusion

Ports serve as the backbone of economic growth, maintaining the global supply chain and assisting in worldwide connectivity. Broader expansion projects of container hubs mirror macroeconomic shifts like offshoring and localized industrial transformations. A massive digital renaissance called 'smart ports' is paving the way for sixth-generation ports which are capable of handling much larger fleets. Maritime operations have a highly repetitive nature and generate vast pools of historical and real-time data. Thus, advanced technology like AI, ML, DL etc. are being leveraged to introduce automation in vehicle locomotion and administration. These technologies also support a specialized function called berth management, which is an important as vessels are moving towards a sustainable future. AI is a critical technology; hence its incorporation must come with appropriate insights about it along with comprehensive workforce training. Adequate training and strategic implementation are required to obtain maximum effectiveness from this technology. The pioneers in this regard are notable maritime hubs like Shanghai and Singapore which have been certified by the United Nations as well. Moreover, for enhancing security while minimizing carbon footprints, the Port of New York and New Jersey, with a five-year strategy, and the

Port of Hamburg have adopted strategies to implement AI and ML respectively into their operations. The logistical mechanism can be streamlined with the use of AI, with ETA forecasting being a prime instance. Refining vessel arrival times can reduce vessel holding periods and improve port congestion, with aerial imagery also playing a role.

In near future as sea ports embrace AI more, the industry will likely evolve into a highly automated, data-driven ecosystem where operational efficiency, safety, and sustainability are enhanced by smart technologies. AI will become a cornerstone of future port operations, but human oversight and domain expertise will remain critical, predominantly in managing complex and unpredictable scenarios. Sea ports heavily influence international trade, specifically 80% by volume and 70% by value, and also ensure national security while being the virtual cornerstone of the blue economy. Nowadays, the aforementioned smart ports leverage AI, ML, digital twins and blockchain technology to enhance reliability, efficiency, traceability and stakeholder trust, thus optimizing almost every arena of port operations. Every facet of port administration has the potential to be refined by modern technology-from automating heavy machinery, proper berth scheduling to equipment maintenance and workforce management and training. Financial and administrative concerns are no longer the limit for smart ports as these advanced hubs champion sustainability by introducing renewable energy alternatives and eco-friendly procedures, keeping the marine ecosystem and carbon footprint in mind. Smart ports eagerly adopt newer, streamlined technologies which suggests a keen interest for innovation. The biggest concern regarding the introduction of AI is the severe vulnerabilities regarding cybersecurity. This sector is especially sensitive as any kind of cyberattack on essential systems like power grids can create a ripple effect across the global economy. For securing its competitive edge and supporting national stability, Bangladesh must embrace these security challenges and heavily invest in automation, AI-monitoring and resilient infrastructure. In this way, Bangladesh can hoist its long-term economic stability on the international stage. Smart port technology is now to be adopted in the Bangladeshi sea ports as a global requirement. The full smart ports system focuses on the technical aspects of the modern seaport ecosystem and specifically analyzes the sea port and ensure smart port implementation. This transformation enables a more transparent and efficient processing of port operations, including integrated port management, digitization and adaptation of smart technologies. All this ultimately helps to improve overall efficiency, reduce the cost of transport, ease of operation, ensure security, and promote environmentally sustainable and resilient port activities with highest safety. The transition to smart ports of Bangladesh involves dealing with numerous challenges like the digital gap, lack of professional manpower, and limited investment resources and requires a thorough understanding of related technologies and available technical options along with an accurate diagnosis of the current status.

The study found that, despite the port's efficiency, strong internal infrastructure and equipment are costly for international maritime trade, due to changing communications systems and the need to apply automation and digital technology fully. This high cost is affecting our daily life, as Bangladesh is heavily dependent on imports. Port authorities need to work closely with customs officials and labour unions to streamline operations and enhance port capacity through investments in equipment and infrastructure. In the era of technology, information technology can facilitate ship movements and cargo handling at ports. Investing in information

technology benefits seaports in multiple ways, aiding both freight forwarders and customers. Enhanced use of information technology reduces the undue influence of customs officials and limits labor union manipulation. By strengthening the role of information technology, perceptions of seaport congestion can be significantly reduced. The port of Chattogram has not been able to reach the world due to geopolitical reasons, which is a unique example for the region but, if used properly, it can become a valuable asset and act as a Hub for South Asia. For this, it is necessary to keep the port of Chattogram in a safe position and feed it container and cargo to upgrade it as a regional port, irrespective of the country boundaries. To improve Chattogram Port and follow the findings and analysis in this paper, it is essential to enhance capacity, efficiency, and productivity by deploying modern communication technology, digital and smart technology inclusion, and intermodal freight transportation systems, by establishing inland ports like rail ICD, dry port, RIC, and inland transport infrastructures, by increasing annual budget allocation for port development, and through the use of smart technology. However, the ongoing initiative of port facilities expansion plan, infrastructure development and attitude to inclusion of digitization and smart technology inclusion will improve overall situation and performance of Chattogram Port within a short time in very near future.

Owing to its large, untapped blue economy, Bangladesh is in an advantageous position when compared to landlocked countries. After securing its due maritime territory after triumphing in border disputes with Myanmar (March 14, 2012) and India (June 7, 2014), Bangladesh now has sovereign rights over its territorial waters. Robust maritime security and resource exploitation are necessary to harness the full potential of Bangladesh's resourceful sea. And an opportune sea port like the Bay Terminal and a deep-sea port like Matar-Bari will be beneficial for such activities. In the 21st century, naval power is paramount to securing these maritime economic hubs, for which the Bangladesh Navy needs to increase naval presence around existing and future maritime projects. For providing Bangladesh with a critical geostrategic leverage in regional trade with its neighbors and the Middle East, deep-sea ports need to be coupled with proper infrastructure like link roads, modern telecommunications etc. More than 100-billion-dollars of trade circulate through small feeder vessels, effectively compelling Bangladesh to spend more on imported goods as secondary, which ultimately causes mother-vessels to increase financial costs and waste more time. The operationalization of Matar-Bari deep-sea port and Bay Terminal will address these bottlenecks by accommodating deep-draft mother vessels which will drastically reduce import and export related expenses. In addition, this maritime achievement will standardize the living quality of people by accelerating macroeconomic growth, generating employment and modernizing local communication networks. So, the successful development of the present and future port projects, smart operation, efficient port management and strategic decision of the government can bring the best output with regards to national economic growth. The government needs to complete these two strategic mega projects named as Matar-Bari Deep Sea Port and Bay Terminal quickly and convert those as smart ports to satisfy all necessary requirements for achieving the global standard in near future. Sea ports that have a clear data strategy in operation, invest in building in-house AI, ML, IoTs and Bog-data expertise and upskill their workforce will be better positioned to reap the benefits of AI. The maritime industry and trade are on the tip of a transformation, and those who act conclusively now will lead the way in shaping the future of global trade effectively. CPA and MPA need to accept and adopt smart

port system and technology as early as possible. It is not mere improvement, rather it is necessary. Bangladesh major sea ports need to complete quantitative assessment of AI, ML, IoT, Big-data and PCS/TOS'S technologies in improving port efficiency, cost savings, safety, security, cargo throughput and decision making. Local sea ports may explore blockchain integration for end-to-end customs transparency, trade documentation, digital trade finance for better service provide to the business and maritime trade people. Simulation-based port operations model may introduce to improve efficiency and cost effectiveness. Such model can provide and guide top management for predictive berth scheduling, real-time yard optimization, energy-efficient routing, ensure safety and security, saving cost.

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