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Improving Sustainability and Logistics at Chittagong Port: A Path Toward a Smart Shipping Hub

Asif Imran[1], Sheikh Adib Tazwar[3], Noufel Kabir[1], Tahmim Alam[2], Baria Jahan Era[1]
[1]Industrial and Production Engineering, Ahsanullah University of Science and Technology, Dhaka, Bangladesh.
[2]Mechanical Engineering, Ahsanullah University of Science and Technology, Dhaka, Bangladesh.
[3]Industrial and Production Engineering, Bangladesh University of Science and Technology, Dhaka, Bangladesh.
E-mail: asifimran024@gmail.com

Abstract:

With Chittagong Port handling over 90% of Bangladesh's international trade, the port serves as the backbone of the country's economy. Yet, it is facing mounting challenges due to rising trade volumes, inefficient logistics, and severe environmental issues. As global trade grows, these difficulties endanger the port's ability to continue operating as it already does and to handle future demands. The need for modernization is evident, particularly considering the trend toward more intelligent, automated, and environmentally friendly port operations on a worldwide scale.

The most recent advancements in port logistics and sustainable practices are examined in this study for their potential to help Chittagong Port become a smart shipping port. The study brings together recent research on port logistics, with an emphasis on the use of smart technologies like advanced robotics, automated guided vehicles (AGVs), and Internet of Things (IoT) systems, all of which have been shown to greatly increase operational efficiency, safety, and accuracy. In addition, the use of digital Port Community Systems (PCS) is highlighted as an essential step toward enhancing stakeholder engagement in port activities through better communication, reduced administrative burdens, and streamlined operations.

Sustainable environmental practices are yet another major focus of this study. Potential green port initiatives that may be implemented by Chittagong are explored in this study, including shore power facilities to reduce emissions from berthed vessels and the utilization of renewable energy sources for port operations, such as solar and wind power. These programs are considered essential for reducing the port's carbon footprint, bringing it into compliance with international sustainability goals, and improving the port's overall environmental effect.

The research also emphasizes how vital it is for the port's infrastructure to be built with climate resilience. The long-term operational viability of the port is dependent on investments being made in early warning systems, coastal fortifications, and infrastructure fortification considering the increasing dangers posed by climate change, which includes an increase in the frequency of extreme weather events and increasing sea levels.

Chittagong Port can overcome its existing difficulties and emerge as a pioneer in contemporary port administration by incorporating smart technologies, embracing digital transformation, putting sustainability measures into action, and embracing climate resilience methods. By strengthening the port's sustainability and efficiency, these upgrades will help Bangladesh achieve its larger environmental and economic objectives while also securing the port's place in the world's marine network. This document presents a comprehensive plan for the port's future, offering practical insights that are in line with global best practices for port sustainability and logistics.

Keywords: Logistics, Sustainability, Ports, Maritime industry, Supply chain.

1. Introduction:

Chittagong Port which is situated in Bangladesh's port city handles over 90% of Bangladesh's international trade, acting as the nation's primary marine gateway and playing a vital role in the economy. The port faces several difficulties despite playing such an important role, including traffic jams, deteriorating infrastructure, environmental problems, and ineffective logistical management. These issues endanger the port's capacity to function effectively, which is also threatened by larger threats to Bangladesh's economic development and environmental sustainability.

Key performance indicators (KPIs) for evaluating the efficiency of a seaport's logistics system in Bangladesh encompass a range of dimensions critical to port management. Research identifies several KPIs, including operational efficiency, financial performance, and security measures, which are essential for comprehensive performance assessment. Research that has already been done on sustainable supply chains points to potential advantages like lower carbon footprints, enhanced stakeholder connections, and better brand perception (Chowdhury et al., 2023). The development of integrated port logistics centers is highlighted as a significant factor in enhancing port performance, emphasizing the need for multi-modal capabilities and technological advancements (Ibrahim & Xuefeng, 2023). Furthermore, a study on public-private partnerships (PPPs) in port development identified 47 KPIs, focusing on sustainability and stakeholder engagement, which are crucial for long-term efficiency (Mathew, Nayar & Sathypal, 2023). A comprehensive performance measurement model for maritime logistics also suggests 19 indicators clustered into four principal factors: Port Performance, Shipping Connectivity, Hinterland Logistics, and Sustainability and Resilience (Sheikh, Chowdhury &Mahmud, 2023). These findings collectively underscore the multifaceted nature of port performance evaluation, necessitating a holistic approach to KPI selection and application in Bangladesh's maritime logistics context (Turcanu & Gasparotti, 2021).

There is a growing recognition of the necessity of transforming conventional ports into intelligent, sustainable maritime centers as the dynamics of global trade change. An eco-

friendly supply chain integrates ethical and ecologically responsible practices at every stage of the production, distribution, logistics, and sourcing phases. By using these tactics, businesses can save costs and increase service quality, paving the way for an increasingly secure and successful future. Recommerce supply networks exhibit great promise as a hybrid supply chain model with lean and agile features combined with the extra advantage of environmentally friendly and sustainable features (Holy, Mohammad & Revu, 2022). The combination of smart infrastructure and green technologies in harbors can make an important contribution to their effectiveness and sustainability. AI for instance plays a crucial role in optimizing fuel usage, energy management, and predictive maintenance; this reduces emissions as well as improving port operations effectiveness (Duelik et al., 2024). In addition, adopting policies of integrating ports may improve the efficiency of greens just like what is evidenced by the cases of nearby Zhejiang ports that have contributed to reducing carbon emissions (Liao, Hong & Han, 2024). The use of intelligent systems including digital twins and automated procedures also enhances effective planning and swift decision making to establish sustainable harbor environment (Toygar, 2024). However, these changes can be obstructed by some encountered challenges such as competition for resources or decentralized management (Zhang, Dai &Wang, 2024). All in all, combining AI with smart infrastructure and policy integration effectively would result into significant improvements in sustainability and efficiency in seaports. Automation, digital technology advancements, and green measures that improve port efficiency, reduce carbon footprints, and increase resilience to environmental changes are driving this revolution. In order to improve port operations' efficiency and environmental friendliness, the "smart port" idea combines cutting-edge technologies such as automated guided vehicles (AGVs), digital Port Community Systems (PCS), Internet of Things (IoT) systems, and renewable energy sources. Blockchain is still a new concept in supply chain but blockchain technology can significantly enhance supply chain management by providing transparency, traceability, and security (Haque et al.,2022).

It is imperative that Chittagong Port adopts these technologies to maintain its competitiveness and sustainability in the global market, according to recent studies on port logistics. For example, the implementation of automation and digitalization can efficiently address some of the port's most urgent logistical concerns by streamlining cargo processing, reducing delays, and improving supply chain visibility. It is also possible to significantly lessen the environmental effect of port operations and contribute to the achievement of global sustainability goals by implementing green port initiatives including shore power facilities and the integration of renewable energy. A research was done on circular economy where it is stated that the use of circular economy techniques has several potential advantages for both enterprises and society, such as less waste, enhanced resource efficiency, and the creation of jobs (Noha et al., 2023).

The objective of this article is to investigate and suggest feasible approaches for improving the sustainability and logistics of Chittagong Port. In addition to improving operational efficiency, the report offers a plan for turning Chittagong into a smart port that supports Bangladesh's long-term economic resilience and environmental responsibility by utilizing recent research and successful models from other international ports. By means of these endeavors, Chittagong Port may position itself as a frontrunner in the realm of sustainable marine commerce, equipped to meet the obstacles and grasp the prospects of the 21st century.

2. Literature Review:

Driven by the need to reduce environmental impact and maximize operational efficiency, the concept of transforming conventional ports into intelligent, sustainable hubs has attracted a lot of interest lately. To find tactics that could be used to improve Bangladesh's Chittagong Port, this literature analysis examines current port logistics research, with a focus on sustainability and the development of smart port technologies.

According to Heikkilä et al. (2022), adopting smart port technologies is crucial to maintain competitiveness in the world's shipping market. To improve operational efficiency and optimize logistics, smart ports must integrate automation and digital technologies. To enhance cargo handling procedures, research has highlighted the need of deploying automated technologies such as automated guided vehicles (AGVs), robotic container handlers, and automated stacking cranes. These technologies increase productivity while lowering the need for manual labor, lowering mistakes, and boosting security.

According to Zohaib, Nasir & Zaidi (2023), Port Community Systems (PCS) enhance port efficiency by improving data exchange, reducing congestion, and boosting trade operations, leading to increased trade throughput and economic growth. Ports must get digitalized to develop into smart hubs. Using Port Community Systems (PCS), which facilitate easy data sharing and communication between stakeholders like port authorities, shipping firms, and customs, is one of the main tactics. Supply chain visibility is increased, administrative workloads are reduced, and procedures like cargo tracking, vessel scheduling, and customs clearance are streamlined by digital PCS. According to Dinh et al. (2024), Port Community Systems (PCS) enhance port operation efficiency by utilizing AI for accurate ship stay predictions, reducing delays, and improving planning. The use of circular economy tactics, which aim to minimize waste and optimize resource utilization, can be achieved through the adoption of strategies such as food waste reduction, utilization of recyclable packaging, and food waste repurposing. IoT and AI are examples of cutting-edge technologies that characterize I5.0. It offers improved supply chain coordination, automation, and real-time data knowledge (Sikder et al., 2023).

Ports in the modern era are highly concerned about sustainability because of their enormous environmental impact. Various methods are used in this case to reduce pollution and enhance the efficiency of resources. According to Karagkouni and Boile (2024), Shore side electricity and alternative fuels amongst other green practices can be adopted by such ports to ensure compliance with regulatory requirements as well as stimulate competitive environmentally safe operations. According to Waluyo et al. (2024), by implementing these methods, the ecological effects of port activities may be minimized thereby promoting sustainable practices. In addition, Cunha et al. (2023), although some Brazilian ports have aligned their sustainability initiatives with international standards, there is still room for improvement in terms of communication and benchmarking. However, Zhou et al. (2023), there are many challenges that limit their success such as lack of cooperation among stakeholders and inadequate incentives for environmentally friendly programs. Generally, green port initiatives offer a viable approach to enhancing sustainability; however continuous monitoring and adjustment is required to narrow gaps existing in them to maximize benefits towards coastal communities they serve.

Climate change is making ports more vulnerable, as operations and infrastructure are threatened by harsh weather and rising sea levels. As such, port authorities have made increasing climate resilience their main priority. Improving infrastructure is essential for reducing the effects of climate change. Examples of this include bolstering coastal defenses and elevating important port facilities. Puig et al (2024), stated that some of the techniques that can be employed to increase the adaptability of the ports to changing climatic conditions include setting greenhouse gas (GHG) reduction objectives, offering onshore power supply (OPS), and introducing green fees. Collaboration and sustainability practices are essential factors needed for effective implementation

According to Kabir and Helal (2021), Inadequate infrastructure, antiquated machinery, ineffective labor practices, and corruption are among the main issues Chittagong Port faces. These issues affect the effectiveness of operations and cause congestion. While there is a strong global trend towards smart and sustainable ports, Chittagong Port faces particular difficulties because of its huge trade volumes and existing infrastructural constraints. According to Sen et al. (2021), Chittagong Port has difficulties because of inefficiencies that affect Bangladesh's supply chain. These issues cause delays, higher expenses, and disruptions in commerce, which calls for infrastructural upgrades for better operations.

In summary, the reviewed literature offers a detailed framework for advancing the sustainability and logistics of Chittagong Port. By adopting smart port technologies, digitalization, green initiatives, and climate resilience strategies, Chittagong Port can greatly enhance its operational efficiency and environmental performance, aligning with global best practices in port management.

3. Methodology

To turn Chittagong Port in Bangladesh into a smart shipping port, this study's methodology—which is described in depth in this section—investigated ideas for improving the port's sustainability and logistics. The structured methodology achieves the goals of the research, tests the hypotheses, and addresses the research issues in a methodical manner.

3.1 Research Question

How can Chittagong Port improve its sustainability and logistics by using smart port practices and technologies? is the main research topic of this study.

3.2 Hypothesis

According to the report, the operational effectiveness, environmental performance, and resilience of Chittagong Port will be significantly enhanced by the merging of smart port technologies with sustainability measures, putting it in compliance with international port management standards.

3.3 Research Design

A mixed-method research design that incorporates both qualitative and quantitative techniques is used in this study. The technical features of smart port technology, along with the logistical and environmental difficulties faced by Chittagong Port, are looked at closely by this method.

To develop workable methods for the port's modernization, a review of the literature, data collected via surveys and interviews, and a thematic analysis of the information acquired are comprised in the study framework.

3.4 Data Collection Method

There are two main stages to data collection:

Phase 1: Secondary Data Collection: A thorough analysis of current scholarly works, industry reports, and case studies is conducted on the topics of smart port technology, sustainable port operations, and logistics management. A good overview of the state of the field is provided by this review of the literature, and best practices that can be used by Chittagong Port are identified.

Phase 2: Primary Data Collection: Primary data is collected through surveys and semi-structured interviews with important parties, including port officials, shipping firms, logistics suppliers, and environmental specialists. Insight into the unique opportunities and problems faced by Chittagong Port is intended to be provided by these questionnaires and interviews, as well as an assessment of the viability of the suggested smart port initiatives.

3.5 Sampling Technique

The participants in the primary data gathering process are chosen using a purposive sampling technique. The sample is made up of people and institutions with a direct stake in Chittagong Port's operations or with knowledge of port sustainability and logistics. This approach guarantees that the information acquired is pertinent and provides insightful information about the unique circumstances of Chittagong Port.

3.6 Data Collection Procedure

The following steps are part of the data collection process:

a. Literature Review: A methodical search and evaluation of current works on smart port technology, sustainability programs, and port logistics.

b. Survey Distribution: To gather quantitative information on the opinions and experiences of chosen stakeholders regarding the state of port operations today and the possible benefits of smart port technologies, structured questionnaires are delivered to them.

c. Interviews: To acquire more in-depth qualitative understanding of the obstacles and possibilities for improving port logistics and sustainability, semi-structured interviews are carried out with a portion of survey respondents.

3.7 Questionnaire Design

The survey's design considers important facets of port operations, such as the state of logistics today, the effects it has on the environment, and opinions on smart technology. It is broken up into sections that assess:

Operational Efficiency: Inquiries concerning prospective automation areas, bottlenecks, and current logistics procedures.

Environmental Sustainability: Questions about energy use, perspectives on green port projects, and current environmental challenges.

Technology Adoption: This section includes questions that gauge stakeholders' interest in and readiness to use digital platforms, automation, and Internet of Things technologies.

3.8 Thematic Analysis

The qualitative information obtained through interviewing is subjected to thematic analysis. To find recurrent themes and patterns pertinent to the study issue, the data is coded. Some of the major themes include operational difficulties, technological barriers, environmental issues, and the possible advantages of smart port efforts. A deeper understanding of stakeholder viewpoints is provided by thematic analysis and the quantitative data is aided in contextualizing.

3.9 Integration of Design and Roadmap Development

The last phase of the process is entailed by the combining of the results of the surveys, thematic analysis, and literature study to produce a thorough roadmap for converting Chittagong Port into an intelligent and sustainable shipping hub. This plan is outlined by specific tactics and measures that are suited to the particular requirements and circumstances of Chittagong Port, including technological adoption, environmental initiatives, and infrastructure renovations.

The provided text in passive voice would be: It is ensured by this methodological framework that initiatives for improving Chittagong Port's sustainability and logistics will be identified and implemented in a comprehensive and efficient manner. Assistance is sought to be provided in the port's transition into a cutting-edge, intelligent facility that adheres to international best practices.

4. Results

Table 01. Challenges found from field research.

Challenges	Data/Findings
Congestion	- Delayed time schedule - Economic impact
Infrastructure Limitations	- Competitiveness with other ports - Cost of shipment compared to market price
Operational Inefficiencies	- Labor related issues - Lack of coordination - Ineffective vessel scheduling
Environmental and Weather Issues	- Sea-level rise and coastal erosion - Soil erosion and sedimentation - High humidity and saltwater corrosion
Logistics Bottlenecks	- Maintenance issues - Inefficient traffic management - Increased costs
Port Security	- Container theft and smuggling - Cyber security problems - Labor strikes - Piracy and maritime security - Terrorism
Insufficient human resource	- Number of bribe givers and receivers have increased - Illegal collection of tolls - Lack of skilled workers
Custom delays	- Bureaucratic procedures - Manual processing
Lack of modernization	- Workers slow adaptation to machines - Lack of digital transformation

Table 2. Problems

Dredging and Siltation Issues	- Frequent need for dredging due to siltation - Impact on navigation and berthing of larger vessels
Limited Container Storage	- Insufficient container storage space - Congestion in container yards, leading to delays
Inadequate Mainland Connectivity	- Poor and slow road and rail connections to inland areas - Increased transportation time and costs
Monsoon Season Disruptions	- Heavy rainfall causing operational slowdowns - Increased risk of flooding and damage to cargo
Dependence on Manual Processes	- Limited automation in cargo handling - Inefficiencies and errors due to manual documentation - Lack of Technological Integration

5. Discussion:

To turn Chittagong Port into a smart shipping port, this study looked for ways to improve the port's sustainability and logistics. In order to test the hypothesis that integrating smart port technologies and sustainability initiatives would significantly improve the port's operational efficiency, environmental performance, and resilience, the research addressed the following research question: How can Chittagong Port improve its sustainability and logistics through smart port technologies and practices?

5.1. Key Findings from the Literature Review

It was made clear by the literature analysis that smart port technology, such as automation, Internet of Things (IoT) systems, and Port Community Systems (PCS), has been successfully embraced by ports all around the world to increase operational effectiveness and reduce environmental impact. To improve Chittagong Port's productivity, affordability, and supply chain resilience for upcoming development plans, the literature research recommends implementing SCM principles, technology integration, and sustainability practices (Obasi, Oyakegha & Okuoyibo, 2024). In order to reduce accidents, the study emphasizes the value of operational risk management, maritime safety, and simulation training. It also suggests that these elements be carefully integrated into strategies for port growth and administration in the future (Ahmed et al., 2024). Significant improvements in safety, accuracy, and speed of cargo handling have been achieved by these technologies, which have helped reduce carbon

emissions through green practices like shore power and renewable energy integration. This theory is backed up by the data that suggests that Chittagong Port could similarly benefit from these technologies.

5.2. Analysis of Primary Data

The stakeholders of Chittagong Port were surveyed and interviewed, yielding primary data that provided valuable insights into the current issues and prospects of the port. Many important difficulties were brought up by the respondents, including traffic jams, cargo processing delays, and the sparse usage of digital technologies. Recurrent themes were revealed by the results of the thematic analysis, such as the need for improvements to the port's infrastructure, the possible benefits of automation, and the importance of environmental sustainability. The research hypothesis is supported by these results, which are aligned with the worldwide patterns mentioned in the literature review.

5.3. Challenges to Implementation

The study found several barriers to deploying smart port technologies at Chittagong Port, despite the possible benefits. In figure 1 and figure 2 the challenges and problems of the Chittagong port are shown. The current infrastructure is a significant obstacle because it is not entirely compatible with contemporary automated technologies. The financial and technical resources required for widespread technology adoption are also insufficient. To ensure successful implementation, the study also underlined how crucial it is to gain stakeholder support and how crucial it is to invest in training and capacity-building. It will take a comprehensive approach to tackle Chittagong Port's many obstacles. The authors Malau et al. (2023) have made important recommendations for the improvement of infrastructure and operational efficiency through targeted investments and maintenance. They underline the significance of encouraging collaborations and strengthening transport connectivity to promote competitiveness. Better information technology and equipment usage are notably needed to address congestion, as noted by Kabir and Helal (2021), who support a comprehensive strategy incorporating all stakeholders to improve port efficiency. Creating an integrated, multimodal freight transportation system is also essential. According to Saha et al. (2023), using river connectivity in conjunction with enhanced rail and road infrastructure can greatly reduce logistics bottlenecks and disruptions to the container supply chain. In addition to addressing operational inefficiencies, this integrated strategy improves mainland connectivity, thereby enhancing the sustainability and productivity of the port. By putting these tactics into practice, Chittagong Port will be able to overcome obstacles and enhance its general performance.

Optimizing dispatch techniques, cutting costs, lowering CO2 emissions, and guaranteeing consistent power system reactivity in the off-grid hybrid microgrid design are among the implementation problems in Chittagong port (Rayhan et al., 2023). To uncover these issues, it was essential that a research design combining qualitative and quantitative methodologies be used. The pertinence of the information gathered was guaranteed by the application of purposive sampling, which offered a comprehensive comprehension of the operating context of the port. A thorough investigation of stakeholders' perspectives was made possible by thematic analysis, which brought to light both their excitement for smart technologies and their reservations about their viability.

5.4. Integration of Design and Roadmap Development

Using the knowledge gathered from the primary data collection and literature study, a roadmap was developed to turn Chittagong Port into an intelligent and sustainable infrastructure. A staged approach is proposed by the roadmap that starts with modernizing the current infrastructure and gradually adds automated technology. In order to enhance coordination and communication among stakeholders, it is also recommended that a digital Port Community System (PCS) be put in place. The key to a successful integration of design and roadmap development for Chittagong Port is the economic and engineering elements used to calculate the requirements for cranes, capacity of container terminals, and jetties (Rahman, 2021). To lessen the port's environmental impact, green measures like shore power and renewable energy are suggested. This addresses environmental sustainability. In Chittagong Port design, inclusiveness of stakeholders, co-creation of values, adaptable design, and multidisciplinary cooperation for sustainable development are critical components of successful integration (Slinger et al., 2017). Policies, the encouragement of competition, the expansion of infrastructure, and the geographical analysis for the formation of logistics corridors all have an impact on the effective integration of design and roadmap development for Chittagong Port (Ibrahim & Xuefeng, 2023).

The roadmap also emphasizes how crucial public-private partnerships (PPPs) are to financing the necessary technological advancements and infrastructure upgrades. The strategy is aimed at guaranteeing that future trade demands can be met by Chittagong Port while promoting national economic growth and environmental sustainability through the coordination of these actions with the larger Smart Bangladesh Vision 2041.

5.5. Implications for Future Research:

The case study of Chittagong Port provided by this paper is contributed to the larger subject of port logistics and sustainability and can be used as a model for other emerging ports dealing with comparable problems. The social and economic ramifications of these changes, as well as the long-term repercussions of smart port technologies on port communities, may be investigated by future studies. Furthermore, insightful information about best practices and lessons discovered could be provided by comparing Chittagong Port with other ports that have effectively implemented smart technologies.

6. Conclusion

In summary, it has been demonstrated by this study how Chittagong Port's environmental performance and logistics might be significantly improved using smart port technologies and sustainability programs. Despite current implementation obstacles, a smart, sustainable marine hub may be achieved by the port with the help of a well-thought-out, phased approach backed by stakeholder involvement and capacity-building. In addition to increasing the port's operational effectiveness, these initiatives will contribute to the achievement of Bangladesh's larger goals of environmental protection and economic growth.

Chittagong Port, as the primary maritime gateway of Bangladesh, plays a crucial role in the nation's economy. However, the port faces numerous challenges that hinder its operational efficiency and sustainability, including congestion, infrastructure limitations, operational insufficiencies, environmental and weather-related issues, logistics bottlenecks, customs

delays, modernization needs, container storage constraints, dredging and siltation problems, and disruptions caused by the monsoon season. Addressing these challenges is imperative for the port to maintain its competitiveness and meet future demands.

This study examined several approaches to address these issues using smart port technologies, infrastructure modernization, and the adoption of sustainable behaviors. It has been determined that implementing automation and digitalization—such as Internet of Things (IoT) systems, Automated Guided Vehicles (AGVs), and Port Community Systems (PCS)—is crucial to increasing operational effectiveness, decreasing traffic, and simplifying logistics processes. Furthermore, including green efforts is essential to improving environmental sustainability and climate change resilience. Examples of these activities include the usage of shore power and renewable energy.

The results indicate that although there are still major obstacles to overcome, like the need for stakeholder support and infrastructural constraints, they can be lessened with a planned modernization strategy and the thoughtful application of smart technologies. Capacity-building programs and public-private partnerships (PPPs) are essential for making sure that the port's personnel are prepared to manage new technology and procedures.

In conclusion, Chittagong Port's transformation into a clever, sustainable, and effective maritime hub is not only doable, but also essential to its long-term prosperity. The port can strengthen its logistics capabilities, lessen its environmental effect, and maintain its position as a major participant in the world shipping network by tackling the difficulties that have been identified and implementing the suggested solutions. This change will help Bangladesh achieve its larger economic and environmental goals in addition to helping the port.

7. Figures and Charts

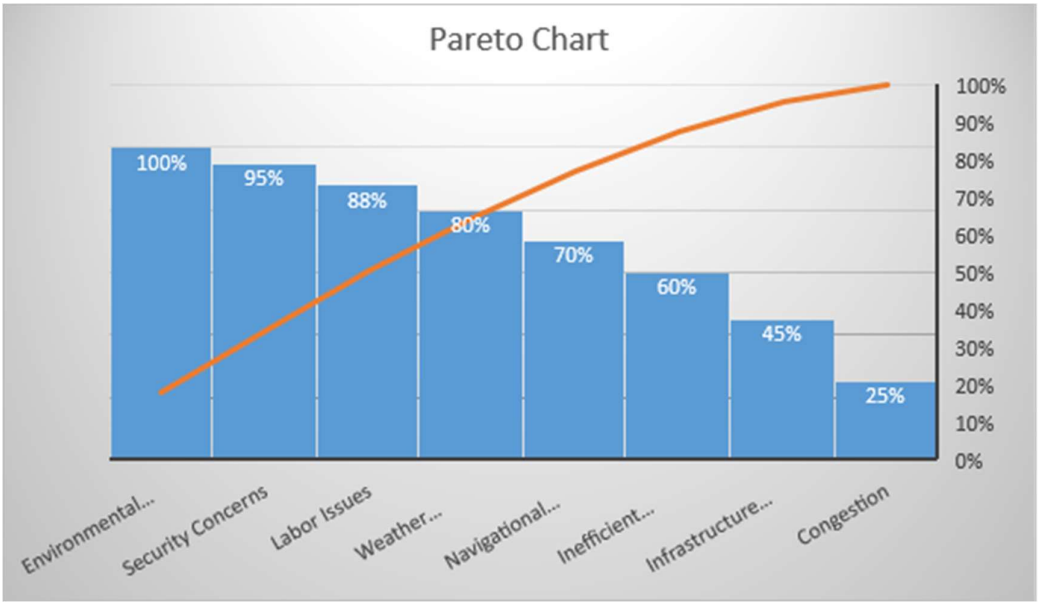

Figure 1. Pareto chart of the problems and challenges.

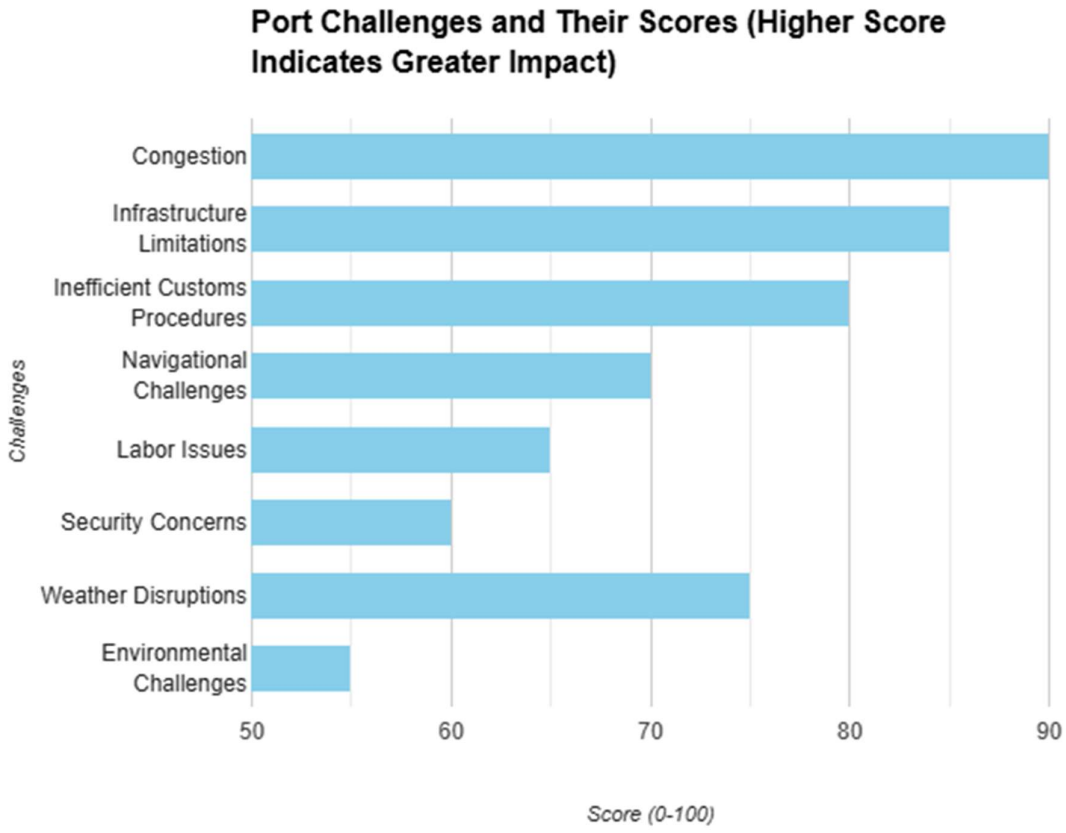

Figure 2. Port Challenges and their scores.

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