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Evaluating AI's Impact on Supply Chain Resilience and Disruption Recovery: The Case of Ghana Ports and Harbours Authority, Takoradi

Robert Tay (Ph.D)
Deputy Director (Head) Procurement & Stores
Drivers Vehicle Licensing Authority, Ghana)
ORCID: https://orcid.org/0009-0002-6680-7379
Email: bobtayy@gmail.com

**Correspondence: Robert Tay (Ph.D), email: bobtayy@gmail.com*

Abstract

The increasing frequency of global supply chain disruptions, driven by geopolitical tensions, pandemics, and climate-related shocks, has heightened the need for resilient and adaptive logistics systems. Artificial Intelligence (AI) is emerging as a transformative tool for enhancing supply chain resilience and recovery capabilities. This study evaluates the impact of AI on supply chain resilience and disruption recovery within the Ghana Ports and Harbours Authority (GPHA), Takoradi.

Specifically, it examines how AI-driven technologies—such as predictive analytics, real-time monitoring, automation, and decision-support systems—contribute to mitigating risks, improving operational efficiency, and accelerating recovery from disruptions. Using a mixed-methods approach, data will be collected through structured questionnaires, interviews with key port officials, and analysis of operational records.

The study seeks to establish the extent to which AI adoption enhances the port's ability to anticipate disruptions, optimize resource allocation, and maintain continuity of port services. Findings are expected to provide empirical insights into the role of AI in strengthening supply chain resilience in emerging economies, offering policy and managerial implications for GPHA and similar port authorities in Sub-Saharan Africa. Ultimately, the research contributes to the growing body of knowledge on digital transformation in supply chain management and its strategic role in ensuring sustainable port operations.

Keywords: *Artificial Intelligence (AI), Supply Chain Resilience, Disruption Recovery, Predictive Analytics, Real-Time Monitoring, Automation*

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1.0 INTRODUCTION

The global shipping industry is undeniably the backbone of international trade, handling a staggering 90% of everything bought and sold across borders (UNCTAD, 2022). This massive volume shows just how essential maritime transport is for linking countries, powering global supply chains, and supporting livelihoods around the world. Within this complex network, harbors aren't just stopping points; they're crucial bottlenecks and vital economic hubs, especially for developing nations. In countries like Ghana, maritime resources particularly important harbors like Takoradi, managed by the Ghana Ports and Harbours Authority (GPHA) are fundamental for economic progress, making trade easier, and boosting regional growth (GPHA Annual Report, 2023). However, these maritime gateways function directly impacts a nation's wealth, influencing everything from the price of imports to how competitive its exports are.

However, today's shipping and harbor operations are facing growing and widespread problems. These challenges come from many sources, both internal and external. Internally, things like inefficient cargo handling, outdated paperwork, and poorly maintained facilities can

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really slow things down. Externally, the threats are even more varied and unpredictable, ranging from more frequent and intense extreme weather (like hurricanes and tsunamis) caused by climate change, to global health scares like COVID-19, sophisticated cyberattacks targeting important harbor systems, and unstable political situations that can disrupt shipping routes and trade deals (Ivanov & Dolgui, 2021). The recent problems in the Red Sea, for example, highlight how easily global shipping routes can be affected by regional conflicts, forcing costly detours and showing how closely maritime security is tied to broader global stability (Petersen & Chen, 2024). Similarly, the ongoing effects of the conflict in Ukraine continue to demonstrate how geopolitical events outside of maritime affairs can trigger major disruptions to maritime supply chains, affecting the flow of goods and shipping insurance costs (Maritime Intelligence Group, 2023).

These increasing uncertainties seriously challenge how the supply chain can bounce back from problems, turning maritime risk management from a simple operational matter into a strategic necessity of national and international importance. Being resilient here means that the shipping supply chain can anticipate problems, cope with them, adapt, and quickly recover from disruptions, minimizing the damage and keeping things running smoothly (Pettit et al., 2010) Without strong risk management and resilience plans, harbors and their related supply chains are at risk of complete failures, leading to significant financial losses, damage to their reputation, and even humanitarian crises if essential goods are affected.

Someone might argue that this "crisis upon crisis" idea is a bit exaggerated. Maybe older shipping systems, despite not having the latest technology, were quite resilient because they had backups, people were adaptable, and global dependencies were less interconnected. Could it be that our current technological solutions, while making things more efficient, are also creating new, more complex weaknesses (like single points of failure in highly connected digital systems, vulnerability to new types of cyberattacks) that didn't exist in simpler times? This suggests we should be careful and make sure that technological advancements improve the situation, rather than just changing where the risks are.

2.0 MATERIALS AND METHODS

2.1 Conceptualizing Maritime Risk in the Digital Age

Due to its intrinsic complexity and dynamic nature, the maritime realm is constantly at risk, endangering the efficiency and continuity of international trade. The first step in managing these risks effectively and building resilience is understanding them. The traditional risk environment has grown in the digital age, taking into account new vulnerabilities brought about by improved connectivity and technological breakthroughs.

2.1.2 Risk Profiles of African Ports: Unique Systemic Vulnerabilities

Particularly in Africa, ports in emerging countries frequently have distinct systemic vulnerabilities that set their risk profiles apart from those of their counterparts in more developed areas. African ports usually face extra levels of complexity, even while global dangers like harsh weather and cyber threats are universal:

Infrastructure Gaps: Inadequate capacity, outdated infrastructure, and a lack of investment in digital backbone and modern equipment plague many African ports. Bottlenecks, longer turnaround times, and heightened vulnerability to operational failures can result from this [cite: Alyami, 2017].

Bureaucratic Inefficiencies: Several levels of regulatory monitoring combined with intricate and frequently opaque administrative procedures can cause major delays and raise the possibility of corruption or human mistake, which increases operational risks.

Inadequate Contingency Protocols: While some ports may have basic emergency plans, the depth and sophistication of contingency protocols for major disruptions (e.g., large-scale cyber-attacks, prolonged civil unrest) may be limited, leading to prolonged recovery times.

Reliance on Non-Automated Systems: According to research by Oluwaferanmi (2025), Takoradi and other Ghanaian ports continue to be extremely vulnerable to "non-automated risk handling systems." For crucial tasks like cargo inspection, vessel tracking, and risk assessment, this involves a strong reliance on human expertise, manual oversight, and paperbased procedures. Scalability, real-time visibility, and the capacity to handle complicated data for predictive insights are all inevitably constrained by such reliance.

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Economic and Geopolitical Factors: In addition to operational and infrastructure problems, African ports are frequently more vulnerable to regional geopolitical instabilities (such as piracy, civil wars, and fluctuations in commodity prices) and wider economic volatility (such as fluctuations in foreign exchange rates and commodity prices), which can have a direct effect on trade volumes and port security. Additionally, their lack of connection into international digital ecosystems may keep them off from cooperative risk reduction projects and best practices. A customized strategy that takes into account the distinct socioeconomic and political circumstances of every port is necessary to address these particular vulnerabilities [Hypothetical Source: African Port Development Review, 2023].

2.2 Digital Technologies Supporting AI in Port Risk Management: Interdependencies

AI does not work in a vacuum; when combined with other fundamental digital technologies, its efficacy is greatly increased. For an ecosystem to be genuinely "smart port" and capable of advanced risk management, these interdependencies are essential.

2.2.1 IoT and Blockchain Synergy

Internet of Things (IoT): Large volumes of real-time data on location, condition, performance, and environmental characteristics are produced by IoT sensors that are integrated into infrastructure, ships, containers, and port machinery (such as cranes and tugboats). Predictive maintenance, real-time asset tracking, and environmental monitoring are made possible by this data, which is the foundation of AI algorithms. For example, reefer containers' IoT sensors may continuously check the temperature and notify AI systems of any possible spoiling hazards. [Probable Source: Logistics Report on IoT, 2023].

Blockchain: Blockchain technology offers a safe, transparent, and unchangeable ledger for documenting transactions and data transfers along the supply chain, while the Internet of Things supplies the data. By guaranteeing the validity and integrity of data, IoT and blockchain together can significantly cut down on delays and enhance traceability. Because every stage of the cargo's route can be validated without the need for middlemen, this is especially useful for customs clearance, cargo provenance, and fighting illicit trade. [Source Hypothesis: Supply Chain Blockchain, 2022].

According to Oluwaferanmi's research in 2025, while there's talk of using cool tech like smart cameras, RFID tags, and those fancy IoT-connected cranes at Ghana's Takoradi Port, they haven't really been put together and used as a complete, working system yet. Basically, they're still more of a dream than a reality because the area doesn't have a strong IoT network to send all the data needed for those clever AI programs to work properly.

The Ericsson Maritime Report (hypothetically from 2024) emphasizes that super-fast wireless connections, like 5G and the even newer 6G, are super important. They're like the foundation for handling tons of data from IoT devices and using AI in real-time. These connections offer super-fast response times, lots of bandwidth, and can connect tons of devices at once. This is exactly what's needed to support lots of IoT sensors, self-driving vehicles, and video analysis happening at the port that feeds information into AI systems. Without a solid, fast internet connection, the real benefits of IoT and AI just can't be unlocked.

2.3 Cybersecurity in Maritime AI Systems: A Critical Safeguard

Cybersecurity is becoming a major strategic objective as marine operations depend more and more on artificial intelligence (AI) and networked digital equipment. The very technologies that are intended to improve resilience and efficiency also give bad actors new ways to attack.

2.3.1 Maritime Cyber Risks

AI systems are extremely susceptible to sophisticated cyberattacks, especially those that handle sensitive port logistics data, cargo information, and operational control. These dangers may appear in a number of ways:

- *Ransomware Attacks:* requesting payment and encrypting vital port systems, which results in total operational paralysis.

- *Data Breaches:* compromising private information, sensitive business data, or intelligence related to national security.

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- *Supply Chain Attacks:* focusing on weaknesses in the supply chain of hardware or software that supports port systems.

- *Adversarial Attacks on AI:* [Hypothetical Source: AI Security Journal, 2023] willfully tampering with input data to trick AI models, resulting in inaccurate predictions or judgments (e.g., tampering with sensor data to misdirect autonomous equipment, or feeding false information to a predictive maintenance system to trigger unnecessary repairs or conceal actual failures).

- *Denial of Service (DoS) Attacks:* Overwhelming port networks or systems to disrupt operations.

Under its ISPS (International Ship and Port Facility Security) recommendations, the International Maritime Organization (IMO) has called for comprehensive cyber risk management strategies in recognition of these growing dangers. Ports and shipping enterprises are required by these standards to evaluate their cybersecurity vulnerabilities and put in place the necessary protections. But often, compliance alone is not enough; a proactive, flexible cybersecurity posture is needed.

2.3.2 The Ghanaian Gap: Policy and Protocol Deficiencies

Ghana's ports, particularly Takoradi, glaringly lack strong AI governance norms and specialized marine cyber risk processes, despite being signatories to international agreements and confronting regional threats [cite: Tachie-Menson, 2023]. This is a huge and vulnerable gap that might seriously impede or perhaps jeopardize any efforts to use AI on a big scale. The absence of a clear framework for:

- *Maritime AI Regulation:* establishing the moral and legal limits on the use of AI in vital port operations, including responsibility for self-made choices.

- *AI Ethics and Accountability:* establishing guidelines for impartial, open, and equitable AI systems, especially when handling sensitive data or having an effect on human livelihoods.

- *Cybersecurity Governance for AI-enabled Systems:* Particular guidelines and technological safeguards to manage access to AI-driven insights, preserve data integrity, and defend AI models from hostile attacks.

This lack of oversight puts the port at intolerable risk and causes considerable operational hesitancy. Port authorities may be hesitant to use AI in risk-critical tasks like cargo verification, national border compliance, or vessel traffic management in the absence of defined standards because they are concerned about possible non-compliance, legal ramifications, or disastrous cyber vulnerabilities. For safe and reliable smart port operations, a thorough cybersecurity plan combined with AI development is therefore a necessity rather than an option.

2.6 Comparative Case Studies: Learning from Global Leaders

Analyzing the experiences of top international ports that have effectively used AI offers Takoradi Port priceless insights and practical takeaways. These case studies demonstrate AI's enormous potential as well as the tactical factors required for its effective application. 25% shorter wait times, better resource allocation, and improved predictive capabilities. Takoradi could adopt similar Vessel Traffic Service (VTS) models and investigate phased digital twin implementation for key operations. Port of Singapore AI for yard optimization, predictive analytics for vessel queuing, Okay, here's a more humanized paraphrase, using simpler language and focusing on the overall takeaways, while keeping the original language, plus adding a few suggestions based on your last point:

- *How Ports Around the World are Using Smart Technology:* Let's look at how different harbors are using fancy technology to work smarter and faster:

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- *Autonomous Guided Vehicles (AGVs) & Maritime Artificial Intelligence Research Centre (MAIC):* These are like self-driving vehicles and a research group focusing on AI for the sea. They're helping ports move things more quickly (up to 30% faster!), use their dock space better, and keep things safer with AI watching over everything.

- *What Ghana can learn:* The Ghana Ports and Harbours Authority (GPHA) could use data to give better arrival time predictions and use AI to organize container yards more efficiently.

- *Port of Hamburg (Germany):* This port has a "smartPORT" plan and uses AI to make cargo flow better, predict when equipment needs fixing, and stack containers intelligently.

- *What they've achieved:* Lower costs, more reliable equipment, better use of space, and a greener operation.

- *What Ghana can learn:* Takoradi port could copy Hamburg's approach to fixing equipment before it breaks, and explore AI to handle cargo better using what they already have.

- *Port of Durban (South Africa):* They're using some computer systems to plan their yards and have started dabbling in smart port technology.

  - *What they've achieved:* Less reliance on people for some jobs and better yard efficiency.

  - *What Ghana can learn:* Ghana could look at Durban's experiences to see how to automate things in a budget-friendly way, and learn from their struggles with getting all their systems to work together.

- *Tema Port (Ghana):* They've started using a basic Port Community System and trying out digital tracking. They're also making some initial moves towards automation.
  - *What they're struggling with:* These systems aren't connected across all departments yet, and they're having trouble getting different data types to talk to each other. Plus, people need more training.
  - *Key lesson for Ghana: It's* really important to make sure all systems can work together and to invest heavily in training people to use these new technologies.

3.0 METHODOLOGY

3.1 Introduction

This chapter explains in detail how we investigated the important role that Artificial Intelligence (AI) play in making maritime operations safer, supply chains more resilient, and recovering quickly from disruptions. We focused our research on the Ghana Ports and Harbours Authority (GPHA), using Takoradi Port as our main example. Our research was carefully designed to combine both qualitative and quantitative methods. This helped us gain a complete and well-rounded understanding of how things work, the views of key people, and the difficulties faced within the Ghanaian maritime industry. The main goal of our approach was to produce reliable and practical results that could not only improve our theoretical understanding of maritime logistics and digital changes but also provide useful advice for implementing changes within a developing port setting.

3.2 Research Design: Combining Different Approaches.

The study use a mixed-methods approach for this study. This approach combines the strengths of both quantitative (numerical) and qualitative (descriptive) research methods to give us a more thorough and well-supported understanding of the complex issues we were studying (Creswell & Plano Clark, 2017).

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This mixed-methods design included:

Descriptive Quantitative Analysis: We used this to measure and analyze different aspects of port performance, assess the current level of automation, and evaluate how past disruptions were done. This involved collecting numerical data through surveys, which allowed us to statistically analyze trends, frequencies, and relationships. This gave us a broad view of the current situation and the opinions of people involved, across a larger group.

Exploratory Qualitative Inquiry: We used this to gather detailed insights from key people, explore management challenges, and understand the complex organizational dynamics at Takoradi Port. This involved semi-structured interviews, which allowed for open discussions, deeper exploration of meanings, and uncovering background factors that numerical data alone couldn't reveal. This combined approach supports what's called "triangulation," a key idea in mixed-methods research. Triangulation means using multiple sources of data, methods, or researchers to significantly improve the trustworthiness, validity, and depth of our findings (Creswell & Plano Clark, 2017). For example, numerical data on AI awareness could be given context and explained by qualitative insights into specific training gaps or attitudes towards technology. This combination of evidence from different angles makes our research conclusions stronger and more reliable.

Benefits and Limitations of Mixed-Methods Research: The main advantage of this mixed-methods design is that it provides a more complete and nuanced understanding than depending solely on quantitative or solely on qualitative methods. It allows us to have both a broad perspective (generalizability from numerical data) and a deep perspective (contextual understanding from descriptive data). It's especially useful for complex, real-world problems involving human perceptions and technological adoption, where a single method might not give a complete picture. However, this approach also requires more resources, including expertise in both quantitative and qualitative data collection and analysis. Challenges can arise when combining different types of data, ensuring the methods are consistent, and managing the time and costs involved. Despite these challenges, the complexity of our research question required this thorough approach.

3.3 Research Paradigm: Pragmatism,

The philosophical idea guiding our research was pragmatism. This idea, unlike stricter philosophical viewpoints, offers a flexible and problem-focused approach. It prioritizes the research question and the most effective methods to answer it, rather than sticking to a single philosophical position (Johnson & Onwuegbuzie, 2004). Pragmatism accommodates both:

Objective measurements (positivist stance): This is consistent with the quantitative component, which looks for patterns and correlations in measurable variables (such as recovery evaluations and AI awareness scores) in an effort to provide generalizable insights. Subjective stakeholder insights (interpretivist stance): This is consistent with the qualitative component, which acknowledges that reality is socially produced and aims to comprehend people's lives experiences, perceptions, and interpretations within their particular environment.

When assessing cutting-edge technology like artificial intelligence in a complicated, real-world institutional setting like GPHA, this dual accommodation was essential. While a simply interpretivist approach might not have the generalizable evidence required to support broad policy recommendations, a merely positivist approach might overlook the complex organizational and human barriers to AI adoption. By choosing approaches that best suited the study's goals and yielded the most useful information, pragmatism enabled the researcher to switch between various viewpoints with ease. The emphasis on "what works" in resolving the study problem produced useful and pertinent results.

Contrast with Alternative Paradigms: The complex, subjective human elements driving AI adoption, such as cultural resistance or fear of job loss, may be difficult for a purely positivist paradigm that emphasizes objective measurement and hypothesis testing to represent. On the other hand, a purely interpretivist paradigm that only considers rich, contextual narratives do not have the statistical generalizability required to offer more comprehensive suggestions for national or port wide policy. Pragmatism was the best option for this study because it embraced methodological diversity, which enabled a more thorough investigation of the interaction between technology promise and organizational/human realities.

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Study Area: Takoradi Port (Ghana)

The study was conducted at Takoradi Port, Ghana's first commercial port, strategically situated in the Western Region. Its selection as a case study was deliberate, given its significant role in the national economy and its current trajectory of modernization and expansion, which renders it an ideal environment for analyzing the integration of AI into risk management frameworks. *Key features of Takoradi Port that make it a compelling case study include:*

- *Management:* It is run by the Ghana Ports and Harbours Authority (GPHA), a state-owned company in charge of the growth, administration, and control of Ghanaian ports. This gives the investigation a defined organizational framework.

- *Economic Significance:* The port is essential to Ghana's extractive industries and energy sector since it handles large amounts of bulk cargo (such as manganese and bauxite), minerals, and petroleum products.

- *Modernization and Expansion:* An automated bulk jetty was recently added to Takoradi Port, which has been undergoing major improvements. This continuous change offers a dynamic framework for researching the benefits and difficulties of digital integration.

- *Digital Experimentation:* Even if there is still a lack of complete AI integration, the port is currently experimenting with a number of digital tracking systems, suggesting a young but growing interest in technological solutions [cite: Oluwaferanmi, 2025; GPHA Annual Report, 2023].

Takoradi Port, with its roots going all the way back to 1928, is a well-established place with a long history and experienced people running things. Because it sits on the Gulf of Guinea, it's right in the middle of busy West African trade, meaning it both rivals and works alongside other ports in the area. It's also closely tied to Ghana's important mining and oil industries, so if something goes wrong at Takoradi, it quickly impacts the country's export income and the supply of materials that industries need. This unique situation – a port with a strong past, currently being updated, and crucial to the economy – makes it a great place to study the good and bad sides of bringing in AI. What we learn here can help other similar medium-sized ports in developing countries that are building on what they already have, rather than starting from scratch.

Target Population: Comprehensive Stakeholder Mapping

To ensure a holistic understanding of AI's potential and challenges in the maritime supply chain, the study targeted a diverse array of stakeholders within the port ecosystem. Each group offers a unique perspective critical to a comprehensive analysis:

Stakeholder Group	*Justification*
GPHA Management	These people are in charge of the port authority's overarching strategic direction, decision-making, and resource distribution. Their capacity to drive organizational change, willingness to spend, and comprehension of AI's potential are critical. They provide significant undertakings their topdown perspective and approval.
IT and Operations Managers	The operational and technical implementers are these people. IT administrators are aware of the data systems, digital infrastructure, and technological viability of integrating AI. Daily bottlenecks, risk factors, and the real-world effects of disruptions are all familiar to operations managers. For determining particular AI use cases and evaluating operational preparedness, their insights are essential.
Maritime Security Officers	They have vital knowledge of smuggling operations, emergency response procedures, and physical and cyber dangers as frontline staff in charge of port security. Their viewpoints on how AI may improve threat

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	identification, surveillance, and quick response are quite helpful, especially when it comes to cybersecurity threats in AI systems.
Shipping Line Representatives	The effectiveness (or ineffectiveness) of port operations, such as communication, cargo handling, and vessel turnaround times, are directly experienced by these external stakeholders. An external, user-centric perspective is offered by their input on the effects of recent interruptions and the anticipated advancements from AI (such as faster port calls and more precise ETAs).
Freight Forwarders and Hauliers	These organizations stand for the supply chain's landside logistics segment. Delays in customs clearance, port traffic, and recovery periods all have a direct impact on them. Their real-world experiences demonstrate the effects of port inefficiencies in real time as well as the potential advantages of artificial intelligence in expediting the movement of commodities from the port to the final destination.
Customs and Regulatory Bodies	These governmental organizations are essential to compliance, security, and trade facilitation. Their viewpoints are crucial for comprehending data sharing standards, the legal landscape surrounding AI, and how AI may facilitate safe and effective customs procedures while abiding by both domestic and international trade regulations. They have an impact on the larger policy environment around the deployment of AI.
Technology Vendors & Consultants	These outside professionals create and execute AI solutions for ports all over the world. Their knowledge of best practices, potential solutions, implementation difficulties, and available technologies is invaluable. They offer a technical and business-focused viewpoint on what is practical and efficient in the application of AI.

Rationale for Inclusion: It was intentional to include such a wide range of stakeholders in order to reduce the possibility of biases that can result from depending just on the viewpoint of one group. For example, operational personnel can point out real-world obstacles, even while management may express grand visions. Likewise, outside parties such as freight forwarders and shipping companies provide a "customer's eye view" of port operations. A more solid and useful set of conclusions resulted from this thorough mapping, which made sure the study covered the multifaceted aspects of AI adoption, including technological, operational, regulatory, and human elements.

3.6 Sampling Techniques: Strategic Selection

Participants for the qualitative interviews and quantitative surveys were chosen using a combination of non-probability sampling procedures, taking into account the particular goals of the study and the characteristics of the target community. These methods were selected to maximize the depth and richness of the data gathered by ensuring that the most pertinent and informed people were included.

Purposive Sampling (for Qualitative Interviews)**:** To gather the best insights, we used a few different approaches to select participants. First, for our in-depth interviews, we used a method called purposive sampling [cite: Patton, 2015]. This meant we carefully chose individuals with specific knowledge and experience relevant to AI in the port. We specifically looked for people directly involved in:

- AI or IT projects at the Ghana Ports and Harbours Authority (GPHA).
- The everyday workings of maritime operations and logistics.
- Keeping the port safe and secure.
- Overseeing maritime activities in Ghana through regulations.
- Digital upgrades at other ports.

Our goal was to talk to people who understood the good and bad of bringing AI to Takoradi Port. We aimed to interview about 10 managers from different GPHA departments (like Operations, IT, and Security), 4 people from companies that sell or consult on maritime AI, and 3 people from regulatory agencies (like the Ghana Maritime Authority). This mix of people would

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give us a well-rounded understanding of the issue. To find even more knowledgeable people for interviews, we also used a "snowball" technique. After talking to someone, we asked them if they knew anyone else who could offer valuable perspectives. This helped us find experts or people with unique viewpoints we might have missed otherwise.

For our broader survey, we used a simpler method called convenience sampling [cite: Etikan et al., 2016]. This means we surveyed GPHA staff (not just managers) and other people who use the port (like freight companies) who were readily available and willing to participate. We aimed for about 30 survey responses. This allowed us to gather a wider range of opinions from people working in and around the port. Why these numbers? We chose these sample sizes to balance in-depth understanding with broader opinions. We wanted to have detailed conversations with a smaller group (17 for interviews) until we stopped hearing new information. For the surveys, we wanted a larger group (30) to identify common trends, even though we knew we couldn't survey everyone due to time and access limitations.

Acknowledging potential problems: We understand that these methods aren't perfect. Because we didn't randomly select everyone, there's a chance our sample might not perfectly represent the whole population. Specifically, with purposive sampling, our judgment could influence who we choose. And with convenience sampling, the people who are easiest to reach might not reflect everyone's opinions. To reduce these problems:

- *Clear Selection Criteria:* Explicit criteria for relevance and expertise were developed and followed for purposive sampling.
- *Triangulation:* Cross-validating results and lessening the influence of individual method biases were made possible by the use of mixed methods, which combine quantitative breadth with qualitative depth.
- *Transparency:* In this methodological chapter, every sampling choice and any possible ramifications are openly explored.
- *Contextualization:* The results are interpreted in the particular context of Takoradi Port, with the understanding that additional research may be necessary before they can be directly extrapolated to all African ports.

3.7 Data Collection Methods: Rigorous and Multi-faceted

A variety of primary and secondary sources were used in the carefully planned and carried out data gathering for this study. This multifaceted strategy was essential for obtaining a range of viewpoints and empirical data, which improved the research's thoroughness and legitimacy.

3.7.1 Primary Data

Semi-structured interviews and structured questionnaires were used to gather primary data directly from the field, enabling direct interaction with Takoradi Port stakeholders.

Semi-Structured Interviews:

Modality: The majority of the interviews took place face-to-face in the participants' Takoradi Port offices, creating an atmosphere that was favorable for candid conversation. Interviews were done through safe online platforms like Zoom in a few cases where in-person encounters were not possible because of scheduling difficulties or travel limitations.

Topics: The literature study and the research questions served as the foundation for the development of the interview guide (Appendix D), which made sure that all important topics were covered. Among the main subjects were:

- Current risk identification, assessment, and mitigation practices at Takoradi Port.
- Experiences with past operational disruptions (e.g., weather, strikes, system outages, COVID-19 impacts).
- Perceptions of Artificial Intelligence and its potential applications in maritime risk management.
- Current levels of digital infrastructure and technological readiness.
- Challenges and opportunities for enhancing supply chain resilience and disruption recovery.
- Specific governance or policy support needed for AI implementation.

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Duration: The duration of each interview was roughly 45 to 60 minutes, which allowed for adequate depth without placing an excessive strain on the participants' time.

Instrument: They used a comprehensive semi-structured interview guide. In addition to offering flexibility for follow-up questions and a more thorough examination of emerging themes, this guide's structure of open-ended questions ensured uniformity across interviews. With the participants' express cooperation, all interviews were audio recorded, making transcription and analysis easier.

Pilot Testing of Interview Guide: Two non-participating GPHA employees' pilot tested the interview guide before the primary data collection to evaluate the questions' relevancy, flow, and clarity. Based on their input, minor modifications were made to increase the instrument's efficacy.

Ethical Considerations: A comprehensive permission form (Appendix F) explaining the study's objectives, participants' rights (such as the ability to withdraw or participate voluntarily), and guarantees of anonymity and confidentiality were given to participants before to each interview. In addition to completed consent forms, verbal consent was acquired and documented before to the interview. To safeguard participant identity, all obtained data was anonymized during transcription and processing.

B. Surveys:

Delivery Method: A larger set of stakeholders received structured surveys (Appendix C). The main distribution routes were Google Forms, official GPHA communication channels when allowed, and direct email to designated recipients. Printed copies of the questionnaire were made available, and arrangements were made for their pickup, for participants who preferred a physical format or had restricted internet access.

Sections: The purpose of the survey instrument was to collect quantitative information on particular constructs associated with the study questions. It was separated into a number of key sections:

- Respondent Demographics (e.g., department, years of experience).
- Current Risk Management Practices (e.g., frequency of specific risks, perceived effectiveness of current responses).
- AI Awareness and Readiness (e.g., familiarity with AI concepts, perceived organizational preparedness for AI adoption).
- Disruption Impacts and Recovery Capabilities (e.g., typical recovery times, use of data-driven processes in recovery).
- Willingness to Adopt AI Solutions (e.g., perceived benefits, interest in AI training).

Scale Usage: A 5-point Likert scale (e.g., 1=Strongly Disagree to 5=Strongly Agree; 1=Very Low to 5=Very High) was predominantly used for measuring perceptions and attitudes, allowing for quantitative analysis.

Pre-testing of the Questionnaire: As with the interview guide, a small group of five members of the target population pre-tested the survey questionnaire to make sure it was clear, had clear wording, and was the right length. Before the instrument was made widely available, feedback was taken into consideration to improve it.

3.7.2 Secondary Data

Secondary data was collected from various authoritative sources to complement the primary data, provide contextual background, and enable benchmarking against global standards.

Sources: Key sources of secondary data included:

- Ghana Ports and Harbours Authority (GPHA) annual reports (e.g., GPHA Annual Report, 2023).
- United Nations Conference on Trade and Development (UNCTAD) Review of Maritime Transport. o Reports from international organizations such as the International Maritime Organization (IMO) and the World Economic Forum (WEF).
- Industry reports from leading consultancies (e.g., Accenture, McKinsey).

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- Academic papers and theses relevant to AI in maritime logistics, supply chain resilience, and port operations (e.g., Aremu Oluwaferanmi, D. Ivanov). o Publicly available port performance dashboards and industry statistics where accessible.

Data Gathered: Specific types of secondary data collected included:

- Historical data on vessel turnaround times and cargo throughput volumes at Takoradi Port.
- Records of past disruption incidents (e.g., reported labor strikes, impacts of global events like COVID-19, significant system outages, major congestion events).
- Information on existing automation levels and digital tracking experiments at GPHA.
- Global trends and benchmarks in AI adoption within the port sector.
- Relevant national policies or strategic documents of digitalization and maritime development in Ghana.

Data Quality and Reliability Assessment: A rigorous evaluation of the quality and dependability of every secondary data set was conducted. This required confirming the reliability of the source, looking for consistency among several sources, and identifying any potential biases or restrictions in the original reports' data collection techniques. Reports from official government or international organizations (such as the GPHA, UNCTAD, or IMO) were regarded as extremely trustworthy sources of data. against ensure objectivity and correctness, industry reports were compared against scholarly works.

3.8 Data Analysis Techniques: Systematic and Robust

In order to derive significant insights and answer the study questions, the gathered data—both qualitative and quantitative—went through a thorough and methodical analytic process. To make this process easier, the right software tools were used.

3.8.1 Qualitative Analysis (Thematic Coding)

Thematic analysis was used to examine the qualitative data, which came mostly from the semi structured interviews. For finding, examining, and summarizing patterns (themes) in qualitative data, this strategy is adaptable and effective [cite: Braun & Clarke, 2006].

Software: The transcribed interview material was managed, arranged, and examined using NVivo 12 Pro software. The formulation of themes, systematic coding, and the investigation of connections between codes and themes are all made easier by NVivo.

Process: The thematic analysis followed the six-phase approach outlined by Braun and Clarke (2006):

Familiarization with the data: All audio-recorded interviews had to be verbatim transcribed, and in order to fully comprehend the information and become immersed in the facts, the transcripts had to be carefully reviewed and reread.

Generating initial codes: During this stage, the complete dataset was methodically examined in order to find and code any noteworthy features. Text passages that constituted a fundamental unit of meaning pertinent to the research issues were given codes. Both inductive (which come directly from the data, such as "Bureaucratic Hurdles," "Fear of Job Displacement") and deductive (which come from the literature study and research questions, such as "AI Awareness," "Digital Infrastructure") codes were employed.

Searching for themes: After the first codes were created, they were categorized into more general possible themes. This required examining the codes for linkages, connections, and patterns.

Reviewing themes: The identified themes have to be refined during this crucial stage. It involved determining if the themes were unique from one another, whether there was enough evidence to support each topic, and whether the themes appropriately reflected the coded data. At this stage, sub-themes were also discovered.

Defining and naming themes: Every theme had a precise definition that outlined its main points and the elements of the data it encompassed. Each subject and sub-theme was given a name that was clear and descriptive.

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Producing the report: To answer the study questions, this last stage entailed integrating the topics that had been examined into a cohesive story that was backed up by participant quotes that served as examples.

Inter-coder Reliability: A thorough process of self-reflection and peer debriefing was used to improve the reliability and impartiality of the coding process, even though this study's qualitative coding was predominantly conducted by a single researcher. To guarantee uniformity in code interpretation and application, early coding techniques were discussed with an academic peer.

Quantitative Analysis (Descriptive Statistics & Correlation): Quantitative data, primarily collected through the surveys, was analyzed using statistical methods to identify patterns, trends, and relationships.

Software: IBM SPSS Statistics version 26 was used for all quantitative data analysis.

Frequencies and Percentages: used to display the distribution of replies for categorical variables (e.g., departments, types of risks) and to compile the demographic data of respondents.

Descriptive Statistics (Means, Standard Deviations: The central tendency and variability of continuous data, such as AI awareness scores and Likert scale ratings of perceived preparedness, are summarized using this method. Finding the biggest dangers or obstacles was made easier with the help of mean rankings.

Cross-tabulations: Employed to examine the relationship between two or more categorical variables (e.g., AI awareness levels across different departments).

Pearson Correlation Coefficient (r): The degree and direction of a linear relationship between two continuous variables were assessed using this statistical test. It was used, for example, to evaluate the relationship between "AI Awareness" and "Risk Management Readiness," or between "Risk Readiness" and "Disruption Recovery Time." No linear association is shown by a Pearson correlation value of 0, which goes from -1 (perfect negative correlation) to +1 (perfect positive correlation).

Justification for Pearson Correlation: Because Likert scale variables can be regarded as interval data for correlation analysis purposes, provided that the replies have a reasonably normal distribution, Pearson correlation was selected. It is a commonly used technique to investigate linear correlations between variables.

Statistical Assumptions and Checks: Basic assumptions were taken into consideration before correlation studies were conducted. Given the sample size, a rigorous normality test was not the main focus; nonetheless, histograms and scatter plots were visually inspected to ensure that there were no extreme outliers that could excessively affect the correlation coefficient and that the data were linear. By combining number-based analysis with insights from people's experiences, we were able to create a much stronger and well-rounded understanding. This mix gave us both solid proof showing how things connect, and detailed stories explaining why we saw what we did.

3.9 Research Validity and Reliability

For research findings to be credible and reliable, their validity and dependability must be guaranteed. Several tactics were used in this study to improve these attributes:

Validity: refers to how well a research tool measures the things it is supposed to measure and how well the results correctly reflect the topic under study.

Content Validity: developed interview guides and survey questions after consulting experts and conducting a thorough literature analysis, guaranteeing that the instruments addressed all pertinent facets of resilience, maritime risk, and artificial intelligence.

Construct Validity: addressed by precisely defining the theoretical concepts (such as supply chain resilience and AI awareness) and making sure that the operational measures (such as interview prompts and survey questions) appropriately represented these concepts.

Triangulation: The use of several data sources (interviews, surveys, secondary data) and methodologies (qualitative, quantitative) to study the same phenomenon greatly improved the validity of the results by offering convergent evidence, as was covered in Section 3.2.

Reliability: relates to how stable and consistent the research findings are. Results from a replication of the study under comparable circumstances should be comparable.

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Internal Consistency (for Surveys): Although it is not stated clearly in the excerpt, it is common practice to use Cronbach's Alpha to evaluate the internal consistency of Likert scales, which makes sure that all of the items on a scale accurately reflect the same underlying construct.

Standardization: To reduce variances in data collection, standardized survey questionnaires and a uniform semi-structured interview guide were used to all participants.

Audit Trail: An audit trail that strengthens the confirmability of the qualitative findings was produced by keeping careful records of every step of the research process, including interview transcripts, coding choices, and statistical analyses.

Credibility (for Qualitative Data): A key criterion for trustworthiness in qualitative research.

Member Checks: Some participants were given access to summaries of the interview findings where practical and appropriate so they could confirm or correct the researcher's understanding and ensure the interpretations were accurate.

Thick Description: Giving readers thorough, in-depth explanations of the background and conclusions backed up by relevant quotations enables them to evaluate the validity and transferability of the qualitative insights.

Confirmability (for Qualitative Data): Refers to the objectivity of the qualitative findings.

Reflexivity: To identify and reduce any potential biases or preconceived conceptions, the researcher kept a reflective notebook during the data gathering and analysis procedure.

Generalizability and Transferability: The rich qualitative insights offer great transferability, whereas the quantitative results may have limited statistical generalizability to the full population of Ghanaian ports due to convenience sampling. Readers can evaluate the findings' relevance to other comparable port environments in underdeveloped nations thanks to the thorough contextual descriptions of Takoradi Port.

4.0 RESULTS AND DISCUSSIONS

4.1 Introduction

This section dives deep into the data we gathered using a mix of methods: surveys, interviews, and existing data. We're looking at how Artificial Intelligence (AI) is affecting risk management, supply chain strength, and how quickly Takoradi Port in Ghana can bounce back from disruptions. We've organized our findings around four key areas: how much port people know and are ready for AI, how they currently manage risks, their ability to recover from problems, and how open they are to using AI. We also compare Takoradi to leading "smart" ports around the world to see where it stands and where it can improve.

4.2 A Simple Look at the Survey Data.

The survey data, which comes from 30 people at the port (you can see some examples in Appendix E), gives us a basic understanding of their thoughts on AI, risk, and resilience at Takoradi Port. We used some simple math (like averages and percentages) to summarize what they told us.

4.2.1 How Much They Know About AI and How Ready They Are for Risk Management.

The survey shows that people have different levels of knowledge about AI and how ready they think they are to use it for risk management. Many people (about 65%) said they have a good understanding of AI, rating their awareness as a 4 or 5 out of 5. This suggests that they generally understand that AI is becoming important in the shipping industry. For example, people like R001, R005, and R010, who are managers or very involved staff, consistently rated their AI knowledge as the highest level

4.2.2 Disruption Recovery Capabilities

The evaluation of how well Takoradi Port bounces back from problems paints a somewhat complicated picture. Around 60% of those surveyed felt their departments recovered from disruptions effectively, giving it a score of 4 or 5 out of 5 (with 5 being "extremely effective"). This implies that, in their opinion, the port usually gets things back on track after something goes wrong. Quotes from certain participants (like R001, R005, and R010 giving top marks, and R002 and R009 scoring it just below that) seem to back this up to some extent.

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However, when we looked closer at *how* they recover, it became clear that they lean heavily on old-fashioned, hands-on methods and past know-how. Only about 30% said they used "data-driven" methods or modern digital tools for recovery. This hints that while the port *does* recover, it's often because of people reacting in the moment and working together, rather than using optimized, predictive, or automated systems. This also fits with what we found in other parts of the study (Section 4.4), which showed that manual coordination and individual expertise are key during tough times.

4.2.3 Willingness to Adopt AI Solutions

Even though they felt a bit behind in some areas, people were surprisingly eager and open to using AI. Most folks (over 75%) said they were pretty excited about it, scoring their enthusiasm high on a scale. Looking at Appendix E, we see that a good chunk of people (60% – specifically folks like R001, R002, etc.) felt the same way, showing a real interest. This feeling matched what they told us in conversations, with many saying that embracing digital changes was "about time" because things are getting complicated and other ports nearby, like Abidjan and Lomé, are pulling ahead. This strong willingness shows that the organization is open to new ideas, which is super important for successfully bringing in AI. The big reasons behind this eagerness seem to be the understanding that AI could make things more efficient, cut costs, and give them an edge over the competition.

4.3 Correlation Analysis and Interpretation

To evaluate the direction and degree of linear correlations between the study's major variables, Pearson correlation coefficients were calculated. The findings show a number of incredibly strong positive correlations, suggesting that risk preparedness, disruption recovery, AI adoption willingness, and AI awareness are all significantly correlated.
The correlations listed below were noted:

- *AI Awareness vs. Risk Readiness:* There was an extremely high positive correlation ($r=0.93$). This suggests that stakeholders' perceptions of the organization's ability to effectively manage risks rise in tandem with their awareness of AI. This implies that a more optimistic view of risk readiness is directly correlated with a deeper comprehension of AI's potential. This correlation is especially strong, suggesting a strong perceptual connection between being aware of AI's capabilities and thinking the company is better prepared.

- *AI Awareness vs. Disruption Recovery Time:* There was a significant positive connection ($r=0.90$). This implies that a perception of quicker or more effective disruption recovery is linked to a higher level of AI awareness. According to this association, a more positive perception of recovery capacities results from an awareness of AI's potential for predictive analytics and improved response mechanisms.

- *AI Awareness vs. AI Adoption Willingness:* An exceedingly strong positive connection was discovered ($r=0.97$). This is the greatest association identified, unambiguously proving that a deeper grasp of AI directly and deeply generates a higher readiness to implement AI solutions within the port. This emphasizes how important it is to spread knowledge in order to create an atmosphere that is favorable to technological advancement.

- *Risk Readiness vs. Disruption Recovery Time:* There was a very high positive correlation ($r=0.94$). This suggests that the perceived effectiveness and speed of disruption recovery also greatly improve when the organization's perceived risk management readiness rises. This emphasizes the obvious connection between excellent post-disruption response and proactive risk management skills.

Implications of High Correlations: The really high numbers we found when comparing the answers (between 0.90 and 0.97) show a very clear connection between these things we were looking at. Even though we're just looking at opinions from the survey, and can't say for sure one thing *causes* another, these numbers are still a big deal. In other research, results like these would make people dig deeper to see if some of the things are really measuring the same

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thing, or if there's some other hidden factor affecting everything. But for our first look at this, it's a strong sign that understanding and feeling prepared for AI are closely tied to feeling tough and wanting to use AI more. It points to a "big chance": if we focus on teaching people about AI and making them feel more comfortable with it, it could have a snowball effect. It wouldn't just help individuals understand AI better, but it could also make the whole organization feel more capable of handling change ("institutional resilience") and work better overall. We didn't use fancy statistical methods to prove cause and effect because we didn't have a huge number of responses, but these connections are still pretty convincing evidence that these important concepts are linked.

4.4 Qualitative Themes from Interviews

The rich, contextualized insights from the in-depth semi-structured interviews supported and extended the quantitative findings. Four main themes emerged from the thematic analysis, describing the present obstacles and anticipated advantages of integrating AI at Takoradi Port.

Theme 1: Fragmented Digital Infrastructure

The major issue presented by the disjointed and frequently separate digital technologies now in use at Takoradi Port was a recurring subject in all of the interviews. Interviewees frequently emphasized how different departmental systems are incompatible with one another, creating data silos and making it difficult to establish real-time visibility throughout the port ecosystem. As one GPHA Operations Manager articulated: "Yes, we have systems, but they are incompatible. Our cargo management system is distinct from those of vessel traffic and customs. You must manually pull data from three or four sources in order to have a complete picture. It is similar to assembling puzzle pieces from several boxes." The ability to gather, combine, and evaluate the extensive datasets required for complex AI applications is hampered by this fragmentation. Among the particular instances mentioned were distinct systems for:

- *Vessel tracking and scheduling: Often reliant on basic AIS data without integration into berth allocation or yard planning.*
- *Cargo management and warehousing: Manual inventory checks and disconnected*
- *databases.*
- *Customs clearance and inspection: Paper-based processes or isolated digital platforms that do not seamlessly share data with port operations.*
- *Equipment maintenance: Reactive maintenance schedules based on manual inspections rather than predictive analytics from sensor data.*

One of the most often cited major obstacles to the smooth flow of data required for AI-driven optimization and predictive risk management is the lack of a uniform Port Community System (PCS).

Theme 2: Skills and Human Capital Challenges

The severe lack of human capital, especially in the areas of technical skills and AI literacy needed for digital transformation, was another major subject. Interviewees recognized a significant gap in the workforce's ability to comprehend, apply, and manage AI systems, despite the high level of enthusiasm for the technology. A GPHA IT Specialist lamented: "Our employees are eager to learn, but they have very little formal training in data science, AI engineering, or even fundamental data analytics. Too few people are capable of creating these AI models or even correctly interpreting the findings, should they be available". There is a significant skills gap.
This issue goes beyond extremely specialized positions to include a widespread lack of digital literacy at many levels of operation. This problem is made worse by the lack of organized AI capacitybuilding initiatives and the inadequate technical onboarding assistance for new digital tools. Leading international ports that have made significant investments in retraining their employees and creating specialized AI talent pools stand in stark contrast to this.

Theme 3: Regulatory Uncertainty and Governance Gaps

The interviewees regularly showed that the Ghanaian maritime industry lacked clear governance frameworks for AI and a sizable regulatory vacuum. Particularly in crucial operational areas, this uncertainty breeds anxiety and prevents proactive investment in AI

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solutions. A Representative from a Regulatory Body stated: "In our ports, there are no explicit laws or regulations pertaining to AI. Given how much data AI gathers, how can we manage data privacy? If an AI system makes a mistake that causes an accident, who is responsible? We do not know the answers to these issues, which makes everyone reluctant to proceed with important AI deployments." In addition to the lack of established cybersecurity governance norms, the lack of a defined legal and policy framework for AI governance also causes "operational hesitation" when it comes to implementing AI in crucial tasks. Data ownership, algorithmic openness, and the possibility of hypervulnerabilities in networked AI systems were among the issues brought forward. The port runs the danger of breaking international regulations and maybe facing legal repercussions in the absence of a strong regulatory structure.

Theme 4: Potential Use Cases for AI

Interviewees were quite clear on the possible high-impact AI applications that might greatly help Takoradi Port, despite the difficulties. These alleged use cases demonstrate a thorough comprehension of AI's usefulness in practice by strikingly aligning with international best practices. A Shipping Line Representative emphasized: "Our planning would be completely transformed if we could obtain precise, AI-driven vessel ETAs. Waiting is a huge waste of time and gasoline. It would be revolutionary to use predictive analytics for berth allocation."

High-priority areas identified by participants included:

- *AI-Based Predictive Vessel Arrival and Departure Systems:* predicting vessel movements with accuracy using historical trends, weather forecasts, and real-time AIS data to maximize berth allocation and minimize congestion.

- *Real-time Yard Congestion Monitoring and Optimization:* analyzing container movements using computer vision and machine learning to improve retrieval and stacking while minimizing bottlenecks.

- *Cargo Theft and Smuggling Detection:* enhancing security and lowering illegal activity with AI-powered surveillance (such as drone photography and anomaly identification in cargo manifests).

- *Weather-Informed Berthing and Operations:* Combining artificial intelligence (AI) with meteorological data to generate real-time suggestions for safe berthing and operational modifications in inclement weather.

- *Automated Customs Inspection and Risk Profiling:* utilizing AI to streamline clearance procedures and cut down on fraud by analyzing customs declarations and identifying highrisk cargo for focused examination.

Stakeholder needs and AI's potential solutions are clearly aligned in these use cases, which immediately address the most urgent issues mentioned in the problem statement.

4.5 Benchmarking: Takoradi vs. Global AI-Driven Ports

Takoradi Port's current level of digital maturity and AI integration was compared to a fictitious "Global Smart Port Average," which was developed from the literature review on top ports including Rotterdam, Singapore, and Hamburg. This analogy emphasizes Takoradi's existing standing and the prospects for strategic growth.

Metric / Function	*Takoradi Port (Current State)*

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Digital Port Average (Hypothetical)	*Smarter Container Yards: Think of it as using smart tech, powered by AI, to arrange shipping containers more efficiently. It figures out the best places to put them and how to move them around, cutting down on wasted time and effort for people.* *Predicting Ship Arrivals Better: We use AI to get really good at guessing when ships will arrive. This system takes into account things like weather, traffic at sea, and how fast the ship is going, and it keeps updating the prediction as things change.* *Spotting Problems Before They Happen: Using AI, we can look at all sorts of information – like sensor readings, past incidents, and weather reports – to anticipate potential problems with operations, security, or the environment before they occur.* *Super-Secure Systems: Our cybersecurity is like having an AI security guard constantly watching our systems. It instantly spots unusual activity, identifies threats, and automatically takes action to protect us. This is all built on a solid foundation of security rules and procedures.* *Getting Back on Track Quickly: When things go wrong (like delays or unexpected events), we have a central dashboard that uses AI to give us a clear picture of what's happening. It also suggests the best ways to recover and tells us how to use our resources most effectively.*
	Everyone Understands AI: Our employees are trained to understand and use AI tools effectively. We invest in ongoing training to make sure everyone has the skills they need to work with these new technologies.

"This comparative table makes it abundantly evident that Takoradi Port lags well behind the fictitious "Global Smart Port Average" in terms of important digital maturity and AI integration indicators. It is at a competitive disadvantage in the increasingly digitalized global marine landscape because of its reliance on manual processes, disjointed systems, and reactive tactics. For example, Takoradi still faces fundamental data integration issues even though top ports deploy AI for automated yard optimization and forecast vessel ETAs. But there is also a window of opportunity within this gap. Compared to mega-ports like Rotterdam or Singapore, Takoradi Port is smaller and is currently undertaking targeted infrastructural upgrades (such as an automated bulk jetty), which could allow for "leapfrogging." This implies that it can get around some of the gradual digital transformation processes that previous smart ports must go through.paints a picture: Takoradi Port is quite a bit behind where a typical, digitally-savvy port would be when it comes to using AI and technology. They're still doing a lot of things by hand, and their systems don't really talk to each other very well.

In today's world, where shipping is becoming more and more digital, this puts them at a disadvantage. For example, while the best ports are using AI to predict when ships will arrive and to organize their storage yards automatically, Takoradi is still struggling with simply getting all its information in one place. But here's the good news: this also means they have a chance to jump ahead. Because Takoradi Port isn't as huge as places like Singapore or Rotterdam, and they're already upgrading things like their loading docks, they could actually skip some of the older, gradual steps in going digital. They could go straight to using more advanced AI solutions that are connected and work together seamlessly. To make this happen, they'll need a clear plan, ongoing investment, and a real focus on overcoming the obstacles they've already identified. The fact that everyone involved is keen to adopt AI makes this potential even stronger."

4.6 Summary of Findings

The comprehensive data analysis, integrating both quantitative and qualitative insights, reveals a multi-faceted understanding of AI's current status and potential impact at Takoradi Port.

High AI Awareness, Low Implementation Readiness: A notable "knowledge implementation asymmetry" exists in that while a sizable majority of stakeholders (65%) are aware of AI's

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potential, just 45% believe the technology is ready for real-world use. This disparity emphasizes the necessity of converting conceptual knowledge into useful skills.

Dominance of Manual and Reactive Risk Management: Reactive responses, human experience, and manual procedures are the mainstays of current risk management procedures and disruption recovery initiatives. The port is susceptible to long-term effects from frequent disruptions like labor strikes, customs delays, and traffic because only 30% of recovery procedures are data-driven.

Strong Positive Correlation between AI Awareness/Readiness and Resilience Outcomes: The quantitative research showed that perceived risk management readiness, effective disruption recovery, and AI awareness all had very high positive connections. According to this empirical link, improving the port's overall resilience requires promoting AI knowledge and creating basic readiness.

Structural and Institutional Barriers to AI Integration: Qualitative interviews consistently pinpointed critical impediments:

- *Fragmented Digital Infrastructure:* AI requires real-time visibility, which is hampered by data silos created by a lack of connectivity across several departmental systems.
- *Human Capital Deficits***:** A significant skills gap in data science, AI engineering, and general digital literacy among the workforce.
- *Regulatory Uncertainty and Governance Gaps:* The lack of explicit guidelines for cybersecurity, ethics, and AI governance causes hesitancy and restricts the use of AI in vital tasks.
- *Lack of Strategic Investment and Prioritization:* The qualitative data suggested that AI efforts have not yet gotten the consistent, strategic investment necessary for largescale adoption, even though this was not specifically quantified.
- *Clear Alignment on High-Impact AI Use Cases:* Despite the difficulties, stakeholders found a number of high-priority AI applications, including as automated customs inspection, real-time yard optimization, cargo security, and predicted vessel ETAs, that directly address Takoradi's operational pain points.

5.0 CONCLUSIONS

Basically, what we found is that people at Takoradi Port get the idea of Artificial Intelligence and are really keen to use it. They see how it could help. However, right now, the port is facing some practical problems. Their computer systems are a bit all over the place, they don't have enough people with the right skills, and there aren't clear guidelines for using AI responsibly. All of this makes it difficult to smoothly introduce AI into managing risks at the port and makes it harder for them to bounce back quickly when things go wrong in the supply chain. Even with these challenges, the fact that there's a clear link between understanding AI and seeing better results when facing disruptions shows that AI has massive potential to improve things. The port has some great ideas about how to use AI, and a chance to really jump ahead of the competition. They're at a key moment.

To really make the most of AI and stay competitive in the global shipping world, Takoradi Port needs a well-planned and thorough upgrade of its digital systems and processes. This means not just investing in technology, but, even more importantly, training staff, changing policies, and having leaders with a clear vision. This will help them close the gap between knowing about AI and actually using it effectively. It will also allow them to move from simply reacting to problems to predicting and preventing them. We'll talk more about what all this means and how to put it into action in the next section.

5.2 AI Awareness vs. Readiness: The "Knowledge-Implementation Asymmetry

One key takeaway from this study is the clear gap between knowing about AI and actually putting it into practice at Takoradi Port. The numbers show that people there are quite familiar with AI (a good average score, with many giving high ratings) and really keen to use it (a very strong connection shown by the data). This suggests that the port is open to new ideas and sees the good that AI could do. However, this understanding and excitement don't translate into feeling ready to actually use AI. Readiness scored lower on average, and fewer people felt very ready. This kind of gap isn't unusual; it's been seen in other developing countries where people often understand new tech better than they're able to use it effectively [cite: Wamba-Taguimdje

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et al., 2020]. We can understand this better using the Diffusion of Innovations Theory. People at Takoradi clearly see the "advantage" of AI and can "observe" how it's helped other ports. However, the "complexity" of AI and the difficulty of "trying it out" in their specific situation seem to be holding them back. The strong link between knowing about AI and wanting to use it suggests that once people grasp the benefits, they're eager to adopt it. But the lower readiness scores suggest that AI doesn't seem to "fit" easily with their current systems, and it's hard to "experiment" with it. This creates a mental and practical barrier: people are convinced AI is valuable, but they don't feel equipped or able to make it happen.

This aligns with research emphasizing that using new tech in logistics successfully requires more than just the technology itself; it also needs changes to how things are done and good strategies for managing change. The gap at Takoradi suggests that while they "know" about AI's potential, they're struggling to "implement" it because they lack plans for changing operations, training staff, and integrating AI into their existing processes. But, is this "awareness" a true indication of willingness, or just surface-level enthusiasm based on current trends, without a real grasp of the complexities, costs, and potential disruptions of AI? Perhaps people are exaggerating their knowledge or willingness to seem modern. Getting truly ready means moving beyond abstract ideas to a solid understanding of what AI needs (like good data, computer power, and ethical considerations) and a realistic view of the effort required. Going forward, it's important to focus on hands-on learning and pilot projects that show the practical effects of AI, rather than just the theoretical advantages, to build a more realistic sense of readiness.

5.3 Risk Management: From Reactive to Predictive Paradigms

The study clearly shows that Takoradi Port's approach to managing risks is largely hands-on, unstructured, and focused on dealing with problems after they happen. Interviews revealed that managers depend heavily on their personal experience, gather information manually, and analyze events after they've already taken place, instead of proactively using data to anticipate issues. This is a major problem because it doesn't align with the fast-paced, ever-changing world of maritime trade. Continuing to react to problems as they arise isn't sustainable when things are changing so quickly and disruptions can easily spread. As Ivanov and Dolgui (2021) point out, truly resilient supply chains need to be designed to be tough from the start, which means using forecasting tools, real-time information, and AI-powered simulations. What we saw at Takoradi – like manual cargo checks, reacting to incidents after they occur, and a lack of digital tools to predict risks – confirms this significant shortcoming. For example, the frequent delays in customs clearance reported by those we spoke to are a direct result of manual processes that don't anticipate and address problems ahead of time.

What this means in practice: While the experience of the port's people is valuable, it has limitations. It's hard to scale, keep consistent, and process the huge amounts of complex data needed to spot early warning signs. In a reactive system, disruptions are usually handled through on-the-spot solutions and extra resources after something has already happened, which leads to longer recovery times and higher expenses. A predictive system, powered by AI, would allow the port to anticipate, for example, potential bottlenecks based on ship schedules, weather forecasts, and past performance. This would enable proactive adjustments to things like berth assignments or cargo handling plans. This shift is essential for moving from simply reacting to crises to systematically preventing or significantly reducing their impact

5.4 AI as a Resilience Enabler: Empirical Validation and Mechanism

A key takeaway from this study is strong evidence supporting the idea that AI can significantly boost how well supply chains bounce back from problems. Our data showed a clear connection between understanding AI, feeling prepared to handle risks, and actually recovering more effectively from disruptions (with strong positive relationships indicated by $r=0.90$ and $r=0.94$). This means that as people become more familiar with AI and their organizations get better at using it, they also feel more confident in their ability to weather any storm at the port. This aligns well with the established theory of supply chain resilience, specifically the four key abilities described by Pettit and colleagues: seeing problems coming, absorbing the initial impact, adjusting to the new reality, and getting back on track quickly. AI can greatly improve each of these areas:

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Seeing problems coming: AI, using its ability to learn from data and predict future events, can analyze huge amounts of information (like weather, ship movements, equipment data, and global news) to spot potential issues before they even happen. This shifts the port from simply reacting to problems to proactively preventing them.

Absorption: While AI can't physically absorb shocks, it can improve how resources are used and create more adaptable plans, helping the system handle the initial impact better. For instance, AI can optimize berth scheduling to create some wiggle room that absorbs small delays without causing bigger problems.

Adaptation: AI-based simulation tools (like digital twins) let port managers quickly create models of different disruption scenarios and try out various adaptation strategies, allowing for fast operational adjustments in real-time.

Recovery: AI can optimize recovery plans by analyzing current data during a crisis and recommending the most effective way to allocate resources (like cranes, workers, and tugboats) to get operations back to normal quickly. This significantly cuts down on recovery time and related expenses.

5.5: To illustrate the mechanism of AI's resilience-enhancing capabilities, consider the following comparative table:

Function / Capability	*Traditional (Manual/Reactive) Approach at Takoradi*
Digital Yard Optimization	**Current State:** Manual processes for container stacking and retrieval. Limited real-time visibility of container locations. Inefficient use of yard space. **Impact:** Increased dwell times for containers, higher operational costs due to manual labor and search times, potential for misplacement, reduced throughput.
Predictive Vessel ETA	**Current State:** Reliance on traditional vessel tracking systems (e.g., AIS) and manual communication for estimated arrival times. Limited ability to account for dynamic factors like weather or unexpected congestion. **Impact:** Suboptimal berth allocation, increased vessel waiting times, higher fuel consumption for waiting vessels, challenges in coordinating landside logistics.
AI-based Risk Prediction	**Current State:** Reactive risk identification based on past incidents and human experience. Limited proactive analysis of potential operational, security, or environmental risks. **Impact:** Inability to anticipate and mitigate risks, leading to more frequent and impactful disruptions, prolonged recovery efforts, and increased vulnerability to novel threats.
Cybersecurity Framework	**Current State:** Basic cybersecurity measures, often fragmented and reactive. Limited or no specific framework for protecting AI systems or managing data privacy within AI applications. **Impact:** High susceptibility to cyber-attacks (e.g., ransomware, data breaches), potential for operational paralysis, legal and reputational risks, hesitation to adopt advanced digital systems due to security concerns.
Disruption Recovery Dashboard	**Current State:** Manual coordination and communication during disruptions. Limited real-time situational awareness across all departments. Recovery plans are often ad-hoc and experience-based. **Impact:** Slower recovery times, inefficient resource allocation during crises, lack of comprehensive postincident analysis for continuous improvement, prolonged economic losses.
Staff AI Literacy	**Current State:** Low to moderate AI literacy among the general workforce, with a significant skills gap in specialized AI roles (e.g., data scientists, AI engineers). Limited structured training programs. **Impact:** Resistance to new technologies, inability to effectively utilize AI tools if implemented, reliance on external consultants, slower adoption rates, and a bottleneck for digital transformation.

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This table makes it clear that Takoradi Port isn't as advanced as the "typical modern port" when it comes to using AI and digital technology. They're still doing a lot of things by hand, their systems don't always talk to each other, and they're often just reacting to problems instead of predicting them. This puts them at a disadvantage compared to other ports that are embracing digital tools. For example, while the most advanced ports are using AI to predict when ships will arrive and automatically manage their storage yards, Takoradi is still struggling to get basic information connected. But this also means there's a big chance to improve. Because Takoradi isn't as huge as ports like Singapore or Rotterdam, and they're already working on improvements like a new automated loading dock, they could potentially "jump ahead." Instead of slowly upgrading their systems step-by-step, they could directly implement more cutting-edge AI solutions, as long as they have a clear plan, consistent funding, and work hard to overcome the challenges they face. The fact that people at the port are eager to adopt AI makes this opportunity even more promising.

5.6 Summary of Findings

A multifaceted picture of AI's current state and prospective influence at Takoradi Port is revealed by the thorough data analysis, which integrates both quantitative and qualitative findings.

High AI Awareness, Low Implementation Readiness: A notable "knowledge implementation asymmetry" exists in that while a sizable majority of stakeholders (65%) are aware of AI's potential, just 45% believe the technology is ready for real-world use. This disparity emphasizes the necessity of converting conceptual knowledge into useful skills.

Dominance of Manual and Reactive Risk Management: Reactive responses, human experience, and manual procedures are the mainstays of current risk management procedures and disruption recovery initiatives. The port is susceptible to long-term effects from frequent disruptions like labor strikes, customs delays, and traffic because only 30% of recovery procedures are data-driven.

Strong Positive Correlation between AI Awareness/Readiness and Resilience Outcomes: The quantitative research showed that perceived risk management readiness, effective disruption recovery, and AI awareness all had very high positive connections. According to this empirical link, improving the port's overall resilience requires promoting AI knowledge and creating basic readiness.

Structural and Institutional Barriers to AI Integration: Qualitative interviews consistently pinpointed critical impediments:

- *Fragmented Digital Infrastructure:* AI requires real-time visibility, which is hampered by data silos created by a lack of connectivity across several departmental systems.
- *Human Capital Deficits:* A notable deficiency in workforce competencies in data science, AI engineering, and basic digital literacy.
- *Regulatory Uncertainty and Governance Gaps:* The lack of explicit regulations for cybersecurity, ethics, and AI governance causes hesitancy and restricts the use of AI in vital tasks.
- *Lack of Strategic Investment and Prioritization:* The qualitative data suggested that AI efforts have not yet gotten the consistent, strategic investment necessary for largescale adoption, even though this was not specifically quantified.
- *Clear Alignment on High-Impact AI Use Cases:* Notwithstanding the difficulties, stakeholders found a number of high-priority AI applications—such as automated customs inspection, real-time yard optimization, cargo security, and predictive vessel ETAs—that directly address Takoradi's operational pain points.
- *Significant Digital Maturity Gap with Opportunity for Leapfrogging:* Takoradi's early stage of AI integration is validated by benchmarking against international smart ports. But instead of taking a strictly incremental approach, its smaller scale and continuous modernization initiatives offer a special chance to strategically leapfrog by using integrated AI solutions.

5.7 Conclusion

This chapter paints a picture of Takoradi Port as a fertile ground for Artificial Intelligence. While stakeholders grasp the idea of AI and are eager to adopt it, the port's actual workings are

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held back by a disconnected digital system, a shortage of skilled personnel, and a lack of clear AI guidelines. These problems together hinder the smooth introduction of AI into maritime safety protocols, restricting the port's ability to bounce back quickly from disruptions and reach its full potential in the supply chain.

However, the clear link between understanding AI and believing in its benefits for resilience highlights its game-changing power. The promising AI applications, combined with the chance to accelerate its development, show that Takoradi Port is at a critical moment. To realize AI's full potential and secure its place in the global maritime world, the port must embark on a well-planned digital transformation.

This requires not only investing in new technology but, more importantly, training staff, updating policies, and having forward-thinking leaders who can bridge the gap between knowing about AI and using it effectively. This will allow them to move from simply reacting to problems to anticipating them. The following chapter will further discuss these findings and their strategic meaning.

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