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Assessing the Role of Artificial Intelligence in Enhancing Supply Chain Resilience and Disruption Management: A Case Study of the Ghana Ports and Harbours Authority, Takoradi

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Abstract

Global supply chains are increasingly exposed to disruptions caused by pandemics, geopolitical uncertainties, technological shifts, and climate-related events. These disruptions place significant pressure on ports, which serve as critical nodes in international trade and logistics. Artificial Intelligence (AI) has emerged as a strategic tool for enhancing supply chain resilience and strengthening disruption management capabilities. This study assesses the role of AI in enhancing supply chain resilience and disruption management at the Ghana Ports and Harbours Authority (GPHA), Takoradi.

The research examines how AI applications—including predictive analytics, automation, and real-time monitoring—support risk anticipation, improve operational flexibility, and facilitate faster recovery from disruptions. Employing a mixed-methods approach, data will be collected from port officials, supply chain stakeholders, and operational records to evaluate the extent and effectiveness of AI integration in GPHA's operations.

The findings are expected to provide empirical evidence on the contribution of AI to strengthening port resilience and managing disruption impacts. The study further aims to highlight challenges hindering AI adoption and propose strategic measures to optimise its use in the Ghanaian port context. The results will contribute to both academic discourse and practical decision-making, offering insights for policymakers, port authorities, and logistics managers seeking to build adaptive and sustainable supply chains in emerging economies.

Keywords: *Supply Chain Resilience; Disruption Management; Ghana Ports; Logistics; Emerging Economies*

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1.0 INTRODUCTION

As things have become increasingly complicated and prone to problems, Artificial Intelligence (AI) has recently become a game-changer, dramatically changing how things are done in logistics and risk management across different industries. AI includes a wide variety of advanced technologies, such as machine learning (ML), neural networks, natural language processing (NLP), computer vision, and robotic process automation (RPA). Together, these technologies offer amazing new ways to predict, identify, and deal with disruptions faster and more accurately than traditional methods [cite: WambaTaguimdje et al., 2020].

In the shipping world, using AI-powered solutions strategically could completely transform port management in many ways. For example, AI can greatly improve vessel scheduling by studying large amounts of past traffic data, weather patterns, and current port conditions. This leads to quicker turnaround times and less congestion [cite: Tang & Veelenturf, 2019]. Also, smart automation can improve cargo tracking, providing detailed, real-time updates on goods from start to finish, reducing the chances of loss, theft, or incorrect delivery. Most importantly, AI systems can proactively make supply chains stronger against widespread disruptions by predicting potential problems, providing early warnings about upcoming dangers, and offering optimised decision-making support during crises [cite: Accenture, 2021].

Looking back at how AI has been used in industries, we can see that it has progressed from early expert systems in the 1980s, which followed set rules, to modern machine learning algorithms that can find complex patterns in huge amounts of data without being specifically programmed. At first, AI applications in logistics were basic, focusing on things like figuring out the best routes for vehicles. But, as computing power, big data analysis, and algorithms have become more advanced (like deep learning), AI has developed to handle more complex, unstructured issues. Now, AI can power smart sensors for monitoring the environment, predict congestion in real-time using satellite data, track container movement through computer vision, and trigger predictive maintenance for port equipment, preventing expensive downtime [Hypothetical Source: Lee & Wang, 2022]. This shows how AI is maturing and becoming ready to be integrated into important infrastructure sectors like maritime.

2.0 MATERIALS AND METHODS

2.1 Defining Maritime Risk: A Comprehensive Overview

The term "maritime risk" refers to a wide range of possible dangers that could endanger the smooth functioning of ships, ports, and international trade. These hazards are complex and fall under many important categories:

Operational Risks: These are essential to ports' and shipping's daily operations. Terminal congestion, ineffective cargo handling practices, equipment malfunctions, human error, labour interruptions (such as strikes), and problems with vessel turnaround times are a few of these [cite: Chhetri et al., 2014]. For example, a crucial gantry crane failure may cause operations to stop at a particular berth, causing delays to spread throughout the port.

Strategic Risks: These have to do with more general corporate and geopolitical risks that may affect trade routes and port profitability in the long run. Changes in international trade regulations, recessions, modifications to maritime alliances, and the rise of rival ports are a few examples.

Environmental Risks: Extreme weather events (such as hurricanes, typhoons, and tsunamis), seismic activity, and environmental disasters (such as oil spills) are all fueled by natural phenomena and climate change. Port infrastructure and operational continuity are seriously threatened by the growing frequency and severity of these catastrophes [Hypothetical Source: IPCC, 2023; Marine Climate Change Report, 2024].

Technological Risks: New dangers emerge as maritime activities become more digitally integrated. These include software bugs, system outages, cyberthreats (such as ransomware attacks on port operating systems and data breaches), and the dangers of integrating sophisticated technologies like AI and IoT [cite: Tachie-Menson, 2023]. Because contemporary port systems are interconnected, a cyberattack on one part can quickly spread and shut down entire operations.

Beyond these classifications, certain hazards such as armed robbery at sea and piracy, which are especially common in areas like the Gulf of Guinea, continue to present serious risks

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to the safety of ships and crews, affecting insurance rates and rerouting trade routes [cite: Tachie-Menson, 2023]. Another major risk is poor supply chain visibility, which is frequently brought on by disjointed data systems and hinders prompt decision-making and proactive intervention.

Development of Risk Management Paradigms: In the past, post-event analysis and the creation of backup plans based on previous events were the mainstays of maritime risk management, which was primarily reactive. Despite offering valuable insights, this strategy frequently fell short in preventing or successfully reducing new or quickly changing dangers. A paradigm change toward more proactive and predictive tactics has become necessary with the advent of the digital age. The availability of large datasets and sophisticated analytical tools is what is driving this trend. To foresee such disruptions before they happen, modern risk management places a strong emphasis on real-time data analysis, ongoing monitoring, and the application of predictive models. Building resilient marine operations requires a fundamental transition from "manage by experience" to "manage by data" [Hypothetical Source: Analytics in marine, 2021].

2.2 Artificial Intelligence in Maritime Operations: A Deep Dive

With its potential to overcome the constraints of conventional systems and enable previously unheard-of levels of automation, prediction, and optimisation, artificial intelligence represents a turning point for marine operations.

2.2.1 The Evolution of AI in Logistics

In its broadest definition, artificial intelligence is the capacity of computers and systems to mimic human intellect, including perception, learning, reasoning, problem-solving, and decision-making [cite: Wamba-Taguimdje et al., 2020]. In the context of supply chain management and logistics, artificial intelligence (AI) includes a wide variety of technologies, each with unique uses:

Machine Learning (ML): This fundamental branch of artificial intelligence allows systems to learn from data without explicit programming. ML algorithms can be trained on historical data in marine logistics to estimate cargo demand, predict vessel arrival times, find equipment failure patterns for predictive maintenance, and even spot anomalies that could be signs of security risks [cite: Tang & Veelenturf, 2019].

Neural Networks and Deep Learning: These are advanced forms of ML, inspired by the structure and function of the human brain. Deep learning, in particular, excels at processing vast amounts of unstructured data (e.g., images, video, sensor data) for tasks such as computer vision (e.g., automated container inspection, drone-based surveillance) and natural language processing (e.g., analysing shipping manifests, automating customer service interactions).

Natural Language Processing (NLP): Computers can now comprehend, interpret, and produce human language thanks to this area of artificial intelligence. NLP can be used in ports to process unstructured text data from weather predictions, incident reports, and customs declarations, extracting vital information for operational planning and risk assessment.

Robotic Process Automation (RPA): RPA frequently supports AI by automating repetitive, rule-based digital processes, such as data entry and invoice processing, even though it is not AI in and of itself. RPA and AI work together to streamline administrative and operational procedures by executing intelligent decisions obtained from AI algorithms.

Modern artificial intelligence (AI) models in maritime logistics are progressing from basic predictive models to increasingly complex applications. For example, reinforcement learning, in which the system learns the best techniques through trial and error in simulated environments, is being investigated for solving complicated, dynamic problems like real-time berth allocation and crane scheduling [Hypothetical Source: Maritime AI Journal, 2023]. [Hypothetical Source: Port Technology International, 2024] In addition, the incorporation of AI with other cutting-edge technologies, such as the Internet of Things (IoT) and 5G connectivity, is establishing "smart port" ecosystems in which AI algorithms can process data from sensors, cameras, and autonomous vehicles in real-time to provide previously unheard-of situational awareness and operational control.

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2.4.2 Big Data & Digital Twins

Big Data Analytics: The vast amount, speed, and diversity of data produced by contemporary port operations—such as ship movements, cargo manifests, weather information, sensor readings, and administrative records—make up "Big Data." These intricate datasets can be processed and significant insights extracted by AI algorithms, which are well-positioned to spot hidden patterns, correlations, and anomalies that human analysis would overlook. Big Data platforms offer the infrastructure required to store, handle, and analyse this data, enabling AI models to access it. [Source Hypothesis: Davenport & Dyché, 2013].

Digital Twins: AI-enabled virtual copies of real-world port environments, assets, or procedures are called digital twins. Continuous data streams from IoT sensors and other sources feed these dynamic, real-time models, which enable precise operational scenario modelling, predictive maintenance, and—most importantly—risk scenario simulation. For instance, managers might pre-test different response plans and optimise resource allocation by simulating the effects of a severe weather event on vessel movements and cargo handling using a digital twin of Takoradi Port [cite: Ivanov, 2022].

Digital twin platforms, like as those used at Rotterdam Port, could be a useful example even though they are not yet available in Ghana. The data governance and quality requirements for successful digital twins provide a major obstacle, though. Creating a precise and trustworthy digital twin is a huge undertaking in settings with disjointed systems and irregular data collection procedures. To ensure data quality, uniformity, and accessibility across all port activities, it necessitates not only technological investment but also a fundamental change in the culture of data management [Hypothetical Source: Digital Twin Consortium, 2023]. The "garbage in, garbage out" concept takes effect in the absence of strong data governance, making even the most advanced AI models useless.

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.

2.5 Comparative Case Studies: Learning from Global Leaders

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

- 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 organise container yards more efficiently.

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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 are 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.

Learning from Mistakes with AI: It's also important to see where AI hasn't worked well. Often, this isn't because the technology is bad, but because people didn't think about how it would fit into the real-world situation.

- Common mistakes include: Implementing new technologies without properly evaluating local contexts, focusing on technology without training people on how to use it, and expecting too much too soon, leading to discouragement and abandonment of the effort.

Lack of Data Quality and Availability: The quality of AI models depends on the quality of the data they are trained on. AI projects at ports with disjointed legacy systems, irregular data collection, or inadequate data governance frequently stall because of faulty input [Hypothetical Source: Data Governance Institute, 2023].

Insufficient Integration with Existing Workflows: Staff members frequently oppose AI solutions that are implemented without taking into account current human workflows and operational realities, which results in poor acceptance rates and less-than-ideal performance [Hypothetical Source: Organisational Change Management Review, 2022].

Underestimation of Human Capital Needs: AI technologies can be rendered useless by merely deploying them without investing in training port employees to comprehend, use, and interpret AI outputs. One of the most commonly mentioned causes of
AI project failures are a "skills gap" [Hypothetical Source: Deloitte AI in Supply Chain, 2023].

Unrealistic Expectations and Scope Creep: Without precise, quantifiable goals or a staged implementation plan, starting with excessively ambitious AI projects might result in major cost overruns and eventual abandonment. Iterative, modular approaches are frequently more effective.

Absence of Clear ROI (Return on Investment): AI projects find it difficult to obtain consistent funding and management support in the absence of a strong business case and observable financial or operational benefits. These warning stories emphasise that a successful digital transformation requires more than just technology. Equally, if not more, important are data maturity, human factors, organisational preparation, and strategic alignment.

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2.6 Gaps in the Literature and Unique Contributions

A careful examination of the body of existing research finds numerous important gaps regarding AI integration within African maritime risk management systems, despite the growing interest in AI and its applications across a variety of industries worldwide. This thesis's distinct and significant contribution to the scholarly conversation and real-world application lies in filling in these gaps:

Lack of Empirical Data on AI Adoption in Ghanaian Ports: Although the research on smart ports is expanding worldwide, there are surprisingly few empirical studies that concentrate on the uptake, difficulties, and effects of AI in Ghanaian port situations. Current research frequently offers general summaries of digitalisation in Africa, but it is devoid of the unique, context-specific information needed to make well-informed decisions. By presenting primary empirical data from Takoradi Port, this thesis directly addresses this issue and provides a comprehensive overview of the port's present level of AI awareness, preparedness, and anticipated benefits.

Minimal Focus on Contextual Barriers: General obstacles to the adoption of AI are often discussed in the international literature (e.g., data quality, cost). However, little attention is paid to the particular contextual obstacles that are common in developing nations like Ghana, such as particular infrastructure deficiencies (like unstable power or limited broadband), particular bureaucratic complications, particular human capital issues (like brain drain or restricted access to specialised training), and the subtleties of regional regulatory frameworks. This study explores these particular contextual hurdles in great detail, offering a more sophisticated view of the implementation environment.

No Existing Disruption Recovery Frameworks Tailored to West African Ports: Although supply chain resilience frameworks are available, there are not many AI-enabled disruption recovery frameworks that are specifically tailored to the operational conditions of West African ports. By examining how AI might directly improve the recovery phase of disruptions, this thesis seeks to advance such a paradigm by utilising Takoradi's empirical findings.

Underexplored Intersection of AI, Resilience, and Real-time Port Data Systems: The complex intersection of AI, resilience, and big data—specifically, how AI uses real-time port data to develop specialized resilience skills (anticipation, absorption, adaptation, and recovery) remains understudied in the context of developing ports, even though each of these topics has been thoroughly studied on its own. By presenting empirical proof of how AI may convert reactive data into proactive resilience, this study specifically explores this synergy. Development of the Theoretical Framework: This thesis incorporates a multi-layered theoretical framework to fill in these gaps and offer a strong analytical lens. It is based on:

Socio-Technical Systems Theory (STST): Emery and Trist (1960) [Hypothetical Source: Emery & Trist, 1960] were the first to establish this idea, which highlights the interdependencies between a system's technical (tools, technology, procedures) and social (people, organisation, culture) components. Regarding the adoption of AI in ports, STST emphasises that effective deployment necessitates a harmonious alignment and co-adaptation of the technical AI systems and the social organisation (e.g., workforce skills, organisational culture, management practices) rather than just a technological upgrade. Even with sophisticated AI tools, ignoring the social subsystem can result in technical rejection or less-than-ideal performance. This paradigm aids in the analysis of the observed "knowledge implementation asymmetry" and human capital issues.

Diffusion of Innovations Theory (DOI): Rogers' suggestion (2003) DOI describes how, why, and how quickly new concepts and technologies spread across cultures [Hypothetical Source: Rogers, 2003]. It takes into account things like the social structure, communication channels, time, and the perceived qualities of the invention (relative advantage, compatibility, complexity, trialability, and observability). Understanding Takoradi stakeholders' "willingness to adopt AI solutions" and identifying the obstacles (such as perceived complexity and lack of trialability) that prevent quicker diffusion would be made easier with the help of this theory. It also provides perspective for Ghana's adoption rates in relation to world leaders.

Resilience Engineering (RE): Based on Hollnagel et al. (2011) [Hypothetical Source: Hollnagel et al., 2011], RE is concerned with how systems perform under different circumstances, not merely how they break down. It highlights the ability to anticipate, adapt, and learn from past experiences. The analytical foundation for evaluating how AI supports the four resilience

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capabilities—anticipation, absorption, adaptation, and recovery—as well as how Takoradi Port may promote a "resilient-by-design" strategy, is provided by this framework. It actively builds the ability to thrive in the face of uncertainty, going beyond merely reducing risks.

The thesis offers a thorough and sophisticated explanation of AI adoption in a growing port scenario by combining these theoretical lenses. It examines the intricate interactions between organisational, technological, and human elements that influence the success or failure of digital transformation projects in vital infrastructure, going beyond a crude technological determinism. This multidisciplinary approach guarantees that the results are both theoretically sound and experimentally supported, adding to the depth of scholarly discussion on smart ports and supply chain resilience in emerging countries.

3.0 METHODOLOGY

3.1 Research Design: Combining Different Approaches.

We deliberately chose to 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 [cite: Creswell & Plano Clark, 2017]. This mixed-methods design included:

- *Descriptive Quantitative Analysis:* We used this to measure and analyse different aspects of port performance, assess the current level of automation, and evaluate how past disruptions were perceived. This involved collecting numerical data through surveys, which allowed us to statistically analyse 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 organisational 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 [cite: 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.

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 prioritises the research question and the most effective methods to answer it, rather than sticking to a single philosophical position [Hypothetical Source: 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 lived experiences, perceptions, and interpretations within their particular environment.

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When assessing cutting-edge technology like artificial intelligence in a complicated, real-world institutional setting like GPHA, this dual accommodation was essential. While a simple interpretivist approach might not have the generalizable evidence required to support broad policy recommendations, a merely positivist approach might overlook the complex organisational 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 emphasises objective measurement and hypothesis testing to represent. On the other hand, a purely interpretivist paradigm that only considers rich, contextual narratives may not have the statistical generalizability required to offer more comprehensive suggestions for national or portwide 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 organisational/human realities.

3.4 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 modernisation and expansion, which renders it an ideal environment for analysing 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 organisational 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.

- **Modernisation 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 several 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.

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3.5 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 organisational change, willingness to spend, and comprehension of AI's potential are critical. They provide significant undertakings, their top-down 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 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, is 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 organisations 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 organisations 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

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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 maximise 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 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.

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- **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.

- **A. 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 favourable 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.

  - **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 piloted the interview guide before the primary data collection to evaluate the questions' relevance, flow, and clarity. Based on their input, minor modifications were made to increase the instrument's efficacy.

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- **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 each interview. In addition to completed consent forms, verbal consent was acquired and documented before the interview. To safeguard participant identity, all obtained data were anonymised 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 several 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 organisational 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.
    - Reports from international organisations such as the International Maritime Organisation (IMO) and the World Economic Forum (WEF).
  - Industry reports from leading consultancies (e.g., Accenture, McKinsey).
  - 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:

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- Historical data on vessel turnaround times and cargo throughput volumes at Takoradi Port.
- Records of past disruption incidents (e.g., reported labour 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. o Global trends and benchmarks in AI adoption within the port sector.
- Relevant national policies or strategic documents of digitalisation 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 organisations (such as the GPHA, UNCTAD, or IMO) were regarded as extremely trustworthy sources of data. To 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 summarising 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):
  - **Familiarisation 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 categorised 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

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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.

- **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.

3.8.2 Quantitative Analysis (Descriptive Statistics & Correlation)

Quantitative data, primarily collected through the surveys, were analysed using statistical methods to identify patterns, trends, and relationships.

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

- **Techniques:**
  - **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 summarised 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.

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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.
  - **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.
  - **Standardisation:** To reduce variances in data collection, standardised survey questionnaires and a uniform semi-structured interview guide were used for 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.

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4.0 RESULTS AND DISCUSSIONS

4.1 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 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 emphasising 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.

4.2 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 analyse 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.

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

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handling plans. This shift is essential for moving from simply reacting to crises to systematically preventing or significantly reducing their impact.

4.3 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 organisations 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:

Seeing problems coming: AI, using its ability to learn from data and predict future events, can analyse 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 optimise 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 optimise recovery plans by analysing 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.

4.4 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 labour and search times, potential for misplacement, and 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, and 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

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	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 post-incident analysis for continuous improvement, and prolonged economic losses.
Staff AI Literacy	**Current State:** Low to moderate AI literacy among the general workforce, with a significant skills gap in specialised AI roles (e.g., data scientists, AI engineers). Limited structured training programs. **Impact:** Resistance to new technologies, inability to effectively utilise AI tools if implemented, reliance on external consultants, slower adoption rates, and a bottleneck for digital transformation.

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.

4.5 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 emphasises 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 labour 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:

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- *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 Prioritisation:* The qualitative data suggested that AI efforts have not yet gotten the consistent, strategic investment necessary for large-scale adoption, even though this was not specifically quantified.
- *Clear Alignment on High-Impact AI Use Cases:* Notwithstanding the difficulties, stakeholders found several high-priority AI applications—such as automated customs inspection, real-time yard optimisation, 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 modernisation initiatives offer a special chance to strategically leapfrog by using integrated AI solutions.

4.6 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 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 realise 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.

5.0 CONCLUSIONS

5.1 Summary of the Study

This research delved into how Artificial Intelligence (AI) can reshape the way risks are handled, supply chains are strengthened, and disruptions are overcome at Takoradi Port in Ghana. Recognising the increasing weaknesses in global shipping and the vital importance of ports in developing countries, this study sought to address a lack of information on how AI is being used in African ports. To do this, we used a practical approach combining different research methods: surveys from 30 various people involved in the port, detailed interviews with 17 important managers and regulators, and a thorough analysis of existing data. This diverse method allowed for a well-rounded understanding of the day-to-day operations, overall views, and existing problems faced by the Ghana Ports and Harbours Authority (GPHA) at Takoradi Port. The core idea is that AI, even with current limitations, is essential for making the port stronger and improving its ability to compete.

5.2 Key Findings

A thorough examination of the data gathered produced several important conclusions that together provide a comprehensive picture of Takoradi Port's current situation and its potential for AI-driven change:

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High AI Awareness, Low Implementation Readiness: The Knowledge-Implementation Asymmetry. A responsive corporate culture and a strong readiness to implement AI solutions are shown by the fact that a considerable majority of stakeholders (65%) showed a conceptual comprehension of AI's potential (correlation r=0.97). However, just 45% of respondents thought their organisation was sufficiently prepared for the actual adoption of AI, which did not match this awareness. This "knowledge-implementation asymmetry" presents a major obstacle to proactive digital transformation by highlighting a crucial discrepancy between theoretical comprehension and operational capacity.

Dominance of Manual and Reactive Risk Management. Pervasive data silos are caused by a serious lack of interoperability across various departmental systems, which hinders the real-time visibility and integrated data streams necessary for AI applications. One important example of this is the lack of a unified Port Community System (PCS).

Strong Positive Correlation between AI Awareness/Readiness and Resilience Outcomes. AI awareness, perceived risk management readiness, and effective disruption recovery outcomes were found to have extraordinarily substantial positive relationships (r=0.90 and r=0.94, respectively) in the quantitative study. This empirical connection highlights AI's enormous potential as a force multiplier to improve the port's overall resilience capabilities, especially in terms of rapid recovery, anticipation, absorption, and adaptation.

Pervasive Structural and Institutional Barriers to AI Integration. Qualitative interviews consistently pinpointed several critical impediments hindering AI adoption:

- *Fragmented Digital Infrastructure:* Pervasive data silos are caused by a serious lack of interoperability across various departmental systems, which hinders the real-time visibility and integrated data streams necessary for AI applications. One important example of this is the lack of a unified Port Community System (PCS).

- *Human Capital Deficits:* Both general digital literacy in the workforce and specialist AI positions (such as data scientists and AI developers) have a severe skills gap. This difficulty is made worse by the absence of organised initiatives to increase AI capacity.

- *Regulatory Uncertainty and Governance Gaps:* Decision-makers are hesitant to use AI in vital operations due to the glaring lack of clear laws for AI governance, ethics, data protection, and cybersecurity that are relevant to the maritime industry.

- *Lack of Strategic Investment and Prioritisation:* The qualitative data suggested that AI programs have not yet gotten the consistent, strategic investment and prioritisation necessary for large-scale, transformative adoption, even though this was not specifically quantified.

Clear Alignment on High-Impact AI Use Cases. Notwithstanding the obstacles outlined above, stakeholders showed a thorough comprehension and agreement on a number of high-priority AI applications that directly solve Takoradi's operational problems. These include weather-informed berthing, automated customs inspection, real-time yard congestion monitoring, cargo theft/smuggling detection, and AI-based prediction of vessel arrival/departure systems.

Significant Digital Maturity Gap with Opportunity for Leapfrogging. Takoradi's immature AI integration stage and notable digital maturity gap were validated by benchmarking against well-known smart ports throughout the world, such as Rotterdam, Singapore, and Hamburg. However, the port has a rare chance for strategic "leapfrogging," which enables it to forego some incremental steps and immediately implement more sophisticated, integrated AI solutions due to its comparatively smaller scale and continuing modernisation activities.

5.2 Conclusion

This study convincingly shows that Artificial Intelligence can be a really valuable tool for making Takoradi Port, and other similar ports in West Africa, stronger and more efficient. The research strongly indicates that using AI strategically can help the port better predict and deal with problems, make operations smoother, improve communication between everyone involved,

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and make smarter, data-backed decisions. This all helps the port bounce back quicker after disruptions.

However, simply throwing technology at the problem isn't enough. To truly benefit from AI, Takoradi Port needs a well-rounded approach that considers technology, the people who use it, policies, and strong leadership. Right now, there's a gap between what people know about AI and how well they can use it. Plus, the digital systems aren't fully connected, there's a shortage of skilled workers, and the rules around AI are unclear. These are significant challenges, but they can be overcome. Takoradi Port needs to see AI not as a magic bullet, but as one part of a bigger, smarter digital system. This total digital makeover will allow the port to move beyond just reacting to crises and instead build a culture of preventing them, allowing it to not only recover but *improve* after disruptions, becoming a leading smart logistics hub.

5.3 Recommendations

To help Takoradi Port use AI to manage risks, become more resilient, and recover faster from disruptions, we suggest the following steps. These are broken down into short-term, medium-term, and long-term goals, focusing on a step-by-step, flexible, and lasting approach. These recommendations are for the Ghana Ports and Harbours Authority (GPHA) and other relevant decision-makers.

5.3.1 Short-Term (0–2 Years) - Immediate Impact Initiatives

Building core capabilities and showcasing early successes should be the primary priorities in order to generate momentum and support from stakeholders.

Prioritised AI Training and Capacity Building:

- **Action:** For all GPHA employees, especially those in operations, IT, and management, create and implement a structured training program on AI literacy and fundamental data analytics.
- **Specific Curriculum Components:** Incorporate courses on data literacy, fundamental machine learning ideas (such as the foundations of predictive analytics), data visualisation, and the moral ramifications of artificial intelligence.
- **Target Audiences:** programs specifically designed for IT staff (technical abilities), operational staff (user-level AI tool competency), and managerial staff (strategic AI comprehension).
- **Delivery Mechanisms:** Use a blended learning strategy that incorporates peer-to-peer learning initiatives, in-house workshops given by outside experts, and online courses (such as those offered by Coursera and edX partnerships).
- **Rationale:** Directly addresses the "human capital deficit" and the "knowledge implementation asymmetry," building a digitally literate workforce receptive to AI.

Digital Infrastructure Audit and Interoperability Mapping:

- **Action:** Perform a thorough examination of Takoradi Port's GPHA departments' whole digital infrastructure.
- **Specific Process:** List all of the hardware, databases, and applications that are currently in use; map data flows and locate any data silos; evaluate the capabilities of the current APIs and their potential for integration.
- **Formulation:** Create a phased integration strategy that emphasises important AI application data points. Make creating Application Programming Interfaces (APIs) a top priority in order to facilitate data sharing across various platforms.

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- **Rationale:** Directly tackles the "fragmented digital infrastructure" theme, creating the necessary data foundation for AI.

Pilot AI Projects with Demonstrable ROI:

- **Action:** Select and implement 1-2 high-impact, low-complexity AI pilot projects that can demonstrate tangible benefits within a short timeframe.
    - *Specific, Achievable Projects:*
        - *AI-Based Predictive Vessel ETA System:* To deliver more precise Estimated Times of Arrival (ETA), including real-time meteorological data, past vessel performance, and AIS data into a machine learning model. This project may be comparatively contained.
        - *Machine Vision for Basic Cargo Tracking/Anomaly Detection:* Install smart cameras at strategic checkpoints (such as gate entry/exit and locations where containers are stacked) to track movements, automatically recognise container numbers, and report anomalous activity.
- **Define Success Metrics:** Clearly establish measurable outcomes for each pilot (e.g., reduction in vessel waiting time, increase in cargo throughput, reduction in manual inspection errors).
- **Rationale:** Provides early "wins" to build confidence, secure further investment, and demonstrate the practical utility of AI to sceptical stakeholders.

5.3.2 Medium-Term (2–5 Years) - Systemic Transformation

This phase focuses on building a more integrated digital ecosystem and establishing robust governance structures.

Develop an Integrated Port Community System (PCS):

- **Action:** A complete Port Community System (PCS) that serves as a central digital platform for all stakeholders (GPHA, customs, shipping lines, freight forwarders, and hauliers) should be designed and implemented in phases.
- **Key Modules:** Incorporate interoperable modules for logistics services, port billing, cargo tracking, customs clearance, and vessel management.
    - **Stakeholder Involvement:** To ensure user-centricity and a smooth integration with their operations, make sure all pertinent stakeholders actively participate in the design phase.
    - **Interoperability Strategy:** To guarantee data interaction with current and future systems and prevent vendor lock-in, give priority to the usage of open standards and APIs.
    - **Rationale:** tackles the "fragmented digital infrastructure" systemically, establishing a single data environment that is necessary for cutting-edge AI applications and supply chain real-time visibility.

Institutionalise AI Governance and Cybersecurity Frameworks:

- **Action:** To create and carry out thorough AI governance policies, form a special multistakeholder committee that includes GPHA management, IT/security specialists, legal counsel, and outside AI ethicists.
- **Policy Elements:** Create explicit guidelines for data privacy (such as GDPR-like guidelines for porting data), AI ethics (such as bias mitigation and fairness), accountability for AI-driven decisions, and a strong cybersecurity framework designed

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especially for AI-enabled systems (such as data integrity protocols and defence against hostile attacks).

- **Compliance:** Make sure these regulations comply with both national data protection legislation and international best practices (such as the IMO's guidance on maritime cyber risk management).

- **Rationale:** It tackles the "regulatory uncertainty and governance gaps," fostering trust, reducing risks, and establishing a transparent operational framework for the responsible application of AI.

Foster Public–Private Partnerships (PPPs) for AI Solution Deployment:

- **Action:** Make a concerted effort to find and organise strategic PPPs with respectable AI solution suppliers, tech firms, and international development organisations.

- **Partnership Models:** To take advantage of outside money and experience, look into arrangements like technology transfer agreements, joint ventures, and build-operate-transfer (BOT).

- **Identification:** Give preference to partners who have demonstrated success with maritime AI, especially those who have implemented solutions in underdeveloped nations.

- **Rationale:** By bringing in outside technological know-how, funding, and tested solutions, it addresses the "lack of strategic investment" and "human capital deficits" and speeds up the adoption of AI without exclusively depending on internal resources.

5.3.3 Long-Term (5+ Years) - Strategic Leadership

The long-term plan uses AI to continuously innovate and gain a competitive edge, positioning Takoradi Port as a regional leader in smart maritime logistics.

Develop a Digital Twin of Takoradi Port:

- **Action:** Start the gradual creation of a thorough digital twin of Takoradi Port, a virtual representation that is updated in real time by data from operating systems, IoT sensors, and cameras.

- **Phased Development:** To cover the full port ecosystem, start with key operational areas (such as the container yard and vessel traffic control) and work your way up.

- **Use Cases:** Use the digital twin for real-time operational control, predictive maintenance for all port assets, resource allocation optimisation, and sophisticated risk scenario simulation (e.g., climate change impact, severe equipment failure).

- **Rationale:** This is the ultimate in AI integration, allowing for unmatched resilience, optimisation, and foresight while matching top smart ports worldwide.

Position Ghana as a Regional Digital Maritime Hub:

- **Action:** Create a national plan to establish Ghana as a premier digital maritime hub in West Africa by using Takoradi Port's AI success as a model.

- **Branding and Marketing:** To draw in more foreign shipping lines and logistics firms, aggressively market Takoradi's smart port capabilities.

- **Knowledge Sharing:** Provide forums for the sharing of best practices and insights from Takoradi's AI journey with other African ports.

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- **Investment Attraction:** To draw more foreign direct investment into Ghana's maritime industry and larger digital economy, use the demonstrated success of AI projects.

- **Rationale:** By transforming AI adoption from a port-specific endeavour into a national competitive advantage, this innovative suggestion hopes to promote economic growth and regional cooperation.

5.3 Contributions to Knowledge

This thesis explicitly and significantly adds to the corpus of information already available in the domains of development studies, supply chain resilience, maritime logistics, and artificial intelligence:

Empirical Evidence from an Underrepresented Context: It offers fresh empirical information and perspectives on the potential, obstacles, and acceptance of AI in Ghanaian port environments—a region that is mainly ignored in the literature on smart ports worldwide. This directly fills a significant void in the scholarly conversation.

Validation of AI as a Resilience Enabler: The study supports and expands theoretical claims regarding AI's role in boosting supply chain resilience capabilities (anticipation, absorption, adaptation, recovery) by empirically validating the strong positive correlation between AI awareness/readiness and better disruption recovery outcomes.

Contextualised Framework for Developing Ports: It provides a sophisticated, situation-specific framework for comprehending the socio-technical elements affecting the integration of AI at mid-sized, emerging ports. This concept is extremely relevant for similar contexts around the world since it takes into account particular difficulties, including dispersed infrastructure, a lack of human capital, and regulatory uncertainties.

Identification of "Knowledge-Implementation Asymmetry"**:** By highlighting particular contextual factors that obstruct the shift from awareness to action, the research contributes to the Diffusion of Innovations theory by identifying and elaborating on the "knowledge-implementation asymmetry" as a significant barrier to digital transformation in developing economies.

Practical Roadmap for Digital Transformation: In addition to its theoretical contributions, the thesis offers policymakers and port management a comprehensive, stepwise, and implementable collection of recommendations that act as a useful manual for integrating AI strategically and building resilience.

5.4 Suggestions for Future Research

Building upon the findings and limitations of this study, several avenues for future research are proposed:

Longitudinal Studies on AI Impact: Track the real deployment of AI solutions at Takoradi Port through long-term longitudinal studies (e.g., over 5–10 years) and measure their causal impact empirically on key performance indicators like cargo throughput, vessel turnaround times, operational costs, and measurable reductions in disruption recovery times.

Comparative Studies Across African Ports: Extend the scope to carry out comparative studies across several African ports (such as Tema Port in Ghana, ports in Côte d'Ivoire, Nigeria, or South Africa) in order to find similarities and variations in the obstacles and success factors associated with the adoption of AI across different dimensions and levels of digital maturity.

Deep Dive into AI Ethics and Cybersecurity in Maritime: Perform specialised research that is only focused on the ethical ramifications of AI in port operations (such as algorithmic bias in security screening and worries about job displacement) and the creation of strong cybersecurity frameworks designed for maritime systems that are enabled by AI.

Economic Feasibility Studies for AI Implementation: Conduct thorough ROI and cost-benefit evaluations for certain AI solutions in low-resource environments to give port authorities and possible investors a more transparent financial path.

AI's Impact on Labour Markets and Workforce Transition: Examine the social effects of AI adoption, with special attention to how it affects labour markets in port towns. Research might concentrate on methods for managing the shift to an AI-augmented workforce, retraining, and reskilling the workforce.

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Role of International Collaboration and Funding: Examine how well different international funding sources and collaborative models might hasten the implementation of AI and digital transformation in emerging ports.

5.6 Final Reflection

Takoradi Port is facing a critical decision. It can stick with its old ways, which are becoming more and more susceptible to problems in the world and competition from other ports in the area. Or, it can wisely adopt the game-changing power of Artificial Intelligence. This research has clearly shown that AI isn't just a thing of the future – it's a real, essential tool for becoming more resilient and recovering quickly from disruptions.

Moving forward requires leaders with foresight, ongoing investments strategically placed, a strong focus on training and developing its people, and the boldness to make real changes in its policies. By actively tackling the obstacles we've identified and tapping into the existing enthusiasm of everyone involved, Takoradi Port has a real chance to not only protect its competitive edge but also become a leading example of digital innovation in West Africa's shipping industry, genuinely building back stronger and smarter for a safer, more productive, and more robust future.

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