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A Blockchain-Integrated Framework for Secure and Efficient Container Release in the Smart Port of NEOM, Saudi Arabia

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Abstract

This study develops a Blockchain-based operational framework specifically designed for the Port of NEOM to address a key gap in digital port operations. Unlike previous research, this model aligns with both Vision 2030 and NEOM Port's unique requirements. It integrates four core technologies: blockchain encrypted storage, automated smart contracts, real-time IoT data collection, and secure digital identity management. This architecture offers a comprehensive solution for rapid, error-free container clearance, while enhancing data security, transparency, and regulatory compliance. By aiming to reduce average clearance time by 40%, the model can significantly improve port efficiency. The study establishes NEOM Port as a leading example and provides a scalable framework for global smart port initiatives. A descriptive-analytical approach was employed to systematically review prior research on Blockchain applications in supply chains and port operations. The findings indicate that integrating Blockchain technology with smart contracts, the Internet of Things, and digital identity can enhance data exchange among stakeholders, accelerate customs procedures, increase transparency, and reduce errors, thereby strengthening security throughout port operations. The study recommends piloting the model at NEOM Port and updating regulatory frameworks to support the adoption of Blockchain technologies in port management.

Keywords
Blockchain, Smart Port of NEOM, Supply chain, Logistics performance indicators, Saudi Vision 2030.

1. Introduction
In the past two decades, the port and shipping industries have undergone significant digital transformation. Advances in automation, data analytics, artificial intelligence (AI), and blockchain technology have driven these changes, resulting in increased transparency, efficiency, and security within logistics operations. As global trade networks expand and supply chains become more complex, the need for data integrity, operational transparency, and cyber resilience has intensified (Liu et al., 2021; Kshetri, 2017). Within this context, blockchain has emerged as a critical enabler for smart port operations by providing a distributed, immutable, and tamper-resistant ledger. This ledger, accessible to all participants and resistant to unilateral alteration, enhances traceability, accountability, and trust among port stakeholders (Casino et al., 2018; Wang et al., 2020).

Despite technological advancements, data fragmentation, reliance on manual documentation, and slow customs clearance continue to impede port performance. Case studies from the Port of Rotterdam, Singapore's Smart Trade Corridor, and Hamburg Port demonstrate that blockchain systems can reduce documentation delays, expedite container release, and enhance real-time data sharing (Ahmad et al., 2022; Taramonli et al., 2024). While these initiatives highlight blockchain's potential, they also reveal challenges related to interoperability, cybersecurity, and regulatory harmonization (Wood et al., 2023). The proposed NEOM Port framework addresses these issues by

implementing standardized protocols to resolve interoperability concerns and employing advanced encryption to strengthen cybersecurity. These measures are designed to ensure that blockchain integration aligns with international standards and establishes a robust, secure operational environment.

At the national level, Saudi Arabia's Vision 2030 prioritizes integrating blockchain and other emerging technologies to advance digital transformation, sustainability, and operational excellence across key sectors, including logistics and transportation. Multiple Saudi initiatives have explored blockchain applications in finance, healthcare, and education, reflecting the Kingdom's increasing preparedness to implement this technology within critical infrastructure (Alahmari et al., 2023).

Within this framework, NEOM's Port introduces a blockchain-based model for secure container release, designed to enhance port efficiency, data governance, and transparency. The model aligns with Vision 2030 objectives for a sustainable and globally competitive logistics sector. It utilizes a private blockchain network managed by port authorities, ensuring clear data ownership, accountability, and regulatory compliance. In contrast to public blockchain consortia such as TradeLens, this approach provides greater flexibility and control within the Saudi digital governance context (Guan et al., 2024).

This study examines a blockchain-based framework for secure and automated container release at NEOM Port. The research connects global blockchain implementations with local Saudi port innovations, providing both theoretical and practical insights to inform future digitalization efforts.

1.1 Objectives

This study proposes a blockchain-based framework to automate container release at NEOM Port, combining blockchain, smart contracts, IoT, and digital identity management to ensure secure and efficient operations. The study aims to:

Automate operations with smart contracts to reduce manual tasks and expedite processing, aiming to save approximately 20 minutes per transaction and decrease administrative workload by 30%.

Enhance transparency and data integrity using an immutable Blockchain ledger for secure transactions, targeting a 25% reduction in data errors and ensuring compliance with international standards.

Enable real-time cargo monitoring via IoT to improve situational awareness and decision-making, aiming to reduce cargo misplacement incidents by 40% and enhance monitoring accuracy by 50%.

Implement secure digital identities for authentication and accountability across all transactions, resulting in a projected 15% increase in data access efficiency and enhanced security compliance.

Support NEOM Port's alignment with Vision 2030 by modeling smart, sustainable, and secure port operations, contributing to a 35% reduction in carbon footprint and aligning operational excellence with Vision 2030 sustainability goals.

Achieving these objectives will allow NEOM Port to implement a scalable framework that streamlines operations, builds stakeholder trust, and strengthens security. This model could serve as a reference for blockchain adoption in ports and supply chains worldwide.

2. Literature Review

The literature on digital transformation in ports and supply chain management reflects a growing global emphasis on automation, transparency, and data security as critical drivers of operational competitiveness. Over the past two decades, ports worldwide have increasingly integrated emerging technologies such as Blockchain, Artificial Intelligence (AI), and the Internet of Things (IoT) to enhance logistics efficiency and support smart infrastructure initiatives (Liu et al., 2021; Kshetri, 2017).

The purpose of this literature review is to examine and synthesize prior research related to the use of Blockchain technology in port and supply chain operations, with a focus on its role in improving data management, container tracking, and process automation. Existing studies highlight that Blockchain's distributed ledger architecture provides a tamper-resistant and transparent digital record of logistics transactions, reducing data fragmentation and enhancing trust among stakeholders (Casino et al., 2020). Accordingly, the literature review is structured as follows:-

- **Section 2.1** discusses the concept and fundamental principles of Blockchain technology and its relevance to digital port ecosystems.
- **Section 2.2** investigates Blockchain applications in supply chain management, concentrating on cybersecurity, IoT integration, and automation.

By combining results from various fields, this review provides a comprehensive theoretical foundation for understanding how Blockchain can improve next-generation port operations' sustainability, efficiency, and transparency.

2.1 Blockchain Technology in Smart Port Operations

Blockchain technology is recognized as a key driver of smart and transparent port operations. Khaksari (2019) and Guan et al. (2024) note that its distributed ledger architecture stores transaction data in sequential, encrypted blocks, ensuring immutability and data integrity. Decentralization provides greater security, removes intermediaries, and enables cross-port real-time validation.

International programs like TradeLens (IBM and Maersk) and the Port of Rotterdam Blockchain Consortium illustrate Blockchain's Possibilities for port logistics. These initiatives increased speed of document verification, less paperwork, and improved traceability (Ahmed & Rios, 2022; Niels & Moritz, 2017). These cases highlight Blockchain's the capacity to maximize cargo flow, cut down on administrative hold-ups, and reduced expenses for operations. Including smart contracts with blockchain in conjunction automates processes for operation. Panda et al. (2018) and Kshetri (2017) highlight that smart contracts enable self-executing agreements, triggering actions like container release once conditions, payments, and documentation are verified. Automation reduces errors, increases consistency, and speeds up clearance, which is especially relevant for NEOM's port management. Combining Blockchain with the Internet of Things (IoT) is a key trend in maritime digitalization.

Taramonli et al. (2024) and Zafar et al. (2021) report that IoT sensors collect container data such as temperature, location, and security status, which is recorded on Blockchain networks for real-time visibility and tamper-proof traceability. Integrating digital identity systems further enables secure authentication for organizations and devices.
Despite these benefits, studies identify ongoing challenges. Tsiulin et al. (2023) and Wood et al. (2023) cite regulatory uncertainty, interoperability issues, and infrastructure costs as major barriers to large-scale Blockchain adoption in ports. The lack of standardized data governance and cross-border interoperability limits scalability.

Yazdi et al. (2024) assessed adoption priorities using a Blockchain-based smart port framework and Multi-Criteria Decision Analysis. Their study found that investment cost and regulatory complexity are major challenges, while transparency, cost-effectiveness, and resilience are key enablers. These findings align with Tsiulin et al. (2023), who also identified transparency as crucial for stakeholder trust in maritime projects.

Recent literature places Blockchain within the broader smart city and sustainability agenda. NEOM's digital logistics and infrastructure for renewable energy sources, in accordance with the NEOM Port Report (2025), place it as a strategically important testing ground for Blockchain-enabled port frameworks. The studies examined highlight both the advantages and difficulties of Blockchain execution in logistics in the maritime industry, stressing the need for regulatory frameworks that adapt and incorporated digital ecosystems.

1.2 Blockchain in Supply chain managements

Over the past two decades, supply chain digitalization has increasingly relied on advanced technologies most notably Blockchain, Artificial Intelligence (AI), and the Internet of Things (IoT) to enhance performance, security, and transparency. As stated by Casino et al. (2018) and Guan et al. (2024), Blockchain's distributed ledger architecture (DLA) makes it easier to record sequential, transactions that are encrypted without centralized middlemen, hence changing reliable data sharing within worldwide networks for logistics.

Despite being initially conceived for the cryptocurrency, Blockchain has quickly changed into essential part of the infrastructure across port management systems & logistics. Its decentralized nature minimizes paperwork, speeds up the processing of documents, and reduces disparities in data among stakeholders (Ahmed & Rios, 2022).

Numerous international ports, including Rotterdam, Singapore, and Hamburg, have piloted Blockchain systems to digitize customs clearance and optimize container flow (Khaksari, 2019; Taramonli et al., 2024).

Empirical studies demonstrate that the integration of Blockchain with Smart Contracts enables automated document exchange and payment validation, reducing reliance on manual verification (Panda et al., 2018). Similarly, combining Blockchain and IoT technologies allows real-time container tracking, significantly improving supply chain transparency.

According to Zafar et al. (2021), such incorporation can lower operating expenses by up to 30% and reduce the cycle time for loading and unloading by approximately 40%. Furthermore, Blockchain's decentralized encryption model enhances cybersecurity within digital supply chains by distributing data across multiple nodes, making it resistant to manipulation (Wang et al., 2018). This is particularly critical in port environments handling sensitive trade and customs documentation. However, Tsiulin et al. (2023) caution that issues such as regulatory fragmentation, data standardization, and interoperability continue to constrain large-scale adoption.

In the Saudi context, Blockchain adoption aligns closely with the objectives of Vision 2030, which seeks to position the Kingdom as a global logistics hub. The NEOM Port, with its infrastructure for renewable energy and integration of digital technologies, is a perfect place to test blockchain applications in smart logistics. In line with the NEOM Port Report (2025), the mean container reside time of 24 hours by Blockchain-enabled automation is projected to decrease by half, demonstrating the transforming possibility of digital logistics.

Table 1 demonstrates an analyses that compare between international ports disclose both possibilities and obstacles. For example, while the Trade Corridor of Singapore emphasizes regulatory interoperability, the Rotterdam Port highlights IoT-Blockchain integration for carbon decrease. Conversely, NEOM's framework incorporates renewable energy and digital identity management to encourage environmentally friendly automation. These analogies propose that Blockchain's achievement depends not only on technological preparedness but also on institutional assistance, workers training, and legal adjusting.

Table 1. Smart Ports analytical comparison summary

Feature	Neom Port	Rotterdam	Singapore	Hamburg
Blockchain Use	Planned integration between customs and supply chains.	Pilot projects led by a consortium of cargo for tracking companies.	Customs Clearance and Trade Documents.	Pilots in container logistics & port community systems.
Smart Features	AI, IoT, 5G, digital twins aligned with Vision 2030.	IoT sensors + Blockchain pilots.	Digital trade corridor with Blockchain-IoT synergy.	Automation, AI decision-support, Blockchain pilots.
Sustainability	Green logistics, renewable energy integration.	Carbon reduction via digitalization.	Green plan with Blockchain-enabled traceability.	Sustainability roadmap linked with EU policies.
Challenges	Regulation, training, infra cost.	Stakeholder adoption, scalability.	Cybersecurity, multi-stakeholder coordination.	Integration complexity, high investment costs.

Figures 1 and 2 display both the expected benefits and primary challenges of implementing Blockchain in ports of the sea. The main benefits mentioned in the literature are depicted in Figure 1, including improved data security, lower operating costs, and increased transparency.

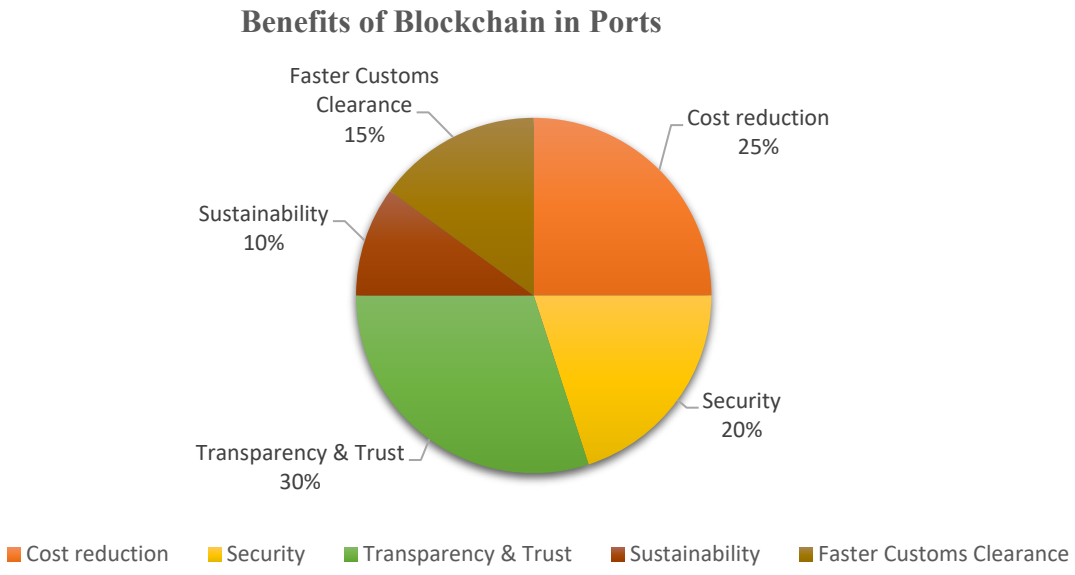

Figure 1. Benefits of Blockchain in Ports

Figure 2 lists the primary barriers, such as investment requirements, interoperability issues, cybersecurity worries, and regulatory ambiguity. Critical insights into the effects of Blockchain adoption can be gained by analyzing these images. It draws attention to the necessity of striking a balance between implementation challenges and operational benefits in port environments.

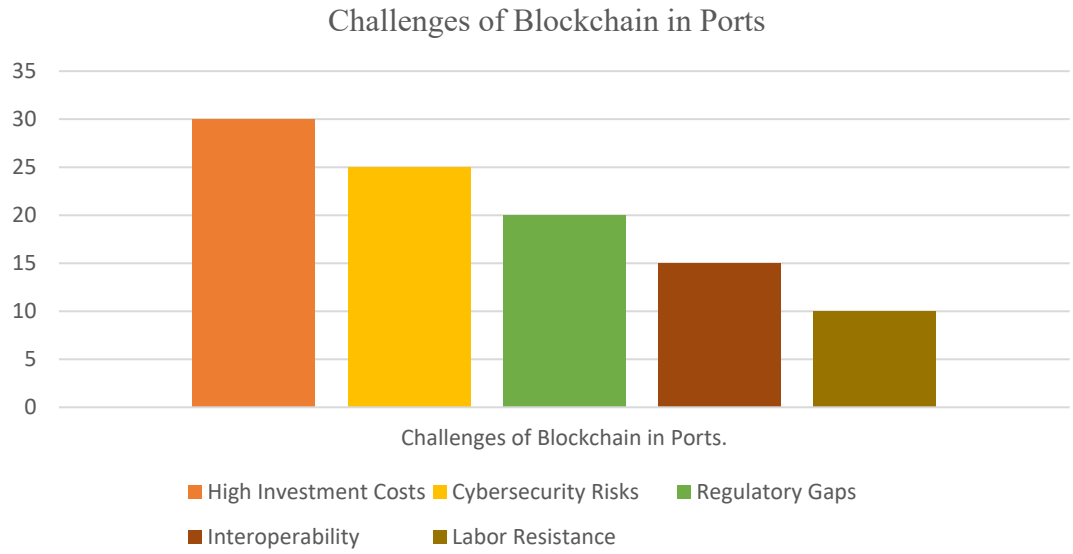

Figure 2. Challenges of Blockchain in Ports.

2. Research Gap

Based on previous literature on the benefits of integrating Blockchain technology with other technologies, including Smart Contracts, the Internet of Things (IoT), and Digital Identity, into global smart port initiatives. This study outlines a comprehensive model tailored to the NEOM Port within its operational and regulatory context and highlight

the need to develop a proposed model that integrates the aforementioned technologies to improve port operations, enhance transparency, and ensure stakeholder collaboration.

3. Conceptual Framework

Based on the results of this analysis, a Blockchain-based model was proposed to provide higher levels of security and transparency, as well as to automate container release and tracking operations. NEOM Port was used as a practical application model.

3.1 The Data Layer

This framework guarantees data unchangeable, honesty, and transparency, which are essential to preserving operational dependability. Every transaction, encompassing results of customs inspections, payments for duties, and coming in of containers, is documented in chronological order on the Blockchain to make a impenetrable trail of audits. This permits authorized gatherings, such as customs officers, Port officials and shipping brokers, to check the data genuineness without middlemen in real time.

By reducing documentation errors and verification delays, NEOM Port can improve turnaround time and accuracy while cutting costs by an estimated $10 per container. Take, for example, a situation in which 1,000 "reefers," or refrigerated containers, were processed in July. Together with a turnaround time reduction of roughly five hours per container, NEOM Port could save a total of $10,000 for those containers alone by minimizing errors. The efficiency and cost-effectiveness of the model are demonstrated by this noticeable improvement. Because every transaction is securely timestamped and verifiable, immutable records also make it easier to resolve disputes between shipping and customs entities. This layer creates the basis for data-driven rivalry and cost effectiveness . Figure 3 illustrate a conceptual view of the blockchain Data layer at our proposed framework.

Figure 3. Blockchain architecture of the Data layer

2.2 The Smart Contracts Layer

The Smart Contracts Layer automates operational procedures within the Blockchain ecosystem. These digital contracts execute automatically when predefined conditions, such as fee payment, document submission, or customs inspection, are met.

At NEOM Port, smart contracts validate fields including Harmonized System (HS) codes, duty receipt numbers, and shipment verification IDs. Upon validation, the system automatically triggers two actions:

1. Authorizes container release.
2. Updates corresponding Blockchain entries in the Data Layer.

This automation reduces human intervention and operational errors, while increasing execution speed and consistency. The result is a streamlined, transparent release process that ensures reliability across all port operations. However, when automation encounters exceptions or complexities beyond its programmed scope, trained staff intervene to handle them manually, ensuring accountability and maintaining system integrity. This blend of automation and human oversight enhances system resilience and aligns with best practices in operational reliability. Table 2 represent the comparative analysis of using this layer over traditional manual used method at port of NEOM.

Table 2. Evaluation metrics for Smart contract process

Metric	Traditional process	Smart contract process
Processing Time	Manual review: 2-4 hours	Automated: Seconds to minutes
Error Rate	5-10% human error rate	Near-zero error rate
Consistency	Variable (human judgment)	100% consistent application
Transparency	Limited documentation	Complete audit trail
Availability	Business hours only	24/7 automated processing
Cost per Transaction	Higher (labor-intensive)	Lower (automated)

3.3 The Communication Layer (IoT Integration)

The Communication Layer integrates Internet of Things (IoT) devices, such as sensors and tracking modules, with the Blockchain network to enable real-time monitoring of containers, cargo, and port equipment. At the scenario of NEOM Port, IoT sensors capture key operational data, including temperature, humidity, location, and cargo integrity, and transmit it directly to the Data Layer. Every sensor examples each 5 seconds with ±0.1°C precision, making sure superior quality data for computerized contract carrying out.

This incorporation permits smart contracts to react in a dynamic manner to changes in the environment or logistics, like sending out alerts or releasing holds in the event that temperature thresholds are surpassed. By connecting these temperature warnings to particular provisions in service-level agreements (SLAs), NEOM Port able to specify precise contractual duties and sanctions, improving openness and responsibility level for each and every party.

For instance, if there is a temperature breach, the SLA may require that all stakeholders be notified right away and that corrective actions begin quickly. The alert gives detailed information to the shipper, consignee, customs officials, and insurance providers. The Communication Layer helps everyone stay informed, makes the supply chain more visible, and reduces the risk of compliance penalties for temperature-sensitive goods. Table 3 presents the aspects utilized in this study to achieve robust results.

Table 3. Evaluation aspect for IoT-Enabled Communication Layer.

Aspect	Traditional Manual Monitoring	IoT-Enabled Communication Layer
Data Frequency	Manual checks (hourly or less)	Automated every 5 seconds
Alert Response Time	Hours (manual notification)	Seconds (automated alerts)
Data Accuracy	Subject to human error	±0.1°C precision sensors
Breach Detection	Delayed or missed	Immediate detection
Documentation	Manual, paper-based	Automated, blockchain-recorded
SLA Enforcement	Dispute-prone, subjective	Transparent, automated, verifiable
Compliance Reporting	Manual compilation (hours/days)	Auto-generated (seconds)

3.4 The Security and Identity Layer

The Security and Identity Layer enhance system reliability through decentralized digital identity (DID) management. Each participant, whether human, corporate, or device, receives an encrypted digital identity issued and regulated by the NEOM Port Authority.

All transactions are cryptographically linked to their respective digital identities, ensuring traceability and accountability. In cases of identity disputes or unauthorized activities, a Conflict Resolution Committee uses Blockchain audit trails to verify authenticity and resolve issues transparently.

This decentralized approach enhances trust, compliance, and governance by ensuring that only verified entities can access, modify, or authorize transactions. It also aligns with global best practices in digital identity management and cybersecurity for smart port ecosystems.

3.5 Framework Implications

The proposed framework transforms NEOM's container release process from a manual, paper-based system to a fully automated, secure, and transparent digital model. It supports data-driven decision-making, reduces human dependency, and advances the sustainability and innovation goals of Vision 2030. By integrating Blockchain, IoT, and smart contracts, NEOM Port can set a benchmark for regional and global smart port excellence.

Figure 4: Flow Diagram: Illustrative of the proposed model for applying Blockchain technology to secure container release operations at Port of NEOM. It demonstrates the integration of the data layer, smart contracts layer, IoT connectivity layer, and security and identity layer, ensuring secure and efficient digital management of shipping and customs clearance operations.

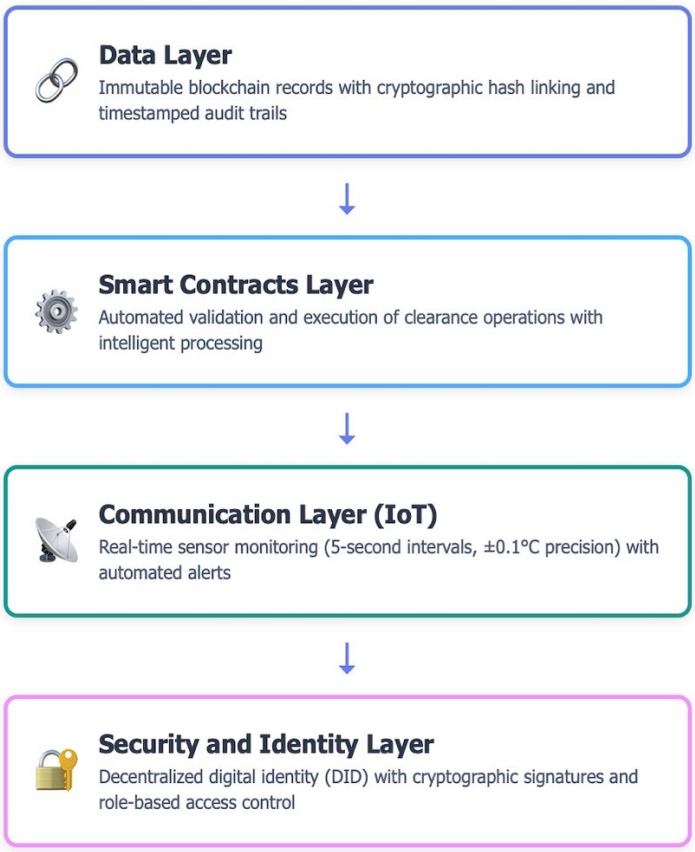

Figure 4. Integrated Blockchain Model for Container Release Operations at Port of NEOM.

Looking ahead, a two-year roadmap could be envisioned to ensure the framework's adaptability and resilience as technologies evolve. Initially, a pilot phase could be launched within six months to test the core functionalities and refine processes under real-world conditions. Subsequently, a scaling phase could expand the implementation across all operational sectors of NEOM Port over the following year, leveraging lessons learned to enhance efficiency and effectiveness. Finally, the framework could move towards federating with other ports and systems globally, creating a network of interconnected smart ports by the end of the second year. This forward-looking perspective not only reinforces investor confidence but also positions NEOM Port at the forefront of global smart port developments.

3. Methodology

3.1 Research Design and Approach

This study adopted a descriptive–analytical methodology underpinned by a systematic review and synthesis of peer-reviewed literature, technical reports, and international case studies related to Blockchain implementation in ports and supply chains. This design enabled a comprehensive, evidence-based understanding of how Blockchain contributes to secure data exchange, transparency, and operational efficiency in container release procedures.

The rationale for adopting this methodological approach lies in its ability to integrate empirical findings and theoretical insights from multiple sources, thereby capturing both technological mechanisms (e.g., smart contracts, IoT integration, and digital identities) and organizational dynamics (e.g., regulatory adaptation and stakeholder acceptance). The descriptive–analytical framework facilitated the identification of critical success factors, implementation barriers, and strategic opportunities for adapting global best practices to the NEOM Port context.

3.2 Systematic Literature Review

A systematic literature review (SLR) was conducted following the PRISMA 2020 framework to ensure methodological transparency and replicability. Relevant studies published between 2017 and 2024 were identified from databases including Scopus, Web of Science, Science Direct, and IEEE Xplore using search terms such as Blockchain, port logistics, smart port, supply chain digitization, and container release.

After applying inclusion and exclusion criteria, a final corpus of 9 studies was selected, covering both conceptual models and applied case studies in maritime logistics. These studies provided the analytical foundation for evaluating Blockchain's capabilities in improving traceability, transparency, and automation, while identifying regulatory and interoperability challenges that hinder broader adoption in port ecosystems.

3.3 Expert Consultation and Delphi Method

To complement the academic analysis with practitioner insights, the study integrated expert interviews and a Delphi panel discussion. The Delphi panel consisted of 4 domain experts, including port employee, logistics coordinators, customs officials, and digital transformation specialists from the Middle East and Europe.

A notable finding from the Delphi process was the unanimous agreement on the importance of streamlining customs procedures as a pivotal enabler of efficiency. This insight was essential in refining the proposed Blockchain model for NEOM Port, ensuring real-world applicability and contextual relevance.

3.4 Triangulation and Validation

The methodology in real-time will employ the data triangulation across three evidence streams:

1. Scholarly literature and case studies (secondary data)
2. Expert interviews and Delphi results (primary qualitative data)
3. Industry reports and port performance statistics (documentary data)

This triangulation increased the validity and reliability of the findings by cross verifying theoretical propositions with empirical observations.

By critically synthesizing insights from international smart port initiatives—such as the TradeLens platform at the Port of Rotterdam and the Smart Trade Corridor in Singapore the study established a robust empirical basis for contextualizing global Blockchain practices within NEOM's regulatory and operational environment.

Overall, this methodological framework ensures that the proposed Blockchain-based model for container release is both theoretically sound and practically implementable, bridging the gap between academic research and operational deployment in the context of Saudi Vision 2030.

4. Data Collection

The research integrates quantitative data on port operations with qualitative stakeholder feedback to evaluate the proposed Blockchain-based system for secure container release at NEOM's Port. The design assesses operational improvements alongside organizational, technical, and regulatory factors influencing Blockchain adoption.

4.1 Data Sources

Three primary sources of data must be gathered in order to establish a complete implementation of the framework:

1. Primary Data: The following groups should serve using semi-structured interviews and structured questionnaires:

- Officials from the port authorities (operations, customs, IT governance)
- Agents involved in shipping and logistics
- Officers who clear customs clearance
- Companies that provide technology for smart port systems

The selection of participants was based on their direct experience integrating digital systems and managing ports.

2. Secondary Data: Source should be collected from the following:

- Databases for NEOM Port operations (e.g., transportation of cargo, time needed for customs clearance, and indicators of cost effectiveness)
- National logistics reports published by the Ministry of Transport and Logistics Services.
- Reports on national logistics issued by the Ministry of Transportation and Logistics Services.

3. Data from Archives and Documents: Consists of regulatory frameworks, rules for port governance, and technical papers on the integration of Blockchain and IoT.

5. Results and Discussion

According on the suggested model, this study shows how a comprehensive framework for security, credibility, and transparency in port operations is established through the integration of Blockchain technology, smart contracts, the Internet of Things (IoT), and decentralized digital identity. The findings demonstrate how Blockchain can drastically lower human error and stop document falsification, two issues that traditional port management systems continue to face.

We can summarize the study findings as follows:

1) Container release operations are made more secure, transparent, and efficient by the suggested model for NEOM Port's use of Blockchain technology.
2) Data integrity is greatly enhanced at the data layer when transactions are kept in unchangeable, encrypted digital blocks that guard against manipulation. Blockchain thus guarantees trustworthy and extremely credible records for the appropriate authorities.

3) Containers are automatically released at the smart contract layer after being verified to meet predetermined requirements. Consequently, human error is decreased, and execution delays are avoided.
4) The container's sensors are used at the Internet of Things layer to track its location, integrity, and state. As a result, data flows continuously, facilitating quicker and safer decision-making.
5) Tracking and legal accountability are made possible by the encrypted digital identity at the digital identity layer. Because it stops unwanted access to data stored on the Blockchain system, it can be referred to as a security layer. According to international smart port standards, this system outperforms conventional techniques and instruments in terms of operational efficiency by cutting down on paperwork and processing time.

According to this technic model, every operational procedure, from container release to customs inspection, is automatically documented, validated, and kept in a tamper-proof. This immutable audit trail eliminates the chance of fraud, dishonesty, or unauthorized alteration by guaranteeing the authenticity and integrity of transactions. Adoption of Blockchain in the port environment of NEOM at the stakeholder level promotes accountability and trust between customs officials, port operators, and shipping companies.

Immediate access to verified, real-time data strengthens transparency, reduces potential disputes, and improves collaboration across operational entities. Consequently, the system enhances workflow harmony and overall port

efficiency.Furthermore, the integration of smart contracts effectively eliminates manual bottlenecks and procedural redundancies by automating clearance, verification, and release processes. This automation ensures consistency, reliability, and speed of execution, substantially minimizing delays resulting from human oversight or procedural congestion. The findings confirm that the model's automated architecture contributes directly to faster, more dependable port operations. Despite its substantial potential, several implementation challenges remain. These include the need for stakeholder training and capacity building, high initial infrastructure costs, and ongoing regulatory compliance to align with international maritime and data-protection standards. Moreover, maintaining system scalability as container volumes increase and ensuring interoperability with existing port management systems are essential to sustaining long-term effectiveness (Wood et al., 2023; Zhang et al., 2023). Importantly, the proposed model is fully consistent with the objectives of Saudi Arabia's Vision 2030, which emphasizes digital transformation, operational excellence, and sustainable logistics development (Ministry of Transport and Logistic Services, 2022). By positioning NEOM Port as a technologically advanced, automated, and secure smart port, the Kingdom can establish a global benchmark for maritime innovation. Compared with other international ports, NEOM's integration of Blockchain with IoT, AI, and renewable energy infrastructure represents a universal model for future-ready logistics ecosystems.

In brief, the analysis affirms the conclusion that the suggested Blockchain-based container publication framework offers a strongly, effective, and safety solution for contemporary port administration. By combining Blockchain with smart automation, the model provides a smooth and operations flow that is resistant to tampering, decreasing unauthorized releases and maintaining traceability at every phase. This approach not only improves data honesty and operational efficiency but additionally placed NEOM Port as a regional and global exemplar of enduring, technology-driven logistics creativity.

6. Conclusion

Blockchain technology has emerged as a transformative digital innovation in the modern smart port and global supply chain ecosystem, offering unprecedented levels of transparency, data integrity, and operational efficiency. Its decentralized architecture and immutable ledger ensure secure, verifiable, and real-time data exchange addressing the inefficiencies inherent in traditional port operations (Casino et al., 2018; Wang et al., 2020).

Findings from international case studies most notably at the Ports of Rotterdam and Singapore—underscore how the integration of Blockchain, smart contracts, and the Internet of Things (IoT) can substantially reduce operating costs, accelerate customs clearance procedures, and enhance inter-agency coordination across logistics chains (Ahmad et al., 2022; Taramonli et al., 2024). These global benchmarks provided critical insights for the development of the proposed Blockchain-based model for NEOM Port .

The proposed model comprises four interconnected layers: Data Layer – ensuring secure, immutable storage of transactions. The Smart Contracts Layer that automates release and customs processes. IoT Connectivity Layer: allowing for accurate data and real-time tracking. Data privacy, accountability, and authentication are ensured by the security and digital identity layer. This multilayered framework establishes a cohesive digital ecosystem that enhances container traceability, automates verification processes, and eliminates intermediaries, thereby fostering a seamless, reliable, and auditable port operation environment.

The findings also reveal that implementing such a model directly aligns with the strategic objectives of Saudi Vision 2030, particularly its emphasis on digital transformation, sustainability, and global logistics leadership (Ministry of Transport and Logistic Services, 2022). By positioning NEOM Port as a benchmark for Blockchain-enabled smart logistics, Saudi Arabia can lead regional efforts in establishing a secure, efficient, and technologically advanced maritime infrastructure. However, achieving this transformation requires addressing key implementation challenges, including establishing a clear regulatory framework, developing interoperability standards, and investing in human capital and technical training. These efforts will be essential for ensuring sustainable adoption and scalability as NEOM Port continues to expand.

In conclusion, this study shows how Blockchain technology, when combined with smart contracts and the Internet of Things, provides a comprehensive way to redefine supply chain operations and port management. The suggested NEOM Port framework demonstrates how Blockchain can improve sustainability, transparency, and challenge inside the Saudi maritime industry and act as a global model for next-generation electronic ports.

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Biography

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