

Blockchain Digital Transformation: Enhancing Port Efficiency and Competitiveness in Egyptian Maritime Logistics

Prepared By

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المستخلص

تتناول هذه الدراسة الإمكانيات المتقدمة لتقنية البلوك تشين في قطاع الموانئ المصري، مع التركيز على دورها في تعزيز الكفاءة الرقمية، ورفع مرونة العمليات، وترسيخ الثقة بين أصحاب المصلحة. ففي الوقت الذي أثبتت فيه موانئ عالمية مثل روتردام وسنغافورة وفالنسيا ولوس أنجلوس فعالية البلوك تشين في تبسيط سلاسل الإمداد البحرية، لا تزال الموانئ المصرية تواجه تحديات مرتبطة بالأنظمة التقليدية، وعدم وضوح الإطار التنظيمي، وضغوط التمويل، والمقاومة المؤسسية تجاه التحول الرقمي. ومن خلال دمج نتائج استبيانات أصحاب المصلحة مع تحليل دراسات حالة دولية، يقدم البحث تقييماً شاملاً لمستوى النضج الرقمي في موانئ محورية مثل الإسكندرية، وبورسعيد، ودمياط، والسخنة، مع تحديد العوائق الحرجة والفرص الاستراتيجية لنشر حلول البلوك تشين.

تؤكد النتائج أن تبني البلوك تشين في الموانئ المصرية ليس خياراً تقنياً فحسب، بل ضرورة لتعزيز الأداء اللوجستي، وترسيخ ريادة إقليمية في تيسير التجارة الرقمية، واستثمار الموقع الاستراتيجي لقناة السويس. وتخلص الدراسة إلى أن البلوك تشين يجب أن يُنظر إليه كمنصة أساسية لبناء الثقة والشفافية والسيادة الرقمية في عمليات الموانئ، وليس مجرد أداة لرفع الكفاءة التشغيلية.

استناداً إلى هذه الرؤى، تقترح الدراسة خارطة طريق مرحلية قابلة للتنفيذ، تشمل إصلاحات قانونية، ووضع أطر معيارية للتشغيل البيئي، وتوسيع مشاريع البلوك تشين التجريبية، وتعزيز الشراكات بين القطاعين العام والخاص، وبناء قدرات بشرية متخصصة. إن مواءمة تطبيقات البلوك تشين مع الاستراتيجية الوطنية للتحول الرقمي من شأنه تحويل المبادرات المتفرقة إلى منصة موحدة تُسهم في تطوير عمليات الموانئ، وجذب الاستثمارات، ودعم النمو المستدام في قطاع اللوجستيات البحرية المصري.

Abstract

This paper explores the potential of blockchain technology within the Egyptian port sector, emphasizing its role in enhancing digital capability, operational agility, and stakeholder trust. While global ports such as Rotterdam, Singapore, Valencia, and Los Angeles have demonstrated the effectiveness of blockchain in streamlining maritime logistics, Egyptian ports remain hindered by legacy systems, regulatory uncertainties, financial constraints, and institutional resistance. Through a combination of stakeholder surveys and analysis of international case studies, this research offers a comprehensive assessment of the digital maturity of key Egyptian ports such as Alexandria, Port Said, Damietta, and Sokhna, and identifies critical bottlenecks and strategic opportunities for blockchain deployment.

The findings affirm that blockchain adoption is not only feasible but essential for Egypt to enhance its logistics performance, assert regional leadership in digital trade facilitation, and leverage its strategic position along the Suez Canal. The study concludes that blockchain should be regarded not merely as an efficiency tool, but as a foundational enabler of trust, transparency, and digital sovereignty in port operations.

Based on these insights, Egypt can modernize its ports into 5th generation digital trade gateways, offering a scalable model for other nations in the Global South the paper proposes a phased, actionable roadmap emphasizing legal reform, standardized interoperability frameworks, pilot expansion, strengthened public private collaboration, and comprehensive capacity building. Aligning blockchain adoption with national digital strategy objectives can transform isolated pilots into a unified platform that improves port operations, attracts investment, and fosters sustainable growth in Egypt's maritime logistics sector.

Keywords: Blockchain, Maritime Logistics, Port Efficiency, Digital Transformation, NAFEZA, CargoX, Egypt.

1. Introduction

Ports serve as critical nodes in global trade networks, with their operational performance directly influencing a nation's competitiveness, trade costs, and supply chain resilience (Notteboom & Rodrigue, 2022, World Bank, 2022). In Egypt, the ports of Alexandria, Damietta, Port Said, East Port Said, and Ain Sokhna collectively handle a significant portion of national import and export activities (Ministry of Transport, Egypt, 2024). Their strategic location along the Suez Canal enhances their potential as both transshipment centers and gateway hubs linking Europe, Asia, and Africa (UNCTAD, 2023).

However, despite notable investments and modernization efforts, Egyptian ports continue to face procedural bottlenecks, repetitive documentation, and limited digital connectivity among key stakeholders (El-Dosouky et al., 2023, Soliman, 2025). Manual paperwork, overlapping inspections, and fragmented communication channels result in extended dwell times and increased

transaction costs for shipping lines, freight forwarders, and authorities (World Economic Forum, 2023).

The digital transformation of ports extends beyond mere technological upgrades; it requires reshaping institutional structures, governance frameworks, and collaborative relationships across the logistics chain (Acciaro et al., 2021, OECD, 2024). Contemporary port systems depend heavily on integrated data flows to optimize berth management, shorten vessel turnaround, and ensure compliance with international standards (Port of Rotterdam Authority, 2021).

Within this evolving digital landscape, blockchain technology has emerged as a transformative enabler. Its decentralized ledger ensures an immutable, transparent, and auditable record of transactions accessible to authorized users reducing reliance on intermediaries and eliminating reconciliation delays (IBM & Maersk, 2022, Treiblmaier & van der Laan, 2021). In maritime logistics, blockchain enables secure trade document exchange, automated smart contract execution, and tamper-proof cargo and certificate tracking (World Bank, 2022, Notteboom & Winkelmanns, 2023).

Egypt has already made preliminary progress in trade digitalization. The creation of the National Single Window (NAFEZA) has streamlined trade data submission, while the integration of CargoX represents an innovative application of blockchain in document exchange (Ministry of Finance, Egypt, 2023, CargoX, 2023). These milestones highlight the government's commitment to modernization, yet a single pilot project cannot deliver systemic reform. A gap remains between demonstrating blockchain's potential and achieving nationwide deployment across ports and related agencies (UNCTAD, 2023, Soliman, 2025).

This research therefore aims to assess Egypt's readiness and capability to expand blockchain adoption within the maritime logistics sector. The core objective is to identify technological, regulatory, organizational, and financial enablers and barriers to adoption, and to propose a practical implementation roadmap aligned with Egypt's national digital strategies (MCIT, 2024). The study employs a structured survey of maritime professionals and qualitative benchmarking against leading international cases to develop evidence-based recommendations that bridge the gap between pilot results and sector wide transformation.

2 Literature Review

This section reviews scholarly and practical literature on blockchain applications in logistics, focusing on transparency, traceability, smart contracts, and data security. It highlights the technology's transformative potential in improving efficiency, trust, and coordination among logistics stakeholders. The review also explores blockchain's technical foundations, adoption challenges, and its adaptability to maritime logistics, particularly in the Egyptian port context.

2.1 Blockchain and Port Digitalization

Ports are central nodes in global supply chains but often struggle with inefficiencies caused by fragmented communication systems, redundant documentation, and bureaucratic procedures.

These challenges result in higher costs, operational delays, and reduced competitiveness (Wang et al., 2021). Blockchain technology has emerged as a response to these inefficiencies, offering a decentralized and transparent method for recording and validating transactions. Its immutability ensures data integrity, while its peer-to-peer architecture enables trusted data exchange without intermediaries (Negi, 2022).

In port logistics, blockchain facilitates applications such as traceability, trade finance, and automation via smart contracts. For instance, blockchain enabled trade finance replaces manual verification with real-time authentication, reducing both costs and delays. However, despite successful applications in advanced economies, large scale implementation in developing regions including Egypt remains limited due to financial, regulatory, and infrastructural barriers (Othman et al., 2022).

2.2 Theoretical Foundations of Blockchain Technology

Blockchain functions as a distributed digital ledger that securely records transactions across decentralized nodes. Each transaction is grouped into a block, cryptographically linked to the previous one, creating an immutable and verifiable chain (Tsiulin et al., 2020). Key components include distributed ledgers, hash functions, consensus mechanisms, and smart contracts.

Distributed Ledgers: Ensure all participants access synchronized copies of records, minimizing reconciliation delays. **Cryptographic Hashing:** Prevents data tampering by creating unique digital fingerprints for each block. **Consensus Mechanisms:** Such as Proof of Work and Proof of Stake, validate transactions without central oversight, maintaining system trust (Wang et al., 2021).

Smart Contracts: Self-executing digital agreements automate port operations such as document verification and cargo release, reducing administrative costs (Alahmadi et al., 2022). The decentralized nature of blockchain enhances resilience by removing single points of failure and fostering secure data exchange among diverse actors' customs, port authorities, and shipping lines (Almeida, 2023). These attributes make blockchain particularly suitable for maritime logistics, where secure and transparent information flow is essential (Al-Masri, 2025).

2.3 Strategic Advantages of Blockchain in Maritime Logistics

Blockchain provides several strategic benefits to port operations and maritime logistics: transparency, efficiency, data integrity, and compliance.

1. Transparency and Trust: Blockchain's immutable ledgers foster shared visibility and accountability among stakeholders, reducing information asymmetry and reliance on intermediaries (Wang et al., 2021). This is especially valuable in Egypt, where traditional documentation systems often create delays and mistrust (Othman et al., 2022).

2. Operational Efficiency: Smart contracts automate repetitive tasks, accelerating cargo release and minimizing administrative errors. The CargoX–NAFEZA integration in Egypt exemplifies these benefits, reducing average cargo clearance times from 29 to 9 days (Othman et al., 2022).

Similarly, IBM-Maersk's TradeLens platform demonstrated 15–20% cost savings through paperless documentation (Wang et al., 2021).

3. Data Security: Blockchain's cryptographic structure ensures record integrity and protection against forgery or cyberattacks. In ports where sensitive trade documents are frequently exchanged, such security features mitigate fraud and unauthorized alteration (Alahmadi et al., 2022).

4. Regulatory Compliance: Time-stamped blockchain records streamline auditing and customs verification, enabling real-time compliance monitoring and faster clearance (Tsiulin et al., 2020). This reduces bureaucratic friction, one of the major obstacles in Egyptian port logistics.

5. Fraud Prevention and Risk Mitigation: Blockchain minimizes fraud by maintaining a tamper-proof and verifiable record of all activities (Almeida, 2023). As all participants share synchronized data, inconsistencies and manipulation become detectable, improving accountability.

6. Transaction and Payment Acceleration: Smart contracts automate settlements once conditions are met, eliminating manual banking processes and reducing transaction delays (Ababneh et al., 2023). This efficiency is critical in international trade, where delayed payments often incur demurrage and liquidity constraints.

7. Scalability and Integration: Blockchain systems can integrate with emerging technologies such as IoT and AI for real-time cargo tracking and predictive analytics (Wang et al., 2021). Such convergence enhances supply chain visibility and supports Egypt's ambition to become a regional logistics hub at the crossroads of three continents.

2.4 Applications in Port and Supply Chain Logistics

Blockchain addresses long-standing challenges in global logistics, especially in data fragmentation, document fraud, and limited traceability. Its applications in port logistics include:

1. End-to-End Traceability: Real time cargo tracking ensures transparency and reduces theft and loss (Wang et al., 2021).

2. Smart Contracts: Automate customs release and payment validation, improving throughput efficiency (Tsiulin et al., 2020).

3. Trade Documentation: Digital bills of lading and certificates of origin increase speed and accuracy in documentation (Othman et al., 2022).

4. Regulatory Integration: Customs authorities can directly verify documentation on blockchain, reducing manual inspections and corruption opportunities.

5. Cold Chain Monitoring: Combining blockchain and IoT ensures that perishable goods maintain quality standards throughout the logistics chain (Ahmet Yunus Cil et al., 2022).

2.4 Case Studies of Blockchain in Port Operations

Global experiences underscore blockchain's role in improving logistics efficiency and stakeholder collaboration.

1. Port of Rotterdam: Introduced blockchain-based data exchange (Deliver Project), improving vessel turnaround by 20% through real time coordination among customs, shipping, and terminal operators (Tsiulin et al., 2020).

2. Port of Valencia: The EU's Data Ports initiative digitized VGM certificates, reducing processing time by 30% while ensuring SOLAS compliance (Almeida, 2023).

3. Port of Los Angeles: Integrated blockchain within its Port Optimizer™ to enhance cybersecurity and visibility across its logistics chain (Port of Los Angeles, 2019).

4. Port of Singapore: The SGTraDex platform connects port authorities, financial institutions, and logistics firms, integrating blockchain with IoT and AI for end-to-end trade visibility (IMDA, 2022).

5. TradeLens (IBM-Maersk): A global blockchain network connecting over 300 entities, improving data transparency, and automating documentation across 600 ports (Ababneh et al., 2023).

These initiatives collectively demonstrate how blockchain fosters transparency, compliance, and process automation, while also highlighting scalability challenges relevant to Egypt's modernization journey.

2.5 Adaptability to Egyptian Ports

Egypt's ports Alexandria, Damietta, Port Said, and Ain Sokhna handle nearly 90% of national trade (Othman et al., 2022). Yet, reliance on manual documentation and legacy IT systems limits their competitiveness. Integrating blockchain within Egypt's existing digital platforms, such as NAFEZA, offers a foundation for modernization. However, effective implementation requires regulatory reform, infrastructure upgrades, and capacity building.

Drawing from the experiences of Rotterdam, Valencia, Singapore, and Los Angeles, Egypt can adopt a phased strategy beginning with customs digitalization and scaling toward full port community integration. Such progress aligns with Egypt Vision 2030 and the transition from traditional to fifth generation smart ports (UNCTAD, 2024).

2.5.1 Evolution of Seaport Generations

UNCTAD's framework traces seaport development through five successive generations, each defined by growing complexity, integration, and technological capability (UNCTAD, 1991, 2017).

First generation ports: were largely functional facilities focused on basic loading, unloading, and storage operations. Operating in noncompetitive environments, they primarily handled bulk and

raw materials. Although technologically simple, such ports were crucial to regional economic activity in developing nations.

Second-generation ports: (1960-1980) emerged with the industrialization era, linking maritime operations to nearby industries and trade zones. They expanded cargo types especially bulk and liquid commodities and improved infrastructure and hinterland connectivity. However, operations remained largely manual, with limited information exchange or environmental regulation (UNCTAD, 1991).

Third-generation ports: (post-1980) reflected the impact of globalization and containerization. They evolved into logistics hubs with broader roles in storage, documentation, and integrated distribution. These ports began using computerized systems for cargo tracking and operational planning, marking the early stages of digitalization and international supply-chain connectivity (Tsiulin et al., 2020).

Fourth-generation ports: (1990s onward) were conceived as global trade facilitators supported by public private partnerships. Their strategies extended beyond infrastructure to include regulatory compliance, workforce development, and stakeholder coordination. Scholars such as Beresford have criticized this generation for lacking standard classification criteria, emphasizing instead the importance of human capital, environmental awareness, and innovation culture in port competitiveness (UNCTAD, 2017).

Fifth-generation ports: represent today's most advanced stage, operating as smart, interconnected logistics ecosystems. They employ automation, artificial intelligence, and blockchain to achieve real-time transparency and predictive decision-making. These ports integrate maritime and inland logistics, focus on sustainability, and provide value-added services exceeding regulatory standards (Kaliszewski, 2018). Fifth-generation facilities thus serve as innovation clusters—actively engaging stakeholders and driving digital trade growth.

2.5.2 Technical and Infrastructure Readiness

Effective blockchain deployment in ports depends on advanced ICT infrastructure, interoperability, and data standardization. While Egypt has launched initiatives such as the NAFEZA single window system, many terminals still rely on paper-based workflows (Othman et al., 2022).

Digitization of customs processes, manifests, and vessel scheduling is essential to ensure that blockchain data inputs are accurate. Connectivity between Port Community Systems (PCS), customs, and terminal operators remains uneven across Egypt's ports. Facilities such as Ain Sokhna, managed by DP World, are more digitally mature, whereas others require upgrades in automation and integration (Almeida, 2023).

Modern ports increasingly use Automated Stacking Cranes (ASCs) to improve yard efficiency and safety. ASCs allow higher-density container storage, consistent handling, and integration with

Terminal Operating Systems for real-time visibility. Despite their benefits in speed and energy efficiency, ASCs involve high initial investment and maintenance complexity. Therefore, a phased adoption approach beginning with technologically advanced terminals is the most feasible path for Egypt's blockchain transition.

2.5.3 Organizational and Stakeholder Readiness

Blockchain's success depends as much on institutional cooperation as on technology. Egypt's port ecosystem involves multiple stakeholders' customs, port authorities, terminal operators, and freight forwarders often operating in silos. Building trust and shared governance is thus critical (Wang et al., 2021).

Pilot programs like CargoX & NAFEZA have demonstrated blockchain's benefits in reducing clearance times and enhancing transparency (Othman et al., 2022). Expanding such pilots to include banks, insurers, and logistics firms can strengthen stakeholder confidence and encourage broader adoption.

2.5.4 Regulatory and Policy Alignment

A robust regulatory framework is vital for blockchain implementation. Current Egyptian trade laws do not yet recognize smart contracts or electronic bills of lading as legally binding, limiting institutional confidence (Ababneh et al., 2023). Issues of data privacy, jurisdiction, and international interoperability also require legal clarity. Comparative experiences from Rotterdam and TradeLens* show that regulatory sandboxes controlled environments for innovation can accelerate blockchain adoption (Tsiulin et al., 2020). Establishing such mechanisms within Egypt's Customs Authority would allow gradual legal adaptation while ensuring compliance and security.

2.5.5 Process Integration and Incremental Implementation

Blockchain's modular architecture enables step by step integration without full system replacement. Egypt could follow models like the Port of Valencia, which digitized weight certification (VGM) through a targeted blockchain pilot (Ababneh et al., 2023).

Initial Egyptian pilots could focus on customs pre-clearance, inter-terminal transfers, or cargo release to generate "quick wins" and demonstrate value to stakeholders. Building on CargoX success, these processes can later link with legacy systems through standardized APIs for smoother interoperability (Othman et al., 2022).

2.5.6 Economic Rationale and Development Impact

Blockchain's ability to streamline logistics, reduce transaction costs, and attract investment strengthens its economic justification. Transaction cost economics suggests that reducing monitoring and enforcement costs promotes efficiency and competitiveness (Tsiulin et al., 2020).

In Egypt, blockchain adoption could improve logistics performance, enhance Suez Canal trade flows, and generate new value-added services such as secure document storage and digital certification. Specific ports could leverage blockchain in tailored ways:

- Alexandria: automate customs clearance.

- Port Said: improve container tracking.
- Damietta: support trade finance for bulk commodities.

These applications would support Egypt's Vision 2030 goals and position its ports as digital trade leaders in the MENA region.

2.6 Research Gaps

Existing literature on blockchain in maritime logistics offers global perspectives but limited empirical focus on Egypt. Studies like Othman et al. (2022) and Wang et al. (2021) highlight digitalization challenges broadly but lack country-specific analysis of blockchain readiness. Comparative works (Tsiulin et al., 2020; Almeida, 2023) often generalize developing economies, overlooking Egypt's regulatory and infrastructural nuances.

No comprehensive research has yet combined stakeholder surveys with case studies of Egyptian ports to assess blockchain adoption barriers and opportunities. Gaps remain in understanding:

- Stakeholder perceptions and readiness for blockchain integration.
- Technical and infrastructural capacities across major ports.
- Legal and cultural challenges, including resistance to automation.

Addressing these gaps will guide policymakers and industry leaders in designing actionable strategies for blockchain deployment in Egyptian ports advancing national competitiveness and regional digital transformation.

3. Methodology

The study uses a mixed method approach combining quantitative and qualitative tools. A structured questionnaire was distributed among **130** maritime professionals from port authorities, customs, terminal operators, shipping agents, and freight forwarders. **112** valid responses were received (86% response rate). Sampling followed the stratified method to ensure coverage of public and private ports.

A quantitative, deductive approach was used to test hypotheses concerning blockchain readiness and its relationship with port efficiency. Data were gathered through a self-administered questionnaire distributed among logistics, customs, and IT professionals. Descriptive and regression analyses were conducted using SPSS to identify statistically significant relationships among variables.

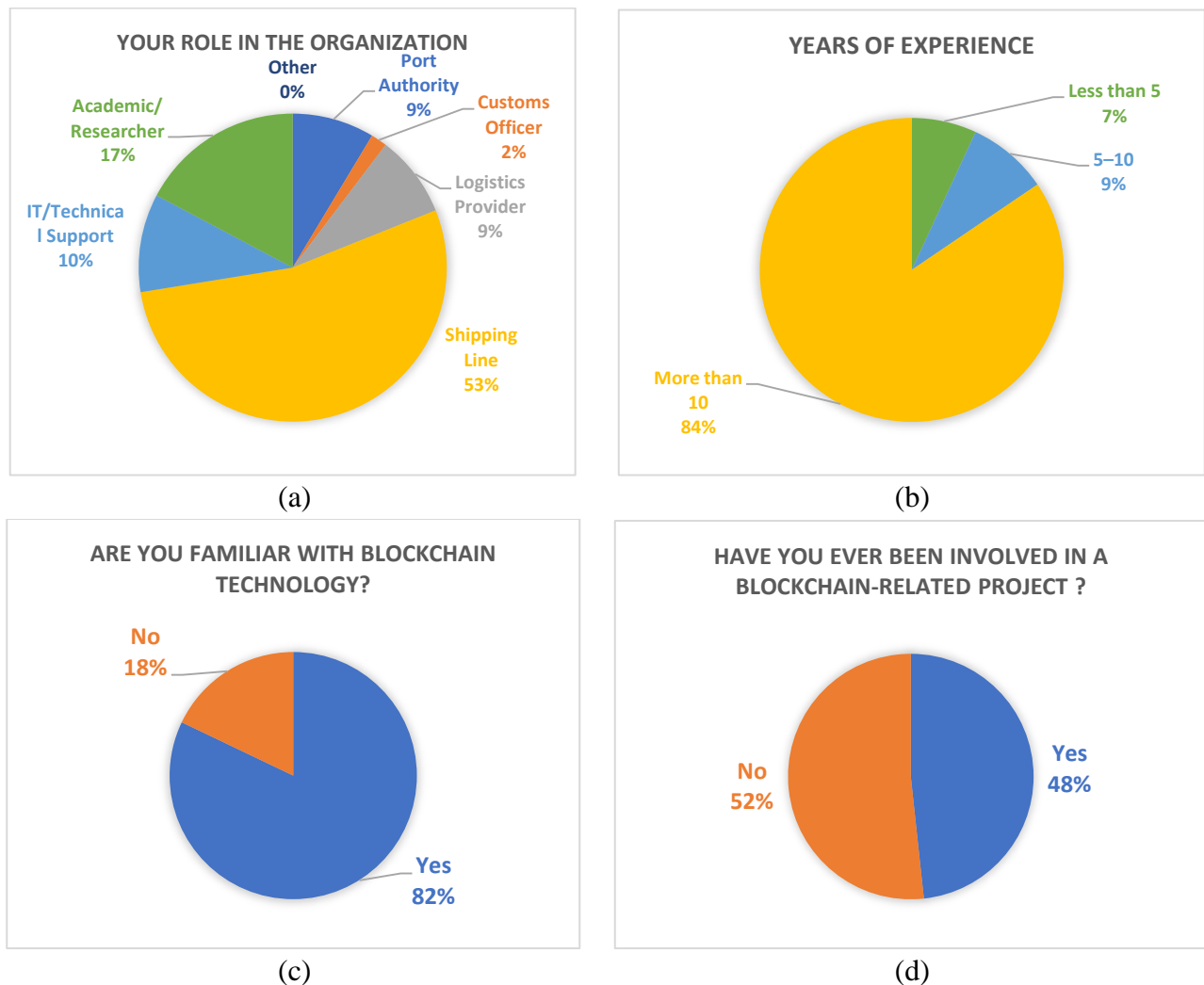


Figure (1): Respondent Profile by Sector, Experience, and Blockchain Involvement.

3.1 Key Findings

- 1. Technological Readiness:** Most respondents ($\approx 69\%$) agreed that current ICT infrastructure is insufficient to support blockchain. Weak API integration, outdated terminal systems, and limited in-house technical expertise were cited as major constraints (Tsiulin et al., 2020). While ports like Sokhna show digital maturity, others remain largely manual, restricting interoperability.
- 2. Financial Constraints:** Around 75% of respondents viewed blockchain implementation as cost prohibitive. Limited public funding and the absence of clear ROI models slow adoption. Unlike EU-backed projects in Rotterdam, Egyptian ports rely primarily on national budgets (Alahmadi et al., 2022). Public-private partnerships and external financing were identified as potential enablers.
- 3. Regulatory Environment:** Only 24% believed Egypt's legal framework sufficiently supports blockchain. The absence of laws recognizing smart contracts or digital records deters investment.

(Othman et al., 2022). Respondents emphasized the need for data governance, privacy regulation, and standardized digital trade policies.

4. Stakeholder Readiness: Approximately 77% highlighted limited blockchain awareness among mid-level managers. Concerns over job displacement, low digital literacy, and cultural resistance persist (Wang et al., 2021). Trust gaps between public and private entities further hinder cooperation.

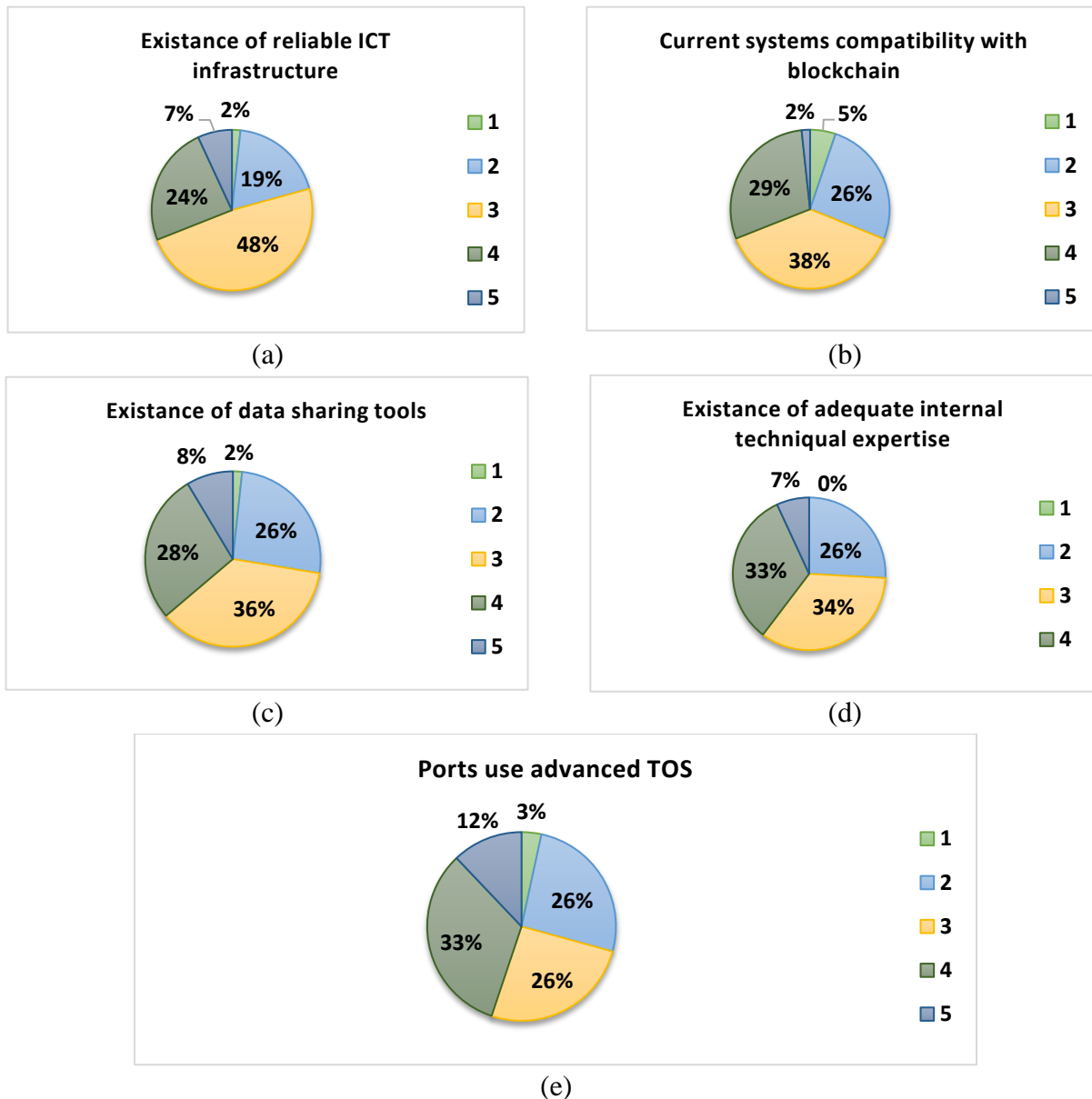


Figure (2): Technological Readiness Indicators in Egyptian Ports values represent the percentage of respondents agreeing with each statement regarding ICT infrastructure, system integration, and tech expertise.

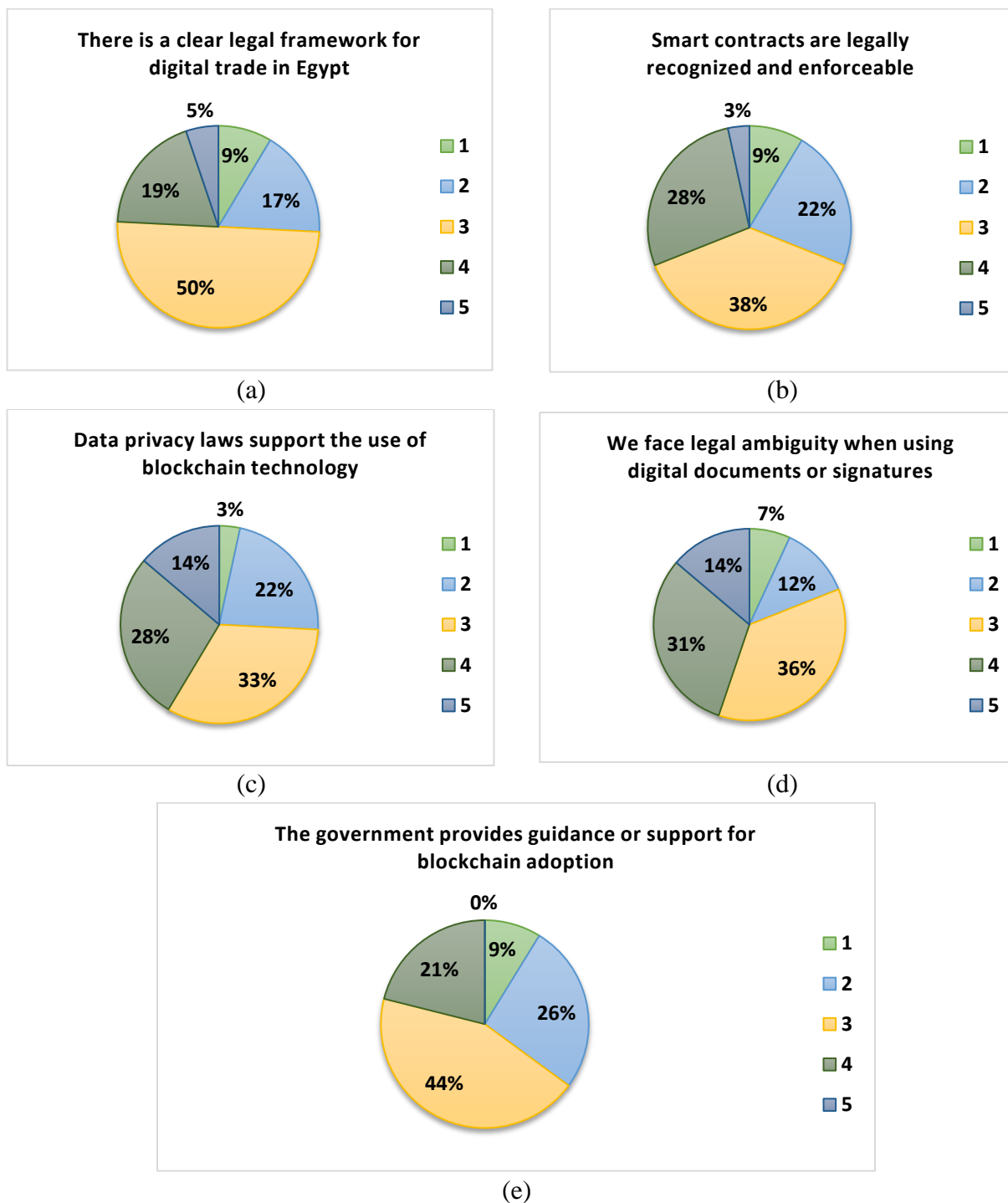


Figure (3): Perceptions of the Regulatory Environment for Blockchain Adoption
 Values represent the percentage of respondents agreeing with statements about legal frameworks, smart contracts, and government support.

3.4 Hypothesis Testing

This research treats the 112 survey respondents as a representative sample of the broader population of professionals engaged in Egyptian port operations, customs, logistics, and IT. The objective is to test whether technological readiness and blockchain enabled transparency significantly influence port efficiency and competitiveness across the entire professional population.

Two hypotheses were tested using regression analysis:

- **H₁:** Technological readiness significantly improves port efficiency and competitiveness.
- **H₂:** Blockchain enabled transparency and data security significantly enhance port efficiency and competitiveness.

The results of Hypothesis testing can be summarized as follows:

- **H_{A1}:** (Accepted, $p = 0.00004$, $R^2 = 0.25$)- Technological readiness explains ~25.7% of the variance in port efficiency.
- **H_{A2}:** Accepted ($p = 0.00094$, $R^2 = 0.179$) – Blockchain enabled transparency explains ~17.9% of the variance in port efficiency.

Results confirm that both technological readiness and blockchain enabled transparency to have statistically significant positive impacts, though technological readiness explains a larger share of variance in port efficiency.

Table (1): Hypothesis Test

Model	R-squared	P-value	Coefficient
Technological Readiness	0.256802655	0.00004914	0.520763211
Blockchain Transparency	0.178868112	0.00094134	1.859765272

Statistical analysis of hypothesis testing.

N = 112. All p-values are < 0.05, indicating statistical significance.

3.5 Stakeholder Support (NPS Analysis)

To complement the regression analysis, the Net Promoter Score (NPS) was calculated to evaluate stakeholder perceptions toward blockchain adoption in Egyptian port operations. Respondents were asked:

On a scale from 0 to 10, how likely are you to recommend the adoption of blockchain in Egyptian port operations?

Responses were classified into three categories:

- **Promoters (9–10):** Strong advocates who are highly likely to recommend blockchain adoption.
- **Passives (7–8):** Neutral or moderately supportive, but not strong advocates.
- **Detractors (0–6):** Opposed, unlikely to recommend adoption.

The NPS is calculated based on stakeholder responses to a 0–10 rating scale. Respondents scoring 9–10 are classified as Promoters (strong advocates), those scoring 7–8 are Passives (neutral or moderately supportive), and those scoring 0–6 are Detractors (unlikely to recommend). The NPS is determined by subtracting the percentage of Detractors from the percentage of Promoters. This produces a score ranging from –100 (all respondents are Detractors) to +100 (all respondents are Promoters). Higher values indicate stronger overall support for blockchain integration, while negative scores reflect more opposition than advocacy.

The Net Promoter Score (NPS) measured overall sentiment toward blockchain. In this research, Promoters accounted for **53.6%** of respondents, Passives for **26.8%**, and Detractors for **19.6%**. Applying the NPS formula:

$$\text{NPS} = \% \text{Promoters} - \% \text{Detractors} = 53.6 - 19.6 = +34$$

An NPS of +34 This positive score indicates that a significant proportion of the professional population is supportive of adopting these innovations aligning with the study’s hypotheses that both technological readiness and blockchain-enabled transparency positively influence port efficiency and competitiveness.

The chart below showcases the distribution of respondents into Promoters, Passives, and Detractors based on their chances of recommending progressive technological solutions and blockchain-enabled transparency in the Egyptian port operations.

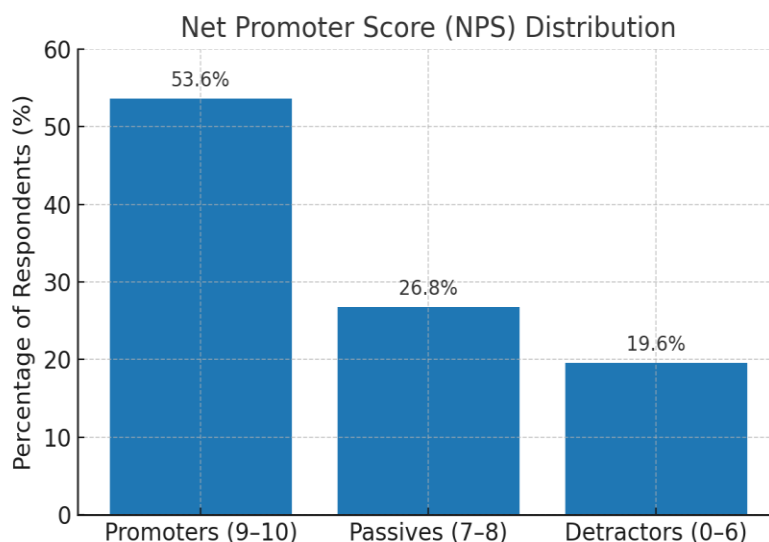


Figure (4): Net promoter Score distribution.

4. Findings & Discussion

The research confirms that blockchain adoption challenges in Egypt's maritime logistics sector are multifaceted spanning technology, finance, regulation, and stakeholder engagement. Unlike advanced European ports supported by strong digital ecosystems and clear legal frameworks, Egyptian ports still operate through fragmented systems with limited interoperability and constrained budgets. These weaknesses restrict the scalability of blockchain initiatives.

4.1 Awareness and Strategic Perception

Survey data indicates broad conceptual awareness of blockchain's potential to reduce paperwork, enhance traceability, and strengthen trust among trading partners (Kouhizadeh et al., 2021). Senior management and IT specialists show the highest levels of strategic understanding, while frontline staff though not resistant display limited knowledge of blockchain's operational mechanisms. Interviews reveal ongoing confusion between blockchain and other digital systems, with some respondents still associating it primarily with cryptocurrency (Saber et al., 2019). This indicates an early adoption stage where general awareness exists, but deep technical and procedural expertise remains underdeveloped.

4.2 Technological Readiness

Findings suggest moderate technological preparedness. Privately managed terminals and concessioned facilities, motivated by commercial efficiency and flexible governance, exhibit stronger system integration and more modern digital infrastructure (World Bank, 2023). Conversely, publicly managed ports continue to rely on legacy platforms with minimal interoperability. Few organizations have initiated blockchain-related pilot programs or established architectural frameworks to link with distributed ledger solutions. Key deficiencies include incompatible data standards, limited API access from older systems, and uneven cybersecurity capabilities all of which impede seamless, secure data exchange across the port ecosystem (UNCTAD, 2022).

4.3 Regulatory Environment

Regulatory clarity stands out as a critical factor. Respondents consistently identified the lack of formal legal recognition for blockchain based trade documentation, particularly electronic bills of lading and smart contracts, as a primary impediment (OECD, 2021). Although the national single window platform centralizes data submission, it does not yet confer full legal status to blockchain-generated records. Interviewees emphasized the urgency of introducing legislative reforms or policy guidelines that establish blockchain outputs as legally valid and enforceable (WTO, 2023). Without such recognition, banks, insurers, and judicial bodies remain cautious about transacting exclusively through distributed ledgers.

4.4 Financial and Investment Considerations

Financial constraints represent a pragmatic challenge. Implementation requires funding for infrastructure modernization, system integration, cybersecurity reinforcement, and employee training (Rodrigues et al., 2021). For many public entities operating with limited budgets, these

costs are significant without external financing or cost-sharing partnerships. While private operators are more financially capable, they demand clear return-on-investment projections through measurable reductions in turnaround times, dispute resolution costs, and administrative inefficiencies. Interviews underscored that collaborative funding mechanisms, including public private partnerships and targeted incentives, could substantially boost adoption rates (World Economic Forum, 2022).

4.5 Organizational Readiness and Human Capital

Organizational readiness reveals mixed progress. Leadership endorsement exists at upper management levels, but operational execution remains weak. A recurring issue is the absence of structured training programs focused on blockchain and digital logistics (Notteboom & Haralambides, 2020). Interviewees proposed modular training, professional certification pathways, and collaboration with maritime academies to cultivate skilled personnel. Addressing cultural resistance to automation requires a structured change management approach emphasizing stakeholder inclusion, transparent communication on job transitions, and upskilling initiatives that position digitalization as a complement rather than a threat to human roles (Hildebrandt et al., 2022).

4.6 Evidence from Pilot Integration: CargoX and the Single Window

The integration of CargoX within Egypt's national single window platform demonstrates blockchain's practical value in improving documentation efficiency and traceability (CargoX, 2024). Recorded reductions in document handling and customs clearance times highlight measurable productivity gains achieved through digital workflows (Egypt Ministry of Finance, 2023). However, the pilot remains limited in scope, it focuses primarily on document exchange and does not yet interface with terminal systems or inland logistics networks. Consequently, while promising, it represents only an initial milestone toward a fully interconnected, end-to-end blockchain ecosystem incorporating IoT and cloud based technologies (UNCTAD, 2023).

4.7 Comparative Lessons from International Examples

Global benchmarking provides several actionable lessons. Successful international implementations are typically driven by coherent policy frameworks and coordinated institutional efforts rather than technology alone (Port of Rotterdam, 2022; Maersk & IBM, 2021). Governments that established clear regulations and interoperable data standards achieved faster adoption. Equally vital is the standardization of APIs and data formats to prevent vendor dependency and ensure platform flexibility (IMO, 2023). Progressive scaling through focused pilot projects covering document exchange, customs pre arrival processing, or secure certification helps demonstrate tangible key performance indicators (KPIs) that justify expansion. Furthermore, joint investment models and public private partnerships accelerate infrastructure readiness and foster market competitiveness (World Bank, 2023).

4.8 Integrated Interpretation

Overall, the empirical evidence places Egypt at a strategic turning point. Initial pilot projects have confirmed blockchain's potential, leadership awareness is growing, and private operators have demonstrated commercial feasibility. The key remaining challenges are institutional and financial rather than technological. Overcoming them will require a coordinated national framework combining legal reforms, targeted funding mechanisms, pilot expansion, and human capacity development. A multi layered strategy integrating regulation, finance, technology, and training can transform early pilot efforts into a sustainable, interoperable digital ecosystem that enhances the efficiency and competitiveness of Egyptian maritime logistics.

5. Research Limitations and Future Directions

This research focused on major Egyptian seaports, smaller inland logistics operators were underrepresented. Future studies should use longitudinal data to track evolving digital transformation and employ simulation models (e.g., system dynamics) to estimate cost benefit impacts.

While this research provides valuable insights into the potential of blockchain for enhancing the efficiency and competitiveness of Egyptian ports, several limitations should be acknowledged.

First, the analysis relied primarily on self-reported survey data, which may involve perceptual biases or subjective optimism among respondents. Future research could incorporate objective performance indicators, such as port turnaround time, cost reduction metrics, or blockchain transaction efficiency, to validate the perceived outcomes.

Second, the study adopted a cross sectional design, capturing stakeholder perceptions at a single point in time. Given the rapidly evolving nature of digital transformation, longitudinal studies would help track how adoption readiness and institutional attitudes change over time as new technologies mature.

Third, although the survey covered major Egyptian ports, smaller inland logistics operators and private terminal entities were underrepresented, potentially limiting generalizability. Expanding the sampling frame to include more diverse logistics actors could enrich the understanding of blockchain diffusion across the wider maritime ecosystem.

Finally, while the research applied a mixed method approach, it did not employ quantitative simulation or econometric modeling to estimate cost benefit impacts. Future studies could integrate data driven modeling, system dynamics, or digital twin simulations to measure the economic and operational gains of blockchain adoption at scale.

Acknowledging these limitations provides a foundation for future research to build upon, ensuring that Egypt's blockchain transformation in maritime logistics evolves through continuous empirical refinement and multidisciplinary collaboration.

6. Conclusion

Blockchain represents a practical and transformative tool for enhancing document integrity, automating conditional workflows, and fostering transparency across maritime logistics chains. Within Egypt, early pilot projects have demonstrated clear operational benefits while simultaneously revealing the need for deeper institutional alignment and policy coordination. The critical enablers of successful adoption extend beyond technology they rest on governance foundations that include legal recognition, interoperability standards, inter agency collaboration, and workforce competency. Focusing solely on technical deployment without concurrent regulatory reform and capacity development will constrain results, likewise, policy changes unsupported by technological infrastructure will fail to yield measurable improvements. Therefore, blockchain implementation must be pursued as an integrated component of Egypt's national digital transformation strategy, positioned not merely as a technological upgrade but as a systemic and institutional innovation.

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