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The Role of Blockchain in Enhancing Transparency and Security in
Port Logistics Networks

School of Management
Logistics and supply chain management

MSc
Academic Year: 2024 - 2025

Supervisor: Ajay Deshmukh

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This thesis is submitted in partial fulfilment of the requirements for
the degree of Master of Science

(NB. Remove if the degree award is based solely on examination of the thesis)

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Abstract

Port logistics networks face significant challenges posed by information silos and a lack of collaborative trust. Although blockchain technology is widely regarded as a promising solution, the failure of large-scale projects such as TradeLens has revealed a critical gap between technological potential and practical application, particularly concerning non-technical barriers such as governance. To address this gap, this study employs a systematic literature review (SLR) methodology, adhering to the PRISMA framework, to synthesise and analyse 43 core academic papers. This analysis first identifies multi-layered technical frameworks proposed in the literature to enhance transparency (e.g., end-to-end traceability, document digitisation) and security (e.g., smart contracts, permissioned chains). However, the most significant finding is that the primary barriers to adoption are not technical, but institutional. Two core dilemmas were identified: 'Governance over technology', emphasising the primacy of establishing equitable, neutral collaborative models; and 'Scenarios over platforms', indicating that applications focused on specific problems are currently more feasible than large-scale platforms.

The paper's principal original contribution lies in proposing an integrative conceptual framework. By positioning 'governance models' and 'application scenarios' as key variables regulating technological implementation success, this framework challenges prevailing technodeterminist perspectives. The findings provide critical theoretical insights and practical guidance for managers, technology developers, and policymakers navigating the complexities of blockchain adoption in port logistics.

Keywords:

Systematic Literature Review, Conceptual Framework, Smart Contracts, Supply Chain Management, information security, data transparency

Acknowledgements

First and foremost, my deepest gratitude goes to my supervisor, Professor Ajay Deshmukh. He was the lighthouse in my foggy sea of 43 academic papers, guiding me towards the (one and only) correct shore. Thank you for pulling me back from the brink of going off-topic countless times with a single sentence, and for the extraordinary patience and calm you displayed during our meetings as I oscillated wildly between "I've got it!" and "I'm lost again!" moments. My supervisor deserves immense credit for this thesis successfully making it to port; of course, any faults found within are entirely my own cargo.

Secondly, a huge thank you to all the professors at the Cranfield School of Management. You successfully managed to cram about three years' worth of knowledge into my brain in a single academic year, which is a remarkable achievement. While the process was mind-bending, the result was wonderful.

Finally, and most importantly, I want to thank my partner. Thank you for saving my stomach and soul with countless delicious meals during this arduous time, preventing me from being submerged by a tide of takeaways and instant noodles. Even more, thank you for the round-the-clock emotional support—from gentle encouragement to (equally important) intense arguments, all of which served as stress tests that ultimately made me stronger. This thesis is dedicated to you; you are the one who gave all this hard work its most special meaning.

Alright, acknowledgements complete. I hope these few pages aren't the only part you read.

Jiayu Qi

Written on a quiet pre-dawn night.

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List of Abbreviations

TOS	Terminal Operating System
PCS	Port Community System
CMS	Customs Management System
PIN	Personal Identification Number
SLR	Systematic Literature Review
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
IoT	Internet of Things
GPS	Global Positioning System
RFID	Radio Frequency Identification
B/L	Bills of Lading
L/C	Letters of Credit
NFT	Non-Fungible Token
AI	Artificial Intelligence
ML	Machine Learning
DMLBC	Dependable Machine Learning for Seaports using Blockchain
RBAC	Role-based Access Control
MSP	Membership Service Provider
CA	Certificate Authority
DSSE	Dynamic Searchable Encryption
TCE	Transaction Cost Economics
TOE	Technology-Organisation-Environment

1 Introduction

1.1 Research Background

With the high degree of global digitalisation and increasingly complex supply chain structures, ports, as central nodes connecting national economic activities and international trade hubs, are facing unprecedented collaboration challenges in their networks. Due to the involvement of numerous participants in the port logistics network system, including customs, port authorities, terminal operators, freight forwarders, and trucking service providers, the system formed by these diverse participants and their interaction processes is defined as the 'port logistics network' in this paper. Furthermore, the information technology systems used by these participants are mostly different and independently developed, lacking unified standards and coordination mechanisms. As a result, problems such as information lag, system fragmentation and unclear responsibilities have become increasingly prominent in port business processes. Although existing port digital platforms (e.g. Terminal Operating System (TOS), Port Community System (PCS) and Customs Management System (CMS)) have the ability to perform their respective tasks independently, due to the closed architecture of most of the systems and the lack of interconnection mechanisms, some key data still need to rely on manual confirmation and transmission. This 'information silo' phenomenon makes it difficult to achieve real-time synchronisation between key nodes in the port, thus reducing the efficiency of collaboration and limiting overall logistics visibility (Jović et al., 2020; Nasser et al., 2025; Papadakis & Kopanaki, 2022a).

In response to the above problems of cross-organisational system fragmentation and lack of trust in collaboration, blockchain technology has been widely regarded as having the potential to solve the 'trust problem' in multi-organisational collaboration in recent years due to its decentralised, tamper-resistant, traceable, and smart-contract enforcement capabilities (Liu et al., 2023; Tsiulin et al., 2020). In port logistics networks, blockchain enables cross-organisational 'on-chain consistency' through the use of shared ledgers, a technology that allows multiple independent information systems to share a single trusted copy of data ((Liu et

al., 2023). Some pioneering projects, such as the TradeLens platform launched by IBM and Maersk, and the T-Mining Secure Container Release project at the Port of Antwerp, Belgium, have already demonstrated the potential of blockchain for tamper-proof data and release verification in port logistics (Jović et al., 2020; Tsiulin et al., 2020). In particular, T-Mining improves the security and traceability of the release process by replacing traditional PIN codes with blockchain tokens. However, the termination of the TradeLens project also revealed an important reality: the technology itself was not the decisive factor for success (Wong et al., 2024). One of the fundamental reasons for its failure was the lack of an effective process design and cross-organisational governance structure, and the failure to develop a sustainable multi-party collaboration mechanism, a gap that led to widespread concerns about overexposure of data and unclear permissions among platform participants. In this context, the 'transparency' brought by blockchain is mistakenly perceived as a risk rather than an advantage, ultimately inhibiting the willingness of platforms to use it (Najati, 2025). Therefore, it is necessary to systematically review the research progress of blockchain in the field of port logistics to enhance transparency and security, to summarise the existing research paths and identify the structural gaps in the process mechanism, and to provide theoretical support and practical reference for the design and optimisation of subsequent governance mechanisms.

1.2 Problem Statement

Although existing research has primarily focused on the design of blockchain platform architecture, security protocols, and inter-node communication efficiency, there has been limited systematic exploration of the distribution of research topics and theoretical advancements in areas such as blockchain-enabled transparency in port business processes, the construction of collaborative mechanisms, and cross-system integration. Additionally, there is no unified theoretical framework or widely accepted collaborative mechanism for how blockchain technology can be applied to actual port business processes. Specifically, there is limited analysis and summary of practical issues such as data visibility between process nodes, permission boundaries, and process traceability. In fact, Pagano et al.(2022)

pointed out that the industry and academia have not yet reached a consensus on how to standardise technical solutions and achieve full interoperability between systems. These limitations highlight that although blockchain technology has rich theoretical knowledge, it has not been fully verified in the actual implementation of port operations. Therefore, these issues underscore the importance of conducting a systematic literature review and thematic analysis focused on port process mechanisms and process transparency and security enhancement, critically evaluating current research progress, and addressing key gaps between theory and practice.

1.3 Research Aim and Objectives

Based on this, the main objective of this study is to comprehensively review the research progress of blockchain technology in improving port logistics transparency and security. To achieve the above objective, this study sets the following research tasks:

1. Through quantitative analysis of port blockchain-related literature from 2019 to 2024, present the annual publication volume, method distribution, and journal distribution, and reveal the overall evolution trajectory of the research.
2. Based on the collected literature, this study will identify the key focus areas in port logistics networks from a mechanism perspective and summarise the methods and approaches scholars have proposed to achieve transparency and security.
3. This study will identify the shortcomings in current research regarding process mechanisms and security controls, and propose future research directions based on these findings.

1.4 Research Questions

To guide this study, the following key research questions are formulated:

1. What is the distribution of research topics and the development trend of blockchain in the field of port logistics?

2. What methods and paths have been adopted in the existing literature to achieve transparency and security in the port logistics network, and which links in the process do they focus on respectively?

3. What process or security dimensions have not been sufficiently discussed in existing research, and what should be done in the future to better support the transparency and security of port logistics processes?

1.5 Structure of the Thesis

Finally, the thesis is structured as follows: Chapter 2 introduces the SLR search process and literature screening criteria, Chapter 3 conducts quantitative trend and thematic mapping analyses, Chapter 4 conducts thematic summarisation and critical analysis based on the literature content, and Chapter 5 summarises the research findings, puts forward theoretical and practical recommendations, and looks into the future research direction.

1.6 Chapter Summary

In summary, this chapter outlined the background, motivation, and key challenges related to transparency and security in port logistics, reviewed the current state of research, and defined the aims and research questions of this study.

2 Research Methodology: Systematic Literature Review

This chapter will systematically describe the Systematic Literature Review (SLR) methodology adopted in this paper, strictly following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) process. The objectivity and reproducibility of the subsequent analyses are ensured through a basic description of the research design and theoretical rationale, databases and search strategies, inclusion and exclusion criteria, PRISMA process and diagrams, and the final scope of the literature.

2.1 Research design and theoretical basis

To ensure the accuracy and rigour of the study, a systematic literature review (SLR) was used in this paper. The SLR method is a systematic approach to collecting, screening, and evaluating literature through strict, transparent, and reproducible steps, which can effectively reduce the subjective bias of researchers and provide a more comprehensive and objective understanding of research status and development trends (Kitchenham, 2024; Tranfield et al., 2003). Considering the complex process of port logistics network, the SLR method provides a suitable research path for sorting out and filling the research gap that the existing research has not yet focused on the transparency and security mechanism at the process level. First, given the highly interdisciplinary nature of the topic ‘Application of Blockchain in Port Logistics Networks,’ relevant knowledge is scattered across journals in fields such as computer science, logistics management, and strategic research. Therefore, based on this significantly fragmented literature background, traditional literature reviews are unable to systematically extract common characteristics and research trends, leading to potential selection biases. However, SLR employs a structured process and transparent screening criteria to systematically identify and comprehensively analyse the core mechanisms and research pathways regarding how blockchain enhances the ‘transparency’ and ‘security’ of port logistics processes. This approach will strictly follow the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework. The

PRISMA framework is an internationally accepted literature review reporting standard, which includes four stages: literature identification, screening, qualification assessment and literature inclusion.

According to the PRISMA framework, in the first step, we will systematically search for all high-quality literature covering the topics of "port logistics" and "blockchain" through database selection and keyword search strategy, laying a foundation for the distribution and development trend analysis of subsequent research topics. Secondly, through strict inclusion and exclusion criteria, relevant literature that only focuses on the application of blockchain technology in the port logistics business is screened out. In the qualification evaluation stage, the selected literature was reviewed one by one to confirm further whether the literature really involved how blockchain could realise the transparency and security of the port logistics network and excluded the literature inconsistent with the theme or unclear research methods. Finally, the selected literature was included to form the final literature pool, providing the data basis for quantitative and qualitative analysis.

2.2 Database and Retrieval Strategies

2.2.1 Database Selection

This study selected Scopus and Web of Science as the two comprehensive databases for literature retrieval to ensure the inclusion of high-quality, mainstream research findings in the fields of blockchain and port logistics. Both are internationally recognised citation databases that extensively collect peer-reviewed articles from various academic journals in fields such as management, engineering, and information systems, providing a structured literature data support system for systematic reviews. The main characteristics of these databases are summarised in Table 2-1.

Table 2-1: Table of Database

Source: the author(2025)

Database Name	Type	Coverage Period	Subject Areas	Main Features
Scopus	Citation Database	2019–2025	Multidisciplinary	Peer-reviewed journals, citation analysis, broad coverage
Web of science	Citation Database	2019–2025	Multidisciplinary	High-impact journals, citation tracking, historical coverage

2.2.2 Keyword Definition and Scope

The literature search was conducted in June 2025, with the time range set from June 2019 to June 2025. Only journal articles and review papers (Article and Review) were included, while conference papers, editorials, book reviews, and technical reports were excluded.

To ensure the accuracy of the scope of literature retrieval and the reproducibility of the methodology, this paper clearly defines the core keywords and their definitions from three aspects: core technology, application scenarios, and business processes. Therefore, only relevant literature that meets all three aspects will be considered. The following sections provide a detailed explanation of the keywords for each aspect: First, from the core technology perspective, the focus is on the technical focus of this study, with the primary keyword being 'blockchain.' However, to ensure coverage of all the latest technologies related to blockchain, the search terms 'smart contracts' and 'distributed ledger' were added, as these terms are synonymous with blockchain in certain contexts. Second, from the application scenario perspective, the focus is on the background environment of this study, with the core keyword being 'port.' However, since port operations are typically linked to shipping, terms such as "shipping" and 'maritime' have been added to ensure that articles related to port operation nodes are also included in the systematic study. Finally, from the business process perspective, the focus is on the functional domain of this study, with the primary keyword being 'logistics.' To align with contemporary academic discourse and expand the search scope, 'supply chain' has also been included. Since ports are critical nodes in the overall supply chain, this expansion ensures

that important studies analysing port processes from a macro-level supply chain perspective are also retrieved, thereby achieving more comprehensive literature coverage. Table 2-2 provides a detailed presentation of these keywords and their specific definitions and scope in this study.

Table 2-2: Table of Keywords and Definition

Source: the author(2025)

Keyword	Definition/Search Scope
Blockchain	Blockchain technology, distributed ledger, smart contracts
Port	Seaports, port logistics, port management
Logistics	Transportation, freight handling, supply chain processes
Supply chain	Supply chain management, end-to-end logistics flow
Smart contracts	Self-executing digital contracts in blockchain systems
Distributed ledger	Decentralised database architecture, blockchain infrastructure
Shipping/Maritime	Maritime transport, shipping industry, sea freight, port operations

2.2.3 Search String Formulation

Based on the above keywords, the final search string was constructed using the Boolean operators 'AND' and 'OR'. The "OR" operator was used within each of the three concept groups to include synonyms, while the 'AND' operator was used to combine the groups. This ensures that the retrieved documents are relevant to both the core technology, its operating environment, and the business process. Therefore, the following search expression was used in the actual search: (TITLE-ABS-KEY((blockchain OR 'smart contract' OR 'distributed ledger') AND (port OR maritime OR shipping) AND (logistics OR 'supply chain'))).

2.3 Inclusion and Exclusion Criteria

To exclude irrelevant research papers and ensure the scientific validity of the literature screening process, this study established clear inclusion and exclusion

criteria based on the predefined scope, time frame, and type of literature. All screening processes were conducted by the PRISMA process.

The inclusion and exclusion criteria for the literature are as follows Table 2-3:

Table 2-3: Table of Inclusion and Exclusion Criteria

Source: the author(2025)

Criteria	Inclusion Criteria	Exclusion Criteria
Publication Year	2019 - June 2025	Before 2019
Document Type	Journal articles (Article), review papers (Review)	Conference papers, book chapters, editorials, technical reports
Language	English	Non-English
Publication Status	Final published version	Drafts, preprints, unpublished works
Subject Area / Topic	Must directly address the application of blockchain in port logistics, maritime supply chains, or port operations.	Research topic does not align (e.g., focuses only on shipping finance, general blockchain theory without a port context, etc.).
Duplicates	Unique records after deduplication	Duplicate records already identified in databases

To enhance the quality and consistency of the screening process, the initial screening (title and abstract) is conducted independently by two researchers. In case of discrepancies, a third-party researcher will assist in making a decision and reaching a consensus.

In summary, the above screening criteria ensure that the research focuses on topics related to port logistics process transparency and security and provide a clear basis for the subsequent construction of the final literature pool and the execution of the PRISMA screening process diagram.

2.4 Final Literature Classification Criteria

In addition, after completing the preliminary screening based on titles and abstracts, all selected literature will undergo a full-text reading analysis. Considering the characteristics of process mechanism research in the port blockchain field, this paper introduces classification criteria in the final inclusion

stage to further categorise and screen the candidate literature, as shown in Table 2-4.

Table 2-4: Table of Final Classification Criteria

Source: the author(2025)

Classification	Definition and Criteria	Inclusion Decision
Class A	Focused on port nodes or business processes; provides detailed analysis of blockchain-enabled transparency/security mechanisms, implementation, concrete cases, or platform deployment, with practical and theoretical integration.	Included in final pool
Class B	Considers blockchain transparency/security only as theoretical background or assumption, without specific mechanisms; focuses mainly on intention, adoption, incentives, or strategic review.	Supplementary only, not in final mechanism pool
Class C	No relevant content on port nodes/processes/mechanisms, or only general logistics, theoretical, market intention, or evaluation research without mechanism innovation.	Excluded

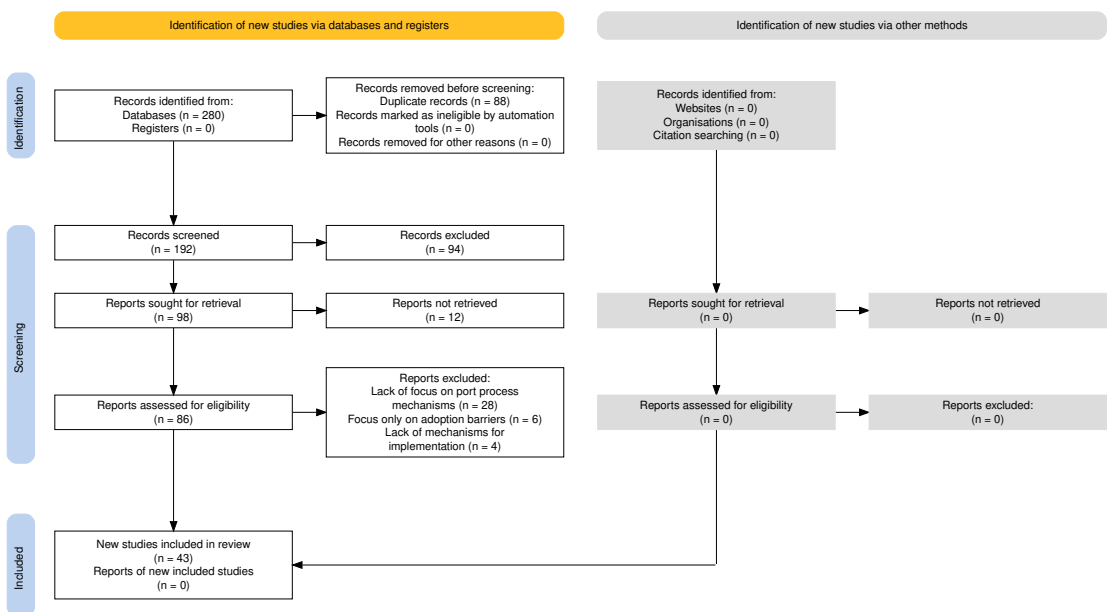
This standard primarily focuses on whether the literature focuses on mechanism innovation, implementation cases, and specific implementation paths in port business processes. The purpose is to ensure that the literature in the final literature pool can provide a solid theoretical and practical foundation for subsequent mechanism modelling and process analysis. It is worth noting that this classification was conducted independently by the author. Therefore, it is inevitable that this process may introduce a certain degree of researcher subjectivity, which may influence the composition of the final pool of documents included in the core analysis (i.e., Category A documents). Although the classification decisions were strictly based on pre-established criteria (Table 2–4), the inter-coder reliability of this study could not be verified due to the lack of independent second researchers to conduct cross-validation. Therefore, future studies should allocate more resources to assign multiple researchers to

independently classify and discuss the full texts, which would further enhance the objectivity and robustness of the research results.

2.5 Literature screening process and PRISMA diagram

The literature screening process strictly followed the PRISMA guidelines for systematic literature reviews. Figure 2-1 shows the PRISMA flowchart, detailing each step:

Figure 2-1: PRISMA Flow Diagram of the Literature Screening Process
(Source: Adapted from Page et al., 2021)



In the initial search, a total of 280 documents were retrieved from two databases, Scopus (n = 160) and Web of Science (WoS) (n = 120). No additional documents were obtained from other sources (n = 0). After merging the documents and removing duplicates (n = 88), a total of 192 unique documents were included in the next screening stage.

Abstract screening stage: The titles and abstracts of the 192 documents were reviewed to assess their relevance to the research objectives. In this stage, 94 irrelevant documents were excluded, leaving 98 papers to proceed to the full-text retrieval stage.

All 86 documents requiring full-text retrieval were successfully obtained (n = 12 documents for which full-text retrieval was unsuccessful).

After further full-text eligibility assessment of these full-text documents, another 43 papers were excluded. The main reasons for exclusion were: ① Failure to focus on port business process or node mechanism innovation, lacking end-to-end mechanism modelling (28 papers); ② Focus solely on the adoption willingness, barriers, or influencing factors of blockchain technology, without specific mechanism innovation or process implementation (6 papers); ③ Only theoretical modelling, case summarisation, or discussions of auxiliary technologies, without systematic implementation or process-level mechanism innovations (4 papers); and 5 papers were excluded for other reasons.

Ultimately, 43 papers met all inclusion criteria and were included in the thematic analysis and results analysis. No additional papers were included from sources outside the initial database search.

This structured and rigorous screening method ensures that the selected literature closely aligns with the research objectives, providing a solid foundation for subsequent analysis and discussion.

2.6 Overview of the final literature scope and summary

Through a rigorous PRISMA screening process, this study ultimately included 43 articles as the primary data sources for the subsequent descriptive analysis in Chapter 3 and the thematic analysis in Chapter 4. All of these documents explicitly focus on the application of blockchain technology in enhancing transparency and security in port logistics processes. In terms of publication year, the documents are primarily concentrated between 2021 and 2024, with the highest number of publications in 2024, reflecting the growing research attention on blockchain in the port logistics sector over the past two years.

Overall, this section provides an overview of the final literature pool, clarifying the basic characteristics of these documents and providing the necessary data support for the more in-depth annual trend analysis, journal domain analysis,

research method classification, and thematic keyword co-occurrence analysis in the next chapter.

3 Descriptive Analysis

This chapter will provide an overview of the results ultimately included in the literature pool. Based on this, we will analyse general descriptive findings regarding the period, research methods, and journal geographical distribution. The aim is to answer the first research question (RQ1): ‘What are the research topic distribution and development trends in the field of blockchain in port logistics?’ Through this analysis, these descriptive insights will provide a theoretical foundation for the thematic exploration in Chapter 4.

3.1 Overview of the Included Literature

In Chapter 2, the author used a rigorous PRISMA screening process to select 43 papers from 280 documents for inclusion in the final literature pool. These 43 papers were published between 2019 and 2025, a period that fully covers the development of this research field from its initial exploration to its rapid rise, reflecting recent research progress and emerging concerns in the application of blockchain technology to port logistics transparency and security mechanisms. All included papers share the following common characteristics: their research contexts are primarily focused on port logistics scenarios, the main applied technology is blockchain, and each paper discusses the implementation pathways and mechanisms of the technology to some extent. These common characteristics ensure that the selected papers are highly relevant to the core objectives of this study.

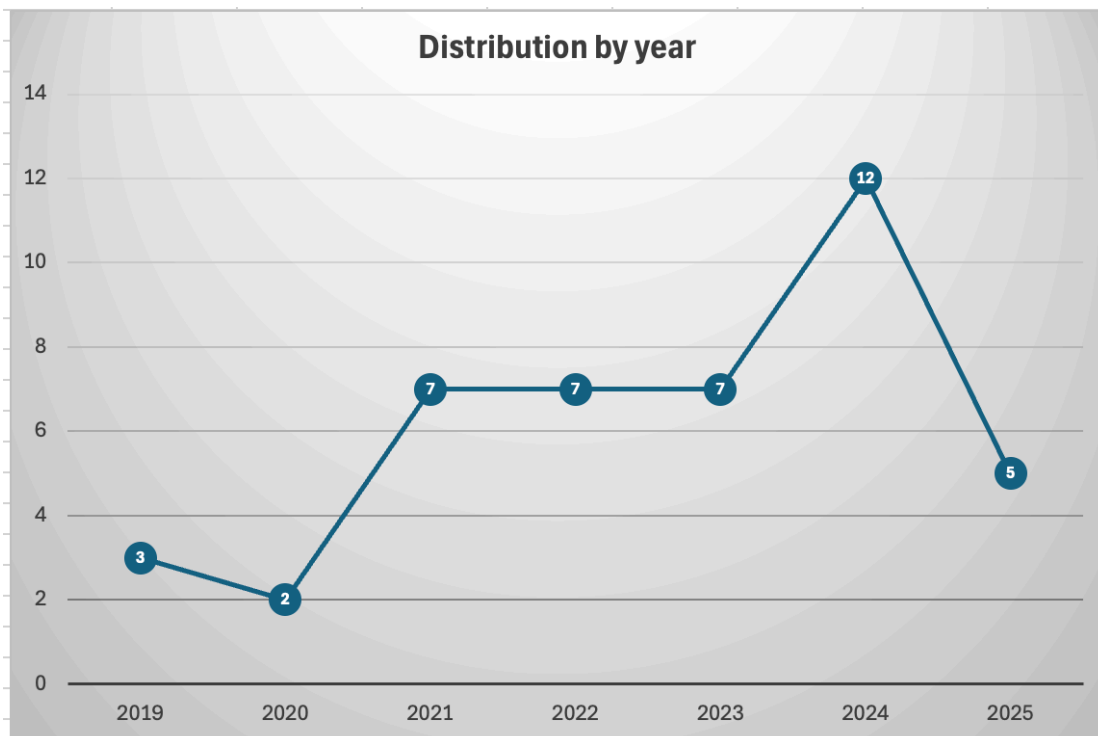
The following sections (3.2–3.4) will further analyse these papers from the perspectives of publication trends, journal distribution, and methodological approaches, providing a solid foundation for the thematic analysis in Chapter 4.

3.2 Publication Year Distribution

This section presents a statistical analysis of the annual distribution of 43 core literature articles, clearly illustrating the evolution of this research field. As shown in Figure 3-1, the number of high-impact (Category A) articles has grown steadily since 2019, reaching a peak in 2024.

Figure 3-1: Annual distribution of core literature

Source: the author(2025)



Data indicates that research interest in this field is not only growing but accelerating, with a significant uptick since 2021. This growth trend reflects not only the potential of blockchain technology attracting widespread attention from the academic community but also the positive response of academic research to events within the industry. During the initial phase of the study (2019–2020), the number of relevant literature publications was relatively low, with only three and two articles published each year, reflecting that the application analysis of blockchain technology in port logistics networks is still in its early stages of exploration. In 2018, the TradeLens platform, jointly launched by IBM and Maersk, went live, sparking initial academic interest(Jensen et al., 2019). Starting from 2021, the academic research atmosphere became increasingly vibrant, with a significant increase in the number of papers published, stabilising at around 7 per year. However, the challenges encountered by the platform during its operation and its eventual shutdown in early 2023 became the primary catalyst for critical exploration by the academic community (K. Li et al., 2024; Najati, 2025; Wong et al., 2024; Zeng et al., 2025). By 2024, the number of publications reached 12,

reflecting the typical lag period (12–18 months) between academic research and publication. This publication’s peak indicates the academic community’s attention to industry dynamics, close connections, and deeper exploration. As of early June 2025, the number of publications had reached 5.

At the same time, the focus of research has shifted from early promotional or purely conceptual discussions within the industry to more critical and analytical work. This shift marks the maturity of a field of study that is actively drawing on the successes and failures of early adopters (such as the T-Mining project) to drive the advancement of both theory and practice.

3.3 Journal and Subject Area

This section analyses the distribution of the 43 selected literature in terms of journal classification, country of publication, and disciplinary field to reveal the academic quality of research on blockchain technology applications in the context of port logistics and its interdisciplinary research characteristics. Details are shown in Table 3-1.

Figure 3-2: Detailed breakdown of journals, countries, quartile rankings, and subject areas

Source: the author(2025)

Journals	Number of Articles	Country	Journal Quartile	Primary Subject Area
IEEE Access	3	United States	Q1	Computer Science/Engineering
Maritime Policy & Management	3	United Kingdom	Q1	Engineering/Environmental Science
Journal of Marine Science and Engineering	2	Switzerland	Q2	Engineering/Environmental Science
Maritime Economics & Logistics	2	United Kingdom	Q1	Economics, Econometrics and Finance/Social Sciences
Systems	2	Switzerland	Q2	Computer Science/Engineering/Mathematics/Decision Sciences
Asia-Pacific Journal of Operational Research	1	Singapore	Q3	
Cogent Business & Management	1	United Kingdom	Q2	Business, Management and Accounting/Decision Sciences
Computer Standards & Interfaces	1	Netherlands	Q1	Computer Science/Social Sciences
Computers	1	Switzerland	Q2	Computer Science
Computers & Industrial Engineering	1	United Kingdom		Computer Science/Decision Science/Engineering
Data and Metadata	1	Argentina	Q3	Computer Science/Decision Science/Health Professions
Foods	1	Switzerland	Q1	Agricultural and Biological Sciences/Health Professions/Immunology and Microbiology/Social Sciences
Future Generation Computer Systems	1	Netherlands	Q1	Computer Science
IEEE Open Journal of Vehicular Technology	1	United States	Q1	Engineering
International Journal of Production Research	1	United Kingdom	Q1	Business, Management and Accounting/Decision Sciences/Engineering
International Transactions in Operational Research	1	Denmark	Q1	Business, Management and Accounting/Decision Sciences/Computer Science
Journal of Global Operations and Strategic Sourcing	1	United Kingdom	Q1	Business, Management and Accounting/Decision Sciences
Journal of ICT Standardization	1	Denmark	Q2	Business, Management and Accounting/Decision Sciences/Computer Science
Journal of Maritime Research	1	United Kingdom	Q4	Arts and Humanities/Social Sciences
Logistics	1	Switzerland	Q2	Business, Management and Accounting/Decision Sciences/Social Sciences
Mathematics	1	Switzerland	Q2	Computer Science/Engineering/Mathematics
Ocean and Coastal Management	1	United Kingdom	Q1	Agricultural and Biological Sciences/Earth and Planetary Sciences/Environmental Science
PLOS ONE	1	United States	Q1	Multidisciplinary
Research in Transportation Business & Management	1	Netherlands	Q1	Business, Management and Accounting/Decision Sciences/Social Sciences/Economics, Econometrics and Finance
Review of International Business and Strategy	1	United Kingdom	Q2	Business, Management and Accounting
Scientific Journal of Maritime Research (POMORSKO)	1	Croatia	Q3	Engineering/Social Sciences
Sustainability	1	Switzerland	Q1	Computer Science/Engineering/Environmental Science/Social Science
Sustainable Cities and Society	1	Netherlands	Q1	Energy/Engineering/Social Sciences
Sustainable Computing: Informatics and Systems	1	United States	Q1	Computer Science/Engineering
Technological Forecasting & Social Change	1	United States	Q1	Business, Management and Accounting/Psychology
Transport and Telecommunication	1	Latvia	Q2	Computer Science/Engineering
Transport Reviews	1	United Kingdom	Q1	Social Sciences
Transportation Research Part B	1	United Kingdom	Q1	Decision Sciences/Social Sciences/Engineering
Transportation Research Part E	1	United Kingdom	Q1	Business, Management and Accounting/Decision Sciences/Social Sciences/Engineering
Transportation Research Procedia	1	Netherlands		Social Sciences
Uncertain Supply Chain Management	1	Canada		Business, Management and Accounting/Decision Sciences

First, research on blockchain in port logistics networks spans multiple disciplines, including computer science, engineering, management, logistics, and policy, exhibiting a distinct multidisciplinary character. This interdisciplinary approach is

precisely what facilitates innovation in this field, introduces diverse research perspectives, and promotes the diversity of theories and methods.

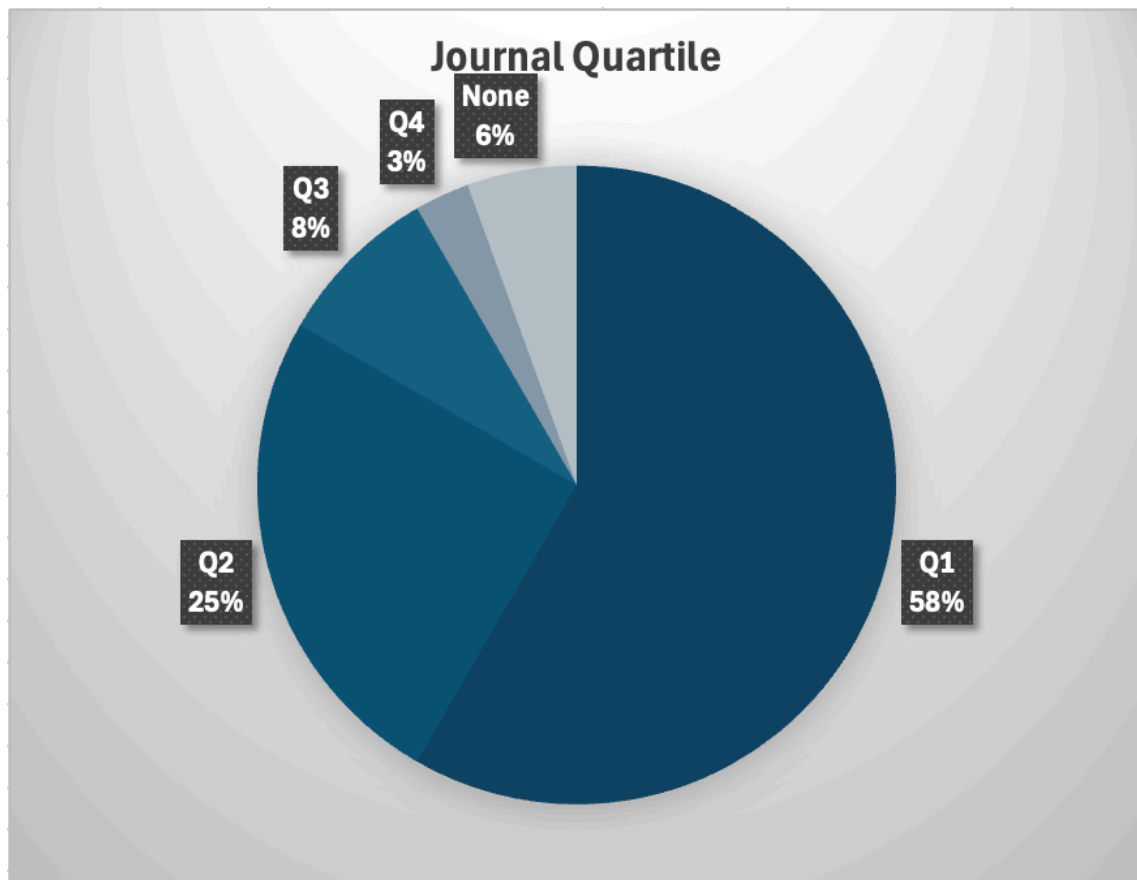
However, further analysis reveals that different disciplines focus on distinct themes and methods. Some publications, such as IEEE Access, Computers & Industrial Engineering, and Computer Standards & Interfaces, which are computer and engineering journals, mainly focus on system architecture design, algorithm modelling, and technical implementation issues. At the same time, Maritime Policy & Management, Technological Forecasting & Social Change, Sustainability, and other management, logistics, and policy journals are more concerned with topics such as the industrial application of blockchain technology, governance models, and adoption intentions.

As such, while these studies all address the same overarching challenge, their differing research perspectives and analytical tools often result in insufficient integration and synthesis of knowledge. This underscores the core value of this study, which aims to systematically bridge the gap between technical feasibility and commercial viability.

Second, from the perspective of journal classification, as shown in Figure 3-2, most of the literature (58.33%) was published in top-tier (Q1) journals. The wide distribution of literature across high-quality journals indicates that research on blockchain in port logistics networks has achieved a high level of academic maturity and research rigour, and that it has gradually gained recognition from the mainstream academic community. This is crucial for establishing an authoritative discourse system and promoting the influence of research.

Figure 3-3: Distribution of journal quartiles

Source: the author(2025)

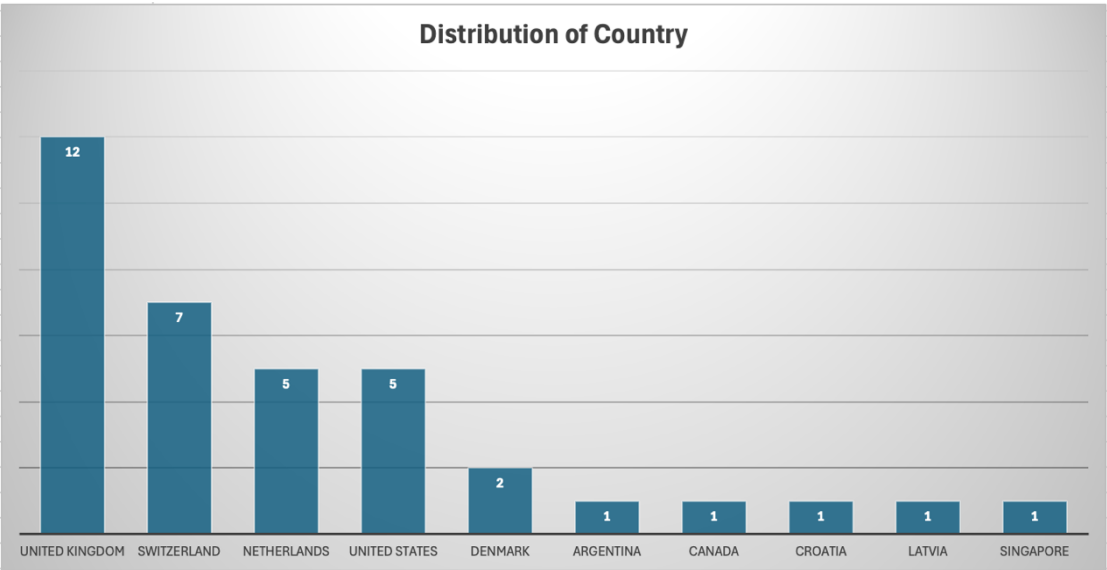


Then, from the geographical distribution of journals (Figure 3-3), the United Kingdom, Switzerland, the Netherlands, and the United States are the core countries publishing research in this field, collectively contributing over 70% of the literature, reflecting that the publishing ecosystem of major academic journals in this field is concentrated in developed countries. However, most of the authors are not from the countries where the journals are published, showing no obvious 'local preference,' but rather are research teams from multiple countries around the world collaborating on the papers. For example, literature published in UK journals may have authors from other countries such as China or Spain. This phenomenon of 'publication concentration and researcher dispersion' reveals two important trends: first, the uneven distribution of the current academic knowledge network, meaning that despite researchers being spread across the globe, academic publishing groups in some developed countries still hold the dominant

voice and publication rights in academia. Second, blockchain research in port logistics networks is a global activity, and some researchers seek to enhance their academic influence by submitting their work to international top-tier journals rather than limiting themselves to domestic journals.

Figure 3-4: Distribution of journals by country

Source: the author(2025)

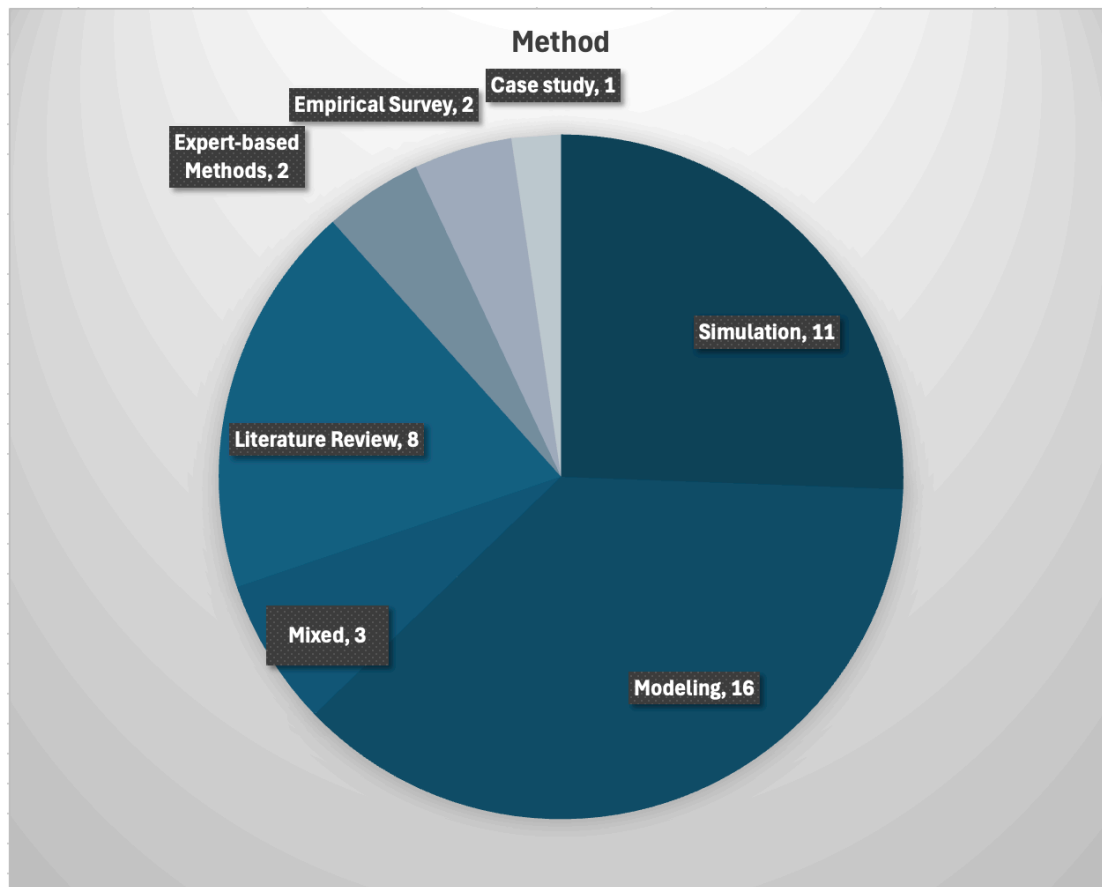


3.4 Research Methods Adopted

This section conducts a systematic analysis of the research methods employed in the literature ultimately included in this study to reveal the methodological preferences and limitations of blockchain research in the field of port logistics networks. As shown in Figure 3-4, modelling-based research accounts for the largest proportion (37%), followed by simulation methods (25%) and literature reviews (19%). Mixed methods, expert assessment methods, and empirical survey methods account for a smaller proportion, while case studies account for only 2%.

Figure 3-5: Distribution of Research Methods

Source: the author(2025)



This methodological imbalance can be understood as the academic community's response to the high-risk, high-cost challenges faced by blockchain projects in real-world implementation. In the port logistics sector, where real-world data and case studies are scarce, coupled with concerns over data privacy, commercial sensitivity, and the high costs of blockchain deployment, researchers have generally opted for mathematical modelling and system simulation as an efficient means of 'pre-implementation' validation in controlled, low-cost environments. This methodological preference not only reflects the early stage of blockchain technology adoption but also indicates that, after incurring significant costs through large-scale projects like TradeLens, the research community has moved away from the idealistic notion that 'if it's built, it will be used' and adopted a more cautious, evidence-based research approach.

However, this mainstream research method also has limitations. It essentially operates in a closed, idealised ‘laboratory’ environment, which can only prove the technical feasibility of a system but cannot capture real-time industry technology dynamics. The actors in the model method make rational decisions according to a predetermined route, while the actors and environment in real-world applications are full of uncertainty. Although systematic review literature can help to sort and summarise knowledge at a certain stage, its value in guiding practice is correspondingly limited. It is particularly worth noting that case studies and empirical investigations in this field are extremely scarce. This means that a large number of model-based theoretical innovations may never have been tested in a real business environment, and their effectiveness and applicability remain questionable.

Overall, research methods in the field of blockchain in port logistics networks exhibit a structural characteristic of ‘strong emphasis on theoretical abstraction but insufficient focus on empirical and practical applications.’

3.5 Chapter Summary

This chapter conducts a systematic descriptive analysis of the 43 literature sources ultimately included in the study, revealing the development trends and research landscape of blockchain technology in the field of port logistics network research. The study finds that this field has developed steadily since 2019, reaching its peak in 2024, indicating the academic community's active response to real-time industry dynamics. The literature spans multiple disciplines, exhibiting a distinct interdisciplinary character. However, there is insufficient integration of research themes and methods across disciplines. Additionally, current research tends to focus on reconstruction, modelling, and simulation, while case studies and empirical investigations are significantly lacking, reflecting a disconnect between theory and practice. The conclusions of this chapter lay the theoretical foundation for subsequent thematic analyses.

4 Thematic Analysis

This chapter will systematically review and analyse the primary mechanisms, typical application pathways, and related challenges of blockchain technology in enhancing transparency and security within port logistics networks. The aim is to address the final two research questions (RQ2 & 3): 'What methods and pathways have been employed in existing literature to achieve transparency and security in port logistics networks, and which specific stages of the process do they focus on?' & 'Which process or security-related issues have not been sufficiently discussed in existing research, and how can future efforts better support transparency and security in port logistics processes?' Through this analysis, this chapter will provide empirical and theoretical foundations for subsequent theoretical advancements and practical recommendations.

4.1 Analysis Methods and Summary of Topics

The analytical framework employed in this chapter combines deductive thematic analysis with inductive coding. This method selection aligns with the literature screening criteria. Specifically, the themes 'transparency' and 'security' were established as core inclusion criteria during the literature screening phase. Therefore, the thematic analysis in this chapter does not start from scratch but is built upon these two core thematic frameworks, ensuring that the literature content remains highly consistent with the research objectives (Braun & Clarke, 2006).

The specific analytical logic is as follows: first, the 43 literature sources were systematically analysed using 'transparency' and 'security' as the main threads, and two major sections were summarised and organised to explore the specific mechanisms and pathways proposed in the literature to achieve these two objectives. Subsequently, under each core theme, inductive coding techniques were used to label and categorise the content of the 43 literature sources, further identifying more representative sub-themes and implementation pathways.

This 'Thematic Analysis method combining deduction and induction' ensures theoretical guidance while accommodating the openness and diversity of data

content, thereby enhancing the rigour and credibility of qualitative analysis (Fereday & Muir-Cochrane, 2006). The structure and content of the themes and sub-themes in this chapter are based on the analytical logic and methodology, ensuring a reasonable structure and systematic content.

In summary, the structure of this chapter is as follows: Sections 4.2 and 4.3 provide a systematic analysis of the two major themes of ‘transparency mechanisms’ and ‘security mechanisms,’ respectively. Section 4.4 provides a summary of this chapter.

4.2 Mechanisms for Achieving Transparency

4.2.1 Introduction and Background

Transparency has become a critical foundation for achieving efficient collaboration and risk management in modern port logistics networks (Filipović et al., 2024). In the field of supply chain management, the definition of transparency is not limited to the complete disclosure of information or full process visibility, but rather emphasises the dynamism, selectivity, and relationship-oriented nature of information sharing. As Lamming et al. (2001) pointed out, supply chain transparency should be understood as the dynamic visibility of multi-dimensional data and processes achieved through selective, two-way, and progressive information sharing among relevant parties under specific supply relationships and cooperative objectives.

However, traditional port information systems often face issues such as ‘information silos,’ fragmented processes, and difficulties in verifying data authenticity, leading to severe process inefficiencies and operational risks. Therefore, a truly transparent port supply chain means that all authorised stakeholders can collaborate and make decisions seamlessly based on a unified, shared, and tamper-proof ‘single source of truth.’ According to Radziwill (2018), blockchain can serve as the single source of truth for the entire network of supply chain actors, fundamentally creating and ensuring transparency for port logistics systems.

Therefore, the remainder of this section will systematically explore the mechanisms through which blockchain technology enhances transparency in port supply chains, laying the groundwork for subsequent mechanism summaries and case analyses.

4.2.2 Representative Mechanisms

Through a systematic analysis of 43 core literature sources, this study identifies three primary mechanisms aimed at enhancing port logistics transparency through blockchain technology: achieving end-to-end traceability of physical assets, promoting digital visibility of key business processes, and enabling data-driven collaborative decision-making. These three mechanisms represent three progressive levels in the development of port logistics transparency, progressing from foundational data authenticity and tracking, to the transparency and efficiency of business processes, and finally to intelligent optimisation and collaborative decision-making based on transparent data. The following sections will provide a detailed explanation of the specific implementation methods, application scenarios, and practical value of each mechanism.

4.2.2.1 Mechanism 1: End-to-end traceability based on shared ledgers

One of the most fundamental, widely studied and applied mechanisms of blockchain technology in the port logistics sector is end-to-end traceability based on a shared ledger. The core logic of this mechanism is to utilise the distributed shared ledger and immutable data characteristics of blockchain to reliably record the entire journey of physical assets (such as containers, goods, and transport vehicles) in complex logistics networks and provide a unique tracking record. Therefore, this mechanism can effectively provide a solution to the question of ‘where is the cargo’ in the supply chain.

In terms of implementation, scholars generally believe that a blockchain ledger alone cannot perceive the physical world, so integrating it with IoT technology can better help record and track cargo status information and improve collaboration efficiency. Literature reviews indicate that this mechanism typically leverages IoT technology for specific applications. IoT devices, such as GPS

devices, radio frequency identification (RFID) tags, and various environmental sensors, continuously collect location, status, and environmental data from physical assets and write this information to the blockchain network in real-time or at regular intervals. For example, Elmay, Salah, Yaqoob, et al. (2022) and Nasih et al. (2024) point out that by combining blockchain with IoT, real-time transparent tracking of container transport status can be achieved, significantly improving the timeliness and reliability of supply chain management.

Additionally, in the management of logistics vehicles, Tesei et al. (2021) and González-Cancelas et al. (2025) emphasise blockchain-based real-time vehicle tracking systems. By continuously recording vehicle location information, travel routes, and credential statuses, these systems achieve comprehensive transparency and controllability of transportation processes both within and outside ports, significantly improving the efficiency of internal resource scheduling and risk management levels within ports.

It is worth noting that many current studies on 'special cargo tracking' or cold chain logistics do not directly focus on the specific pathways through which blockchain technology can be used to control cargo information within port logistics networks. For example, in (L. Li & Zhou, 2025), the study analyses the role of the 'perishable goods loss rate' variable in a blockchain investment return model from an economic decision-making perspective, finding that blockchain technology can help improve customs clearance efficiency and reduce losses for fresh/perishable goods. However, its core focus is on pricing strategies and investment decisions, without addressing physical-level process monitoring mechanisms. Similarly, Shen et al. (2022) pointed out that efficient information sharing is a key factor in achieving excellence in cold chain logistics. Therefore, their research focuses on analysing the willingness of cold chain enterprises to share environmental information (such as temperature and humidity) through incentive mechanisms and game models, with an emphasis on the traceability and immutability of data on the blockchain, rather than the specific deployment and integration of sensors on the blockchain. As such, while existing literature generally acknowledges the theoretical potential of blockchain to enhance data

transparency and process traceability in cold chain and special cargo transportation, systematic and empirical research on how blockchain can be deeply integrated with other technologies and applied for end-to-end process monitoring within port logistics networks remains scarce.

Although traceability is a common goal, most literature emphasises the advantages of blockchain technology in terms of data immutability and trustworthy information flow, while the mechanisms for integrating actual technical implementations with industrial cases remain areas for further exploration and validation in subsequent research.

4.2.2.2 Mechanism 2: Digitisation of Key Documents and Process Visibility

The digitisation of key documents and process visibility mechanisms have further enhanced the transparency of port logistics operations. At the core of this mechanism is the use of blockchain technology to digitise key trade documents such as bills of lading (B/L) and letters of credit (L/C), and to record the entire process of issuance, circulation, and approval on the chain, thereby making the previously opaque offline business processes transparent and auditable in real time.

The vast majority of research has focused on the bill of lading (B/L) as a trade document, as it serves as both a title document, a transport contract, and a cargo receipt (Irannezhad & Faroqi, 2023). In traditional paper-based B/L processes, low circulation efficiency, susceptibility to loss, and forgery have become the primary causes of port inefficiency and trade fraud. Therefore, a significant amount of research has been dedicated to developing blockchain-based electronic bill of lading (BCT-B/L) solutions. The underlying logic is to transform the bill of lading into a unique digital asset recorded on a distributed ledger. Every endorsement transfer, ownership change, or final delivery is treated as an immutable on-chain transaction, thereby providing unprecedented transparency and security for this 'fluid contract.' Liaqat et al. (2024), Irannezhad and Faroqi (2023), and Amico and Cigolini (2024) not only analysed the role of blockchain in the digitalisation of bill of lading processing but also highlighted that digital documents can significantly reduce fraud risks and human errors in document

circulation. Furthermore, some cutting-edge research has even explored the use of non-fungible tokens (NFTs) to manage digital bills of lading (Elmay, Salah, Jayaraman, et al., 2022), leveraging their unique and indivisible characteristics to perfectly map the legal attributes of bills of lading as title documents, and enabling innovative applications such as on-chain auctions for abandoned goods.

Meanwhile, some studies have explored how blockchain technology can enhance the transparency and auditability of overall business processes from a more comprehensive perspective. For example, Philipp et al. (2019) and Tsiulin et al. (2020) emphasised the application of blockchain technology in supply chain process management, specifically including the transparency of approval processes and the automation of logistics document circulation. Additionally, Tan and Sundarakani (2021) and Shin et al. (2024) further highlight the advantages of smart contracts in the management of trade and logistics documentation throughout the entire process, arguing that they help improve the efficiency and accuracy of compliance reviews at critical nodes such as customs and banks.

However, despite the compelling appeal of the concept of document digitisation and process visualisation, translating this vision from theory into practice and driving its implementation in the real world requires overcoming a series of challenges. First, 'a single shipment transaction could involve 28 distinct parties and around 200 different document exchanges' (Shin et al., 2024, p. 1063). The parties involved are not only stakeholders but also include incompatible operational systems within their organisations. Without a unified standard architecture, this could lead to the emergence of new 'digital silos.' Second, the absence of legal status and regulatory frameworks, particularly the jurisdictional conflicts faced in cross-border transactions, also presents uncertain challenges in implementing the plan in practice. Additionally, 'transparency' itself is a double-edged sword. While it can theoretically increase trust among stakeholders through transparent business processes, it may also heighten suspicion among participants due to the potential for revealing commercially sensitive information, as seen in the TradeLens platform.

Therefore, in the future, research and practice should not only focus on blockchain technology itself, but also concentrate on solving various practical issues such as cross-organisational cooperation, standardisation, and legal compliance, to achieve the effective implementation and sustainable development of blockchain technology in the port logistics field.

4.2.2.3 Mechanism 3: Data-Driven Collaborative Decision-Making and Intelligent Optimisation

After achieving visibility into assets and processes, the highest level of transparency mechanism discussed in the literature is to leverage transparent and trustworthy data secured by blockchain to empower cross-entity collaborative decision-making and intelligent optimisation. This mechanism marks a paradigm shift: blockchain is no longer merely a passive 'recording system,' but rather serves as the cornerstone of trust for an active 'decision support system' through trustworthy data. Its core logic is that when all parties trust the authenticity and integrity of the shared data pool, advanced analytical tools such as artificial intelligence (AI), operations research optimisation, and game theory can be applied to seek the optimal solution for the entire port ecosystem, rather than merely maximising local interests.

In specific applications, scholars have explored various data-driven optimisation scenarios through modelling and simulation. Taking vessel traffic optimisation as an example, Wang et al. (2021) proposed a blockchain-based data-driven intelligent port management framework. By real-time sharing information such as the expected arrival time (ETA) of incoming vessels, pilot boarding preparation time, and tugboat preparation time, the framework achieved efficient collaborative management of port traffic flow, significantly reducing vessel waiting time and resource idleness, and optimising berth utilisation and pilot scheduling decisions (Wang et al., 2021).

Secondly, blockchain technology enhances the intelligence of port operations by integrating with advanced analytical tools, such as artificial intelligence (AI) and machine learning (ML), in collaborative decision-making for port logistics. For example, the DMLBC framework (Dependable Machine Learning for Seaports

using Blockchain) proposed by Durán, Fernández-Campusano, et al. (2024) uses machine learning algorithms to conduct real-time analysis and prediction of actual conditions in port loading and unloading processes, facility maintenance, and container handling. The combination of blockchain-based data transparency and AI-driven intelligent analysis enables ports to proactively identify potential risks or operational bottlenecks, adjust decisions, and optimise resources, significantly enhancing overall operational efficiency and reliability (Durán et al., 2024).

In addition, data-driven collaborative decision-making and intelligent optimisation enabled by blockchain technology can also support the sustainable development goals of ports. Z. Li et al. (2024) points out that the integration of blockchain with government low-carbon policies, through smart contracts to manage government subsidies and investments for low-carbon port operations, can incentivise ports to proactively upgrade their low-carbon facilities and optimise their low-carbon operational strategies. Through the data transparency of blockchain, governments can more accurately assess port emissions reduction performance, thereby implementing more efficient financial support and strategic optimisation. Similarly, Mhiri et al. (2024) proposed a blockchain-based optimisation framework for container inland transportation, achieving optimal matching between inland shippers and consignees through blockchain and planning optimal routes via intelligent optimisation algorithms, significantly reducing empty container transportation and logistics costs (Mhiri et al., 2024).

In summary, data-driven collaborative decision-making and intelligent optimisation mechanisms, combined with advanced optimisation tools through a blockchain-based trustworthy and transparent data-sharing platform, have significantly improved the overall collaborative efficiency, resource utilisation levels, and risk management capabilities of port logistics networks. Although current research has demonstrated significant advantages, further exploration of the specific technical implementation, standardised processes, and quantitative assessment of long-term benefits of this mechanism remains a promising direction for future research.

4.3 Mechanisms for Ensuring Security

4.3.1 Introduction and Background

In port logistics networks, 'security' and 'transparency' complement each other and together form the cornerstone of a trustworthy supply chain. In a supply chain network, security is a multi-layered, comprehensive concept that encompasses not only information security—such as preventing data breaches and cyberattacks—but also transaction security—such as safeguarding cargo ownership and preventing document fraud—and physical operational security—such as preventing cargo theft and delivery errors (Fu & Zhu, 2019).

However, traditional port logistics processes rely on easily forged paper documents, vulnerable centralised information systems, and weak operational authentication mechanisms, resulting in inherent vulnerabilities in transaction and information security. Therefore, a high-security port logistics system ensures that the flow of assets and data is trustworthy, controllable, and reliable in a complex, multi-party environment. According to Saberi et al. (2019), blockchain technology, with its immutable, decentralised, auditable, and self-executing characteristics, can strengthen the information security, transaction security, and operational security of supply chain systems at the structural level, particularly in addressing typical supply chain security threats such as fraud, data tampering, and systemic risks.

Therefore, blockchain is not only a tool for enhancing port logistics transparency but also a critical underlying technology for achieving comprehensive security protection. This section will systematically review the main categories, innovative practices, and practical challenges of blockchain security mechanisms in port logistics based on this theoretical framework.

4.3.2 Representative Mechanisms

Through a systematic analysis of 43 core literature sources, this study summarises three main implementation mechanisms aimed at enhancing port logistics security through blockchain technology. These are: an automated access control and process execution mechanism based on smart contracts; an

identity and data security mechanism based on cryptography and permissioned chains; and a layered security defence mechanism tailored to specific scenarios. These mechanisms are not mutually exclusive but collectively form a multi-layered, three-dimensional security framework spanning upper-level business processes, mid-level data foundations, and frontline specific scenarios.

4.3.2.1 Mechanism 1: Automated access control and process execution based on smart contracts

First, the most frequently proposed and fundamental application layer mechanism in the literature is the use of smart contracts to control and automate access to and enforce processes. The essence of smart contracts is to codify complex business rules and operational permissions and deploy them on the blockchain. Therefore, it acts like an unwavering ‘automated security officer,’ ensuring that all operations adhere to predefined and fixed logical workflows, thereby significantly reducing security risks caused by human complacency, operational errors, or malicious behaviour.

In detail, smart contracts primarily ensure process security through two methods. First, by incorporating role-based access control (RBAC) logic or permission modifiers into the smart contract, strict restrictions are placed on ‘who’ can perform “what” actions ‘when.’ For example, Liaqat et al. (2024) proposed a ‘role-based + credential chain’ permission control mechanism in their oil port platform. This mechanism requires real-time verification of the caller's identity by the contract for all operations related to viewing, signing, and unlocking port documents, thereby ensuring compliance and traceability of the operations. Additionally, Gao et al. (2022) emphasised in the Fabric-PSChain system that collaboration between smart contracts and the Membership Service Provider (MSP) in the Fabric architecture can achieve an access control model where port operations are ‘chained based on permissions and retrieved based on roles’.

Secondly, smart contracts can automatically monitor on-chain events and trigger state changes based on them, ensuring that each step is strictly carried out according to pre-set rules. In the complex, multi-node collaborative environment of a port, different business systems are typically maintained by separate

organisations, posing challenges for unified scheduling and process synchronisation. Existing research has proposed embedding an 'event-driven + state-locking' logic framework within smart contracts, enabling the contract to automatically advance subsequent node tasks once specific events (such as 'shipment completed' or 'pickup appointment successful') are detected. For example, Tan and Sundarakani (2021) emphasise that the application of smart contracts in logistics process control, particularly at critical nodes such as approval processes and document circulation, helps to avoid human errors or skipping necessary steps, thereby ensuring process integrity. Additionally, González-Cancelas et al. (2025) demonstrated through a port vehicle management case study how smart contracts can automatically monitor on-chain events and trigger state changes, thereby ensuring that processes advance automatically according to predefined rules. These mechanisms play a crucial role in enhancing process compliance and preventing unauthorised access.

Although smart contracts demonstrate significant potential in enhancing process automation and execution security, their actual deployment still faces multiple challenges. On the one hand, smart contracts typically lack flexible governance mechanisms. Once business requirements change or cooperative relationships are redefined, modifying contract rules and coordinating among multiple parties often becomes complex and time-consuming. On the other hand, the triggering of smart contracts heavily relies on off-chain data inputs. If the data sources themselves lack credibility or deviate from the actual business state, this can easily lead to incorrect execution or even systemic failures. Additionally, since contracts are difficult to modify once deployed, any design flaws or logical oversights in the code may result in process rigidity, functional failures, or security vulnerabilities, thereby limiting their scalability and adaptability in complex dynamic environments.

Therefore, future research and practice should not only focus on the technical mechanisms themselves but also prioritise cross-organisational collaboration, standardisation, and rule adaptation to promote the sustainable implementation of smart contracts in port logistics.

4.3.2.2 Mechanism 2: Data security based on cryptography and permissioned chains

Current research on port logistics blockchain generally believes that the data and identity security mechanisms underlying the system are core elements for ensuring its reliability and stable operation. This fundamental design determines whether information can be securely collected, stored, and shared, and also affects the subsequent construction of permission control and risk prevention capabilities.

First, cryptographic mechanisms form the core foundation of blockchain technology in terms of data security and identity management. On the one hand, the block structure uses cryptographic hash functions to link all on-chain transactions in chronological order, ensuring that any tampering with a single piece of data would trigger a systemic change in the entire chain structure, which would be swiftly detected by all network nodes, thereby achieving data immutability (Ahmad et al., 2021; Liu et al., 2023). On the other hand, digital signature technology ensures the traceability and non-repudiation of on-chain operations. Each transaction must be signed by the node's private key before being broadcast, and other nodes can verify it using the public key to confirm the authenticity of the operator's identity and the legitimacy of their authorised actions.

Secondly, in business scenarios such as ports, which involve multiple parties and highly complex processes, permissioned blockchain architecture is widely recognised in the literature as the preferred choice for enterprise-level applications. Among these, the Hyperledger Fabric platform is frequently adopted in actual deployments due to its flexible module design and powerful identity control capabilities. This platform uses a Membership Service Provider (MSP) and a Certificate Authority (CA) to register and authorise all users and organisations, ensuring that only trusted entities can participate in the blockchain network. Additionally, the channel mechanism allows multiple business participants to divide private communication environments based on specific cooperative relationships, enabling cross-organisational data sharing while effectively avoiding the risks of information leakage and unauthorised access.

Research cases have validated the effectiveness of the mechanisms. Liaquat et al. (2024) achieved data isolation and secure transmission between different organisations by leveraging CA issuance and multi-channel configuration when designing a petroleum port blockchain platform.

Although the aforementioned underlying security mechanisms provide a solid technical foundation for port blockchain systems, there are still many practical limitations in actual applications. On the one hand, the governance structure and identity management of consortium blockchain platforms typically rely on centralised maintenance by the dominant party. While this improves management efficiency, it may also give rise to new trust issues and collaboration asymmetries. Especially in a port environment with multiple participants and dispersed interests, how to achieve a fair and transparent authority allocation mechanism remains a challenge. On the other hand, the lack of unified standards across different platforms in terms of identity authentication, data structures, and interface protocols results in high barriers to cross-system data interoperability and collaborative processing.

Overall, identity and data security mechanisms based on cryptography and permissioned chain architecture lay an important foundation for trusted collaboration in port blockchain systems. How to optimise governance models and achieve more efficient data sharing and cross-platform interoperability remains an important direction for continued exploration in this field in the future.

4.3.2.3 Mechanism 3: In-depth security defence for specific scenarios

In addition to existing general security frameworks, recent years have seen a growing number of studies focusing on more complex and profound security challenges, proposing a series of targeted ‘defence-in-depth’ solutions. The focus of such research is no longer limited to traditional data encryption and identity verification. Still, it has expanded to include physical asset tamper-proofing, digital ownership verification, deep data privacy protection, and the security and verifiability of contract code itself. Compared to the construction of foundational mechanisms, these explorations are more forward-thinking and innovative,

representing an important trend in current research on port blockchain security mechanisms.

First, in terms of security integration between the physical and digital worlds, Le et al. (2023) proposed and demonstrated a blockchain-based electronic seal (e-seal) prototype system to enhance physical security in container transportation. The system integrates on-chain records with physical sensors, enabling automatic triggering of on-chain alerts when the seal is tampered with or damaged, thereby creating an immutable chain of evidence. This significantly improves the port logistics system's ability to detect and respond to abnormal events (Le et al., 2023). Secondly, in terms of ensuring the security of digital asset ownership, Elmay, Salah, Jayaraman, et al. (2022) explored the application of non-fungible token (NFT) technology in electronic document management, proposing to tokenise critical digital credentials such as bills of lading as NFTs on the blockchain. Leveraging the uniqueness and non-replicability of NFTs, this solution effectively curbs issues of counterfeiting and multiple transfers of traditional electronic documents in cross-border logistics, enabling secure transfer of digital ownership and providing a more reliable anti-counterfeiting pathway for international trade finance (Elmay, Salah, Jayaraman, et al., 2022). What's more, in terms of deep data privacy protection, Li et al. (2025) developed a data sharing mechanism for port supply chains that integrates blockchain technology with dynamic searchable encryption (DSSE). The system achieves fine-grained multi-party permission management through on-chain smart contracts, while leveraging off-chain DSSE technology to enable efficient and secure retrieval of encrypted data. This enhances data circulation efficiency under multi-organisation collaboration while ensuring data privacy and the principle of minimal disclosure (J. Li et al., 2025). Additionally, to ensure the logical security and automated reliability of smart contracts, Liu et al. (Liu et al., 2023) introduced formal verification and probabilistic model testing methods to conduct mathematical pre-reviews and vulnerability avoidance for contract execution paths. By identifying potential defects prior to deployment, this method helps reduce business interruptions and security risks caused by code errors

during system operation, thereby strengthening the trustworthy operational foundation of the port blockchain system from the source (Liu et al., 2023).

However, while these cutting-edge technological solutions demonstrate tremendous potential, they also face significant practical limitations. First of all, these solutions (such as NFT, DSSE, and formal verification) are highly complex and costly to implement, posing a major obstacle to their large-scale commercialisation in the port logistics industry, which emphasises operational efficiency and cost control. Currently, most port companies remain cautious in adopting new technologies. Balancing technical maturity with investment returns has become the core issue constraining their actual deployment. Additionally, the sustainable operation of such complex systems does not solely depend on technology itself but also requires aligned, clear, and feasible business models and governance frameworks. However, existing literature has paid relatively little attention to this area, lacking systematic exploration of the institutional support, operational mechanisms, and cross-organisational coordination strategies required for the post-implementation phase of these technologies. This has resulted in some cutting-edge solutions remaining stuck in the prototype validation stage, unable to progress to practical application.

Overall, the in-depth defence mechanism tailored to specific scenarios has expanded the technical boundaries of the port blockchain security system. In the future, how to establish a practical governance model while continuously improving security will be a key issue that needs to be addressed in this field.

4.4 Chapter Summary

This chapter focuses on the theme of enhancing transparency and security in port logistics networks through blockchain technology, systematically reviewing and summarising mainstream mechanisms and their application pathways. Through an in-depth thematic analysis of existing literature, the innovative value of blockchain technology in the following areas is highlighted: first, achieving end-to-end traceability; second, promoting the digitisation and visualisation of critical business processes; third, enhancing data-driven multi-party collaborative decision-making capabilities; fourth, automating process control through smart

contracts; fifth, establishing secure boundaries for identity and data through permissioned blockchains; and sixth, exploring layered security defence mechanisms in complex scenarios. This systematic analysis addresses the second and third research questions posed in the paper: What mechanisms and pathways have been adopted in existing literature to enhance transparency and security in port logistics networks? At which critical stages of the process do these mechanisms operate?

Overall, the thematic summarisation in this chapter not only lays the foundation for subsequent theoretical advancements and practical recommendations but also provides robust academic support for a deeper understanding of the structural logic and application evolution of port blockchain mechanisms.

5 Discussion

This chapter will critically examine the research findings presented in the systematic literature review, with a particular focus on the role of blockchain mechanisms in enhancing the transparency and security of port logistics networks. Unlike the presentation of results in the preceding sections, this chapter will further explain the underlying implications of these mechanisms, assess their alignment with existing theories, and analyse their practical feasibility and potential limitations. Additionally, this chapter will reflect on the tension between technological capability and governance readiness, discussing key issues such as standard fragmentation, multi-stakeholder conflicts, and the evolution of trust mechanisms.

5.1 Key Findings

First, a descriptive analysis of 43 literature sources revealed the overall development trajectory of this field: academic attention has steadily increased since 2019 and will peak in 2024. Research exhibits interdisciplinary characteristics but is highly concentrated in theoretical modelling and simulation in terms of methodology. The lack of empirical research suggests a significant gap between theory and practice.

Second, This study focuses on the core themes of ‘transparency’ and ‘security,’ systematically reviewing and analysing relevant literature on port logistics blockchain technology to identify a multi-layered mechanism system. Existing research has gradually constructed an idealised blockchain technology architecture at the theoretical level, covering the following key dimensions: end-to-end physical goods traceability, digital processing of critical documents, data-driven collaborative optimisation, smart contract-driven process automation, identity and data management mechanisms under permissioned blockchains, and layered security defence models tailored to specific scenarios. These mechanisms collectively form the core technological landscape of blockchain in enhancing process visibility, data integrity, and trust levels within a multi-party

collaborative port environment, and also provide an important foundation for understanding its institutional logic and application evolution.

However, a growing consensus in the literature is that there is a significant disconnect between this idealised technical blueprint and the actual governance structures in place. Multiple studies have pointed out that the failure of large-scale blockchain platforms, such as TradeLens, clearly demonstrates that the maturity of the technology alone is insufficient to determine the success or failure of its deployment (Najati, 2025; Pagano et al., 2022; Papadakis & Kopanaki, 2022b; Wong et al., 2024). In contrast, the core obstacles hindering the practical implementation of blockchain systems are the asymmetry of governance mechanisms, unclear boundaries of data sovereignty, and the lack of effective inter-organisational incentive and coordination mechanisms. While many academic studies still treat governance as a secondary variable, or even assume its natural existence, recent empirical findings have begun to emphasise that in highly diverse collaborative scenarios such as ports, 'governance over technology' is increasingly becoming a prerequisite for the success of blockchain applications.

In addition, the study also observed a clear shift in the adoption path of blockchain technology. Existing literature generally agrees that, compared to large-scale platform solutions such as TradeLens, 'small modular' blockchain projects focused on specific application scenarios demonstrate greater potential for practical implementation. For example, T-Mining's secure clearance system, with its controllable risks, clear value chain, and simple participant structure, is more easily deployable in practice (Tsiulin et al., 2020). This suggests that blockchain technology is gradually shifting from a 'tool for large-scale system transformation' to an 'innovation logic centred on problem-oriented governance modules.' This shift highlights a critical assessment: the key obstacles hindering the implementation of blockchain in port logistics are no longer technical feasibility itself, but rather the design of organisational governance mechanisms, the construction of institutional coordination capabilities, and the sustainability of

business models. The next section will further explore these structural issues from existing theoretical perspectives.

5.2 Link to Existing Theories

Although blockchain technology has long been regarded as a key tool for enhancing the transparency and security of port logistics systems, its practical application has shown a marked divergence in effectiveness. This disparity not only highlights the mismatch between technological design and actual usage scenarios but also reveals that, in complex environments involving multiple stakeholders and cross-organisational collaboration, the effectiveness of mechanisms is often constrained by institutional rules, organisational capabilities, and external structural conditions. To gain a more systematic understanding of this phenomenon, this paper introduces two complementary theoretical perspectives: Transaction Cost Economics (TCE) and the Technology-Organisation-Environment (TOE) framework. TCE, from the perspective of institutional economics, emphasises how blockchain can reduce transaction uncertainty and coordination costs, providing institutional support for process design in multi-organisation environments; the TOE framework offers a more comprehensive analytical approach, helping us understand the organisational and environmental barriers encountered in the adoption of technology in real-world contexts.

Transaction Cost Economics (TCE) posits that the fundamental purpose of organisations is to reduce the various costs incurred in market transactions, such as information search, contract negotiation, and enforcement supervision (Williamson, 1987). From this perspective, blockchain mechanisms, particularly shared ledgers and smart contracts, are seen as important tools for reducing transaction friction. For example, the end-to-end tracking mechanism enabled by distributed ledgers can significantly reduce the costs incurred by participants in data queries and status verification, allowing all parties involved in port operations to access a unified, tamper-proof record of transactions (Elmay, Salah, Jayaraman, et al., 2022; Tsiulin et al., 2020). Another example is the document approval process driven by smart contracts, which enables automated access

control and process triggering, thereby reducing human intervention and execution uncertainty, and lowering supervision and coordination costs (Ahmad et al., 2021; Liaqat et al., 2024). In high-friction, high-risk processes such as customs clearance, such mechanisms not only improve processing efficiency but also help prevent fraud (Irannezhad & Farooqi, 2023).

However, while TCE helps explain why blockchain mechanisms have ‘potential value’ in multi-party transaction environments, it struggles to address a more critical question: why these mechanisms have yet to gain widespread adoption in real-world scenarios. Building on this, the Technology–Organisation–Environment (TOE) framework offers a structural complementary perspective for understanding the practical barriers to technology adoption (Tornatzky et al., 1990). The TOE framework emphasises that the adoption and application of technology do not depend solely on the merits of the technology itself but are influenced by the complex interactions between technological conditions, organisational capabilities, and the external environment. In the context of port blockchain, the technological level still faces challenges such as complex system integration, lack of interoperability between platforms, and high deployment and maintenance costs (Irannezhad, 2020; Le et al., 2023). At the organisational level, particularly in small and medium-sized ports, there are widespread issues of weak digital foundations, insufficient willingness to transform, and a lack of effective change mechanisms (Philipp et al., 2019). At the external environment level, factors such as regulatory policy uncertainty, unclear platform dominance structures, and fragmented industry governance collectively raise the institutional barriers to technology adoption, ultimately making it difficult for large-scale platform projects like TradeLens to sustain themselves (Wong et al., 2024).

TCE (Transaction Cost Economics) and TOE (Technology-Organisation-Environment Framework) provide a dual explanation for understanding the challenges faced by blockchain in port logistics. In terms of mechanism design, TCE explains that blockchain has economic rationality due to its ability to reduce costs. However, in real-world adoption, the TOE framework reveals structural resistance from technological, organisational, and environmental dimensions.

These two factors together create the core contradiction of blockchain being 'theoretically feasible but difficult to implement in practice.' However, both theories also have obvious limitations. TCE's theoretical assumptions are too stable to capture the dynamic evolution of power relationships among stakeholders in the port ecosystem. While the TOE framework considers multiple factors, it functions more like a static checklist, failing to effectively explain complex dynamic processes such as how stakeholders negotiate, build trust, and establish governance rules in collaborative settings.

Therefore, future research cannot simply apply these theories; it must shift its perspective from 'technology' to 'governance.' By constructing a more composite analytical framework, issues such as the neutrality of the platform, the fair distribution of costs and benefits, and the power dynamics among participants can be centralised. Only in this way can we truly address the structural challenges faced by blockchain in practical implementation and provide more persuasive theoretical guidance for the digital transformation of port logistics.

5.3 Critical Discussion of Mechanism Limitations

Although blockchain mechanisms are widely regarded as an ideal tool for enhancing the transparency, security, and collaborative efficiency of port logistics systems in theory, their actual deployment frequently encounters structural obstacles. These obstacles are not merely due to the immaturity of the technology itself but more fundamentally reflect a fundamental mismatch between technological ideals and institutional realities. To gain a deeper understanding of the implications of this mismatch, this section will engage in critical reflection around three key tensions: the trust paradox arising from transparency, the risk of process rigidity triggered by automated mechanisms, and the governance dilemmas stemming from institutional inertia and incentive imbalances. The existence of these issues is precisely the fundamental reason why blockchain appears perfect on paper yet remains challenging to implement in practice.

5.3.1 Data Sharing vs. Data Control

One of the most frequently highlighted advantages of blockchain technology is its potential to achieve end-to-end visibility and information consistency within complex logistics networks. In particular, shared ledgers and end-to-end traceability mechanisms aim to enhance information synchronisation efficiency and cross-organisational collaboration levels (Ahmad et al., 2021; Elmay, Salah, Yaqoob, et al., 2022). However, in practice, the ideal of 'complete transparency' often conflicts with businesses' need to protect data sovereignty and commercial secrets. Najati (2025) refers to this phenomenon as the 'transparency-trust paradox,' pointing out that excessive visibility may actually weaken the foundation of trust and trigger defensive games between organisations over the exposure of sensitive data. For this reason, an increasing number of studies and practices have begun to introduce permissioned chain architectures, 'channel mechanisms,' and other 'limited transparency' designs to strike a balance between collaborative efficiency and information control. For example, the channel mechanism widely adopted in the Hyperledger Fabric platform enables participants to share data only within an authorised scope, effectively defining the boundaries of information visibility (Liaqat et al., 2024). J. Li et al., (2025) further propose that through smart contract access control and dynamic key mechanisms, granular management of data operation permissions can be implemented to strengthen data sovereignty protection. This tension is particularly evident in the TradeLens project: although the system has the technical capability to achieve data sharing, due to the platform being dominated by Maersk, competitors withdrew collectively out of concerns over data control and platform neutrality, leading to the project's failure (Wong et al., 2024). This paradox reminds us that future blockchain mechanism design should not be confined to the binary opposition of 'completely open' and 'completely closed,' but should instead focus more on the negotiation of 'visual boundaries' among participants and the trustworthy neutrality of governance mechanisms. Only by designing a 'controllable transparency' architecture can we enhance collaborative efficiency while alleviating the asymmetry anxiety of information exposure, thereby achieving a truly sustainable cross-organisational trust mechanism.

5.3.2 Automation vs. Rigidity

Smart contracts are often regarded as a key mechanism for driving logistics automation and process security. By embedding access permissions and execution rules into the code, smart contracts can reduce human intervention, improve process consistency, and effectively lower execution costs. However, the very mechanism advantage of ‘automation equals execution’ also brings about the issue of ‘process rigidity.’ The execution of smart contracts relies on comprehensive modelling and logical programming of all business scenarios in advance, but real-world business operations often involve asynchronous, uncertain, and exceptional scenarios. Ahmad et al. (2021) and Liaqat et al. (2024) point out that smart contracts typically lack the ability to support ambiguous scenarios, dispute resolution, and human intervention. Dutta et al. (2020) further warn that once contract logic is deployed, it is often difficult to modify if coding errors or business changes occur, and may even cause irreversible chain reactions. Additionally, the ‘oracle problem’ has long plagued smart contract operations: the instability and reliability of off-chain data sources directly impact contract execution outcomes. In contrast, the T-Mining project has achieved relative success. The platform limits blockchain applications to the highly standardised, low-exception ‘container release’ process (Tsiulin et al., 2020), thereby maximising automation advantages while avoiding the risks of complex logic processing. This indicates that the effectiveness of automated mechanisms is highly dependent on the degree of standardisation in process structures.

Therefore, future smart contract design should not pursue ‘full automation’ but instead shift toward a ‘human-machine collaboration’ paradigm, incorporating flexible processing mechanisms, exception intervention rules, and multi-tiered execution architectures to achieve dynamic compatibility between security and flexibility.

5.3.3 Institutional Barriers and Lack of Incentives

Although blockchain technology holds great promise for port logistics, the core obstacles to its adoption often lie not in the technology itself but in institutional barriers, particularly those related to insufficient organisational capacity and the

absence of collaborative incentive mechanisms. First, many port operators—especially smaller terminals—lack the infrastructure, expertise, and financial resources required to deploy and maintain blockchain systems. Liu et al. (2023) emphasize that organisations often adopt a wait-and-see or even resistant attitude toward change due to reliance on existing systems and long-standing process inertia. Second, the operation of blockchain mechanisms relies on multi-party collaboration, but in reality, issues such as asymmetric trust, unclear role definitions, and uneven distribution of costs and benefits often act as barriers (Papadakis & Kopanaki, 2022b). Elmay, Salah, Yaqoob, et al. (2022) further point out that the absence of a neutral governance framework and unified industry standards leaves most potential participants lacking both trust and motivation in the platform.

These phenomena reflect a deeper contradiction: the design of blockchain mechanisms often assumes that ‘technical feasibility’ can naturally translate into ‘institutional adoptability,’ yet overlooks the fact that in the complex port ecosystem, technology must be deeply integrated with governance frameworks, incentive logic, and collaboration models to truly take root. If future platform designs fail to treat institutional adaptability as a core prerequisite and instead treat it as an afterthought, even the most advanced technology will struggle to overcome adoption barriers.

5.4 Proposed Viewpoint and Integrative Framework

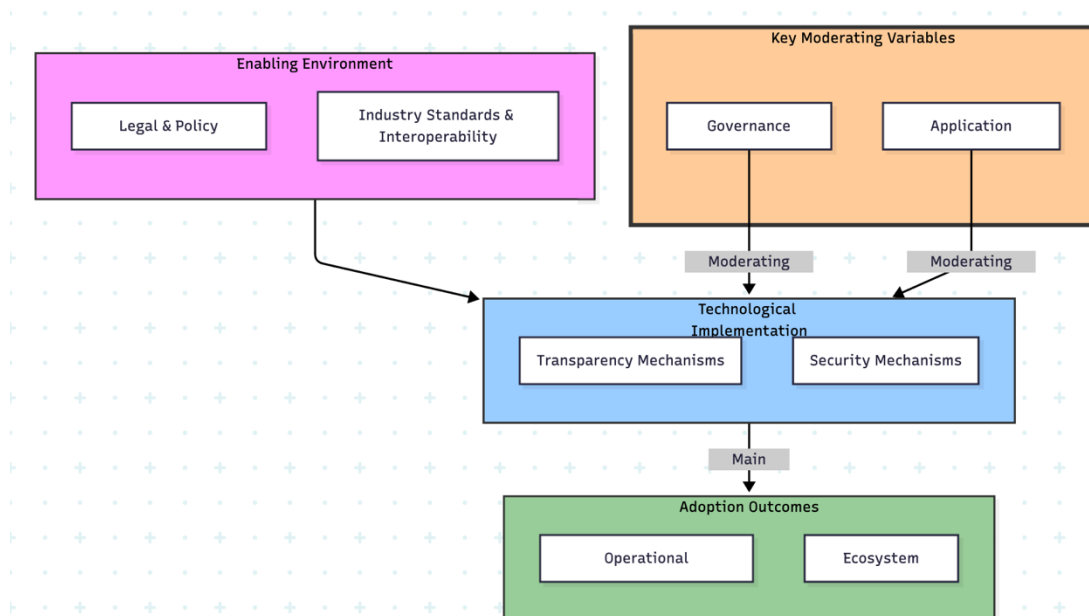
The critical discussion above reveals a profound disconnect between existing theory and practice when addressing the development of blockchain in port logistics. Whether it be the ‘paradox of transparency’ or the ‘dilemma of security,’ their root causes point to a complex challenge that transcends purely technical boundaries, involving multi-party collaboration and co-creation of value. To respond to this core challenge, this study contends that a novel analytical framework capable of integrating technology, governance, and application scenarios must be constructed.

Based on this, the present study proposes an integrated conceptual framework (as illustrated in Figure 5-1). The core logic of this framework is that the

effectiveness of technological mechanisms does not directly lead to successful adoption outcomes. Instead, it is strongly moderated by two core variables: ‘governance models’ and ‘application scenarios’. In other words, technology itself does not directly guarantee success. Only when deployed under the appropriate governance model, applied within the correct application scenario, and supported by a healthy external environment, can technology truly realise its value.

Figure 5-1: An Integrated Conceptual Framework for Blockchain Adoption in Port Logistics

Source: the author(2025)



This framework comprises four core components: (1) technical implementation, namely the transparency and security mechanisms outlined in Chapter Four; (2) adoption outcomes, representing the operational performance and ecosystem value sought; (3) External environment, comprising the foundational soil of laws, policies, and standards; and (4) Core moderating variables, which constitute the framework's innovation. This emphasises the decisive moderating role of governance models (platform neutrality, cost-benefit distribution, rule-making mechanisms) and application scenarios (process scope, intensity of operational pain points) in determining the successful transformation of technology.

Based on the aforementioned framework, this study proposes the following core research propositions, with the aim of providing direction for future empirical research:

Proposition 1 (Governance Priority): Within the port logistics ecosystem, a blockchain platform's governance model (e.g., neutrality, equitable revenue distribution) exerts a stronger positive influence on the willingness of diverse stakeholders—particularly competitors—to participate than its technical performance.

Proposition 2 (Scenario-Driven): The success rate of blockchain applications is positively correlated with the clarity of boundaries within their targeted application scenarios. Compared to broad-spectrum 'platform-type' applications, 'scenario-driven' applications focused on singular, standardised processes are more likely to achieve initial success.

Proposition 3 (Value Co-creation): A blockchain application that enables all key stakeholders to clearly foresee their return on investment (ROI) and establishes a fair value distribution mechanism will achieve significantly superior adoption rates and network effect formation compared to applications with ambiguous value propositions or unequal distribution.

Proposition 4 (Environmental Dependency): The efficacy of blockchain technology in enhancing port operational efficiency is significantly modulated by the external legal and standards environment. Its positive impact is amplified in settings where the legal validity of digital documents is clearly established and industry data standards are unified.

By constructing this integrated framework and proposing specific research propositions, this study aims to steer future academic discourse away from mere examination of the technology itself towards systematic investigation of the complex interplay between technology, governance and operational scenarios. This approach seeks to provide more practically relevant theoretical tools for the sound development of blockchain applications in port logistics.

5.5 Chapter Summary

Building upon the systematic analysis presented in Chapter Four, this chapter offers an in-depth interpretation and critical examination of the research findings. By engaging core dilemmas such as ‘governance over technology’ with existing theoretical frameworks, it reveals the profound disconnect between theory and practice within the current port logistics blockchain domain. To address these challenges, the chapter ultimately constructs an original conceptual framework integrating technology, governance, and application scenarios, proposing a series of theoretical propositions for future research validation.

In summary, the chapter's discussion culminates in a central conclusion: the success of port logistics blockchain has shifted from mere technical feasibility to the ability to establish a fair and sustainable governance framework. This finding underscores the necessity for parallel advancement of technological and institutional innovation, laying a solid foundation for the concluding summary and recommendations presented in the subsequent chapter.

6 Conclusion

6.1 Summary of the Thesis

This study focuses on the challenges to transparency and security within port logistics networks arising from “information silos” and a lack of collaborative trust. To address these challenges, the core objective of this research is to comprehensively and thoroughly examine and analyse the research progress, core mechanisms, and practical dilemmas of blockchain technology in enhancing port logistics transparency and security through a systematic literature review methodology. To achieve this objective, the study rigorously adheres to the PRISMA framework, employing the systematic literature review (SLR) methodology. Through systematic searches of the two core databases, Scopus and Web of Science, and multiple rounds of screening based on predefined inclusion and exclusion criteria, the study ultimately identified 43 high-quality core academic publications. These form the data foundation for subsequent descriptive and thematic analyses.

Findings are not distant from the research questions posited. Descriptive analysis first reveals that research concerns in this area are closely related to major industry initiatives, such as TradeLens. Interest increased in 2024 in response to TradeLens’s 2023 failure, with a strong inclination towards theoretical approaches rather than empirical research. Thematic analysis then groups a multi-layered technology framework consisting of six basic mechanisms revealed in the literature. Such a framework delineates optimal technical approaches within two general objectives: raising transparency (e.g., full traceability, digitalised paperworks) and security (e.g., smart permissioning contracts, permissioned blockchain architecture). Most notably, the discussion finds key roadblocks towards advancements are not technical but are inherently grounded in issues non-technical in nature. These are summarised in two key focal tensions: “technology is secondary to governance” and “use cases over platforms are more essential.”

6.2 Contributions to Theory and Practice

6.2.1 Theoretical Contributions

The theoretical contributions of this study are primarily manifested in two dimensions: firstly, through a systematic literature review, this research constructs a comprehensive knowledge map for the emerging and highly fragmented field of port logistics blockchain; secondly, based on the preceding critical analysis, an integrated and original conceptual framework is proposed in Chapter Five.

The first contribution lies in constructing a systematic knowledge map for this field. Prior to this, relevant academic literature was scattered across different journals and disciplinary contexts, lacking a unified, structured analytical framework to integrate these fragmented insights. Through a systematic review of 43 core publications, this study has, for the first time, categorised the implementation mechanisms within this domain under two core themes: ‘transparency’ and ‘security’. Building upon this foundation, the study further reveals the structural characteristics within these two themes, systematically presenting them in the knowledge map below (Table 6-1). This ‘two themes, six mechanisms, dual structure’ knowledge map constitutes an original contribution in itself, providing subsequent researchers with a clear, reusable analytical framework for comprehending the full scope of knowledge within this field.

Table 6-1: Knowledge Map of Mechanisms for Transparency and Security in Port Logistics Blockchain

Source: the author(2025)

Core Theme	Mechanism	Core Idea / Value Proposition
Enhancing Transparency	1. End-to-end traceability	Employing IoT and shared ledger technology to enable end-to-end tracking of physical assets (containers, cargo, vehicles), thereby resolving the issue of 'whereabouts of goods'.
	2. Digitization of Key Documents and Process Visibility	Digitise key documents such as Bills of Lading (B/L) to achieve visibility and auditability of business processes (rather than merely goods).
	3. Data-Driven Collaborative Decision-Making	Building upon reliable data, employ optimisation models or game theory to empower coordination between ports and among multiple stakeholders, thereby seeking the optimal solution for the ecosystem.
Ensuring Security	4. Smart Contract Access Control	Encode business rules to achieve automated, enforced process security and access control based on "who, when, and what".
	5. Cryptography and Permissioned Blockchain Architecture	Ensuring data integrity through cryptography, while safeguarding identity and commercial privacy via mechanisms such as MSPs and channels within permissioned blockchains like Fabric.
	6. Defence in Depth	Integrating cutting-edge technologies such as NFTs, DSSE, digital seals, and formal verification to address specific challenges including digital ownership, deep privacy, physical interlocking, and code integrity.

Secondly, the most significant original contribution of this study lies in transcending a mere inductive summary of existing mechanisms. Through critical analysis, it proposes an integrated, original conceptual framework (as illustrated

in Figure 5-1). To address the pervasive tendency towards “technological determinism” in existing research and its inability to explain the failure of practices such as TradeLens, this study constructs an entirely new theoretical model. The core innovation of this framework lies in explicitly elevating ‘governance models’ (such as platform neutrality and cost-benefit distribution) and ‘application scenarios’ (such as process scope and intensity of operational pain points) from contextual factors to key moderating variables. It systematically elucidates that the efficacy of technological mechanisms does not directly lead to success but is strongly moderated by governance models and application scenarios. The theoretical value of this framework lies in providing a more comprehensive and explanatory analytical tool for understanding and guiding the healthy development of port logistics blockchain. It shifts future academic discourse from a focus on the technology itself towards systematic research into the complex interplay between technology, governance, and application scenarios.

6.2.2 Practical Contributions

The findings of this study also hold significant implications for industry practitioners, offering valuable decision-making guidance for port operators, technology developers and policymakers.

Firstly, for managers at ports, shipping companies and logistics enterprises, the research provides a ‘strategic guide’ for the blockchain adoption process. The findings explicitly state that when formulating investment decisions, managers should not confine their focus solely to the merits of technical solutions, but rather concentrate on the project's governance structure, value distribution mechanisms and the sustainability of its business model. Existing literature indicates that compared to large-scale, comprehensive platform initiatives such as TradeLens, solutions like T-Mining—which concentrate on specific operational scenarios and establish trust and collaborative mechanisms through small-scale pilot projects—often achieve more readily implementable outcomes. This finding underscores a strategic shift towards ‘building alliances’ rather than ‘selecting technology’.

Secondly, for developers and providers of technical solutions, this study reveals multiple structural blind spots in current system designs, including the rigidity of

automation, the absence of exception handling mechanisms, and the lack of collaborative tools. The research recommends that developers shift from a 'platform-centric' approach towards a 'scenario + service' logic, creating more flexible, modular, and interoperable solutions. Concurrently, integrating 'governance tools' as core components of technical products—such as smart contract modules for voting, arbitration, and revenue distribution—will become a key competitive advantage in driving multi-party collaboration.

Finally, for policymakers including governments, port authorities and international organisations, this study indicates that the current institutional environment's lag has become a significant barrier to blockchain implementation. The research recommends that policymakers should assume the dual roles of 'neutral facilitator' and 'standard promoter', prioritising the following institutional developments: cross-border legal recognition of digital bills of lading, judicial interpretation and liability definition for smart contracts, and unified industry data standards alongside platform interface specifications. Only through synchronised evolution of the institutional environment can the blockchain ecosystem achieve robust implementation within port logistics.

6.3 Limitations of This Research

Although this study rigorously adhered to the methodology of a systematic literature review (SLR) to ensure its rigour, certain limitations are unavoidable. These limitations also point the way forward for future research.

Firstly, this study is constrained by the scope of its literature screening. The literature search primarily focused on academic publications in English, with the databases consulted (Scopus, Web of Science) predominantly containing English-language materials. Consequently, significant research or industry reports published in Chinese or other languages may have been omitted, thereby limiting the global applicability of the findings to some extent. Secondly, the inclusion criteria for this study centred primarily on peer-reviewed journal articles and conference papers, without systematically incorporating 'grey literature' such as industry white papers and government reports. This may result in findings that

lean more towards theoretical discussions within academia, potentially underrepresenting cutting-edge practical explorations within the industrial sector.

Secondly, this study is subject to the inherent limitations of the systematic literature review (SLR) methodology. The SLR approach itself may be susceptible to publication bias, whereby successful cases or studies yielding significant findings are more likely to be published than unsuccessful cases or those without notable results. This may have resulted in the literature pool for this study exhibiting a certain degree of over-optimism regarding the potential of blockchain technology. Furthermore, although a rigorous coding process was employed during the thematic analysis phase, the synthesis of literature content and refinement of themes inevitably incorporate the researcher's subjective interpretation.

Lastly, and most significantly, this study is constrained by limitations in theoretical construction. Its core output—the integrated conceptual framework and associated research propositions—is derived from analysis and synthesis of existing literature, rendering it inherently theoretical in nature. This study has not empirically tested the framework or the relationships between its variables using primary data (such as large-scale questionnaires, in-depth interviews, or field experiments). Consequently, the validity and generalisability of this framework remain subject to further validation through future empirical research, constituting the primary limitation of this study.

6.4 Future Research Directions

This study constructs a theoretical framework for the adoption mechanisms of blockchain in port logistics, yet several avenues warrant further exploration. Firstly, empirical validation of the proposed mechanism logic and propositions is required through case studies, interviews, or questionnaire surveys. Comparative analysis across different port types would particularly aid in testing the framework's applicability. Secondly, subsequent research may incorporate dynamic perspectives such as institutional change or platform governance to enrich understanding of the mechanism's evolutionary process. Concurrently, methods like structural equation modelling could be employed to achieve more

causal and hierarchical theoretical construction. Finally, it is recommended that research be extended to diverse regions and port types, with particular attention to developing nations, inland ports, or multimodal transport nodes. This would foster a more comprehensive understanding of the adoption mechanism's contextual adaptability and institutional embeddedness logic.

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Appendices

Appendix A Ethical approval letter



22 July 2025

Dear Miss Qi ,

Reference: CURES/26098/2025

Project ID: 28775

Title: The Role of Blockchain in Enhancing Transparency and Security in Port Logistics Networks.

We are pleased to inform you that you have successfully declared that your research project is a **Literature Review – based solely on openly available literature which is in the public domain, and you are undertaking desk-based research not involving any other form of data or information.**

You have also confirmed that your project **does not meet** any of the literature review specified exceptions, listed both within the relevant section of the CURES form and below:

1) Your supervisor has requested that you apply for approval through CURES because:

- The journals or data are in a sensitive area (please discuss this with your supervisor)
- The project will be embargoed i.e. **will not be publicly available via the Cranfield library immediately or longer term**

2) Approval is/will be specifically required by another external body e.g. journal publishers

Therefore, **you do not require ethical approval** and your CURES application will be automatically closed.

Please keep a copy of this letter safe, if this exception is in relation to your thesis project, you will need to include a copy with your final thesis submission.

If you have any queries, please contact CURES Support.

We wish you every success with your project.

Regards,

CURES Team