

UNIVERSITY OF BAHRAIN

College of Information Technology



**Novel Framework for Integrating Blockchain
Technology into Logistics and Supply Chain
Services**

A Thesis Submitted in Partial Fulfilment of the Requirements for the
Doctor of Philosophy Degree in Computing and Information Sciences

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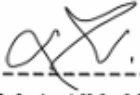
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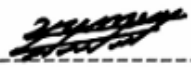
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ABSTRACT

Bottlenecks and operational inefficiencies in supply chains still persist despite technological innovations, due to structural and managerial issues. Blockchain integration presents a viable solution to these long-standing issues by offering tamper-resistant ledgers, secure transactions and automation capabilities. This research takes a novel approach by designing a blockchain integration framework for supply chains, modifying the MOHBSCChain framework to create the Supply-Blockchain framework. This framework is validated by developing a functional prototype using Hyperledger Fabric, by considering a port decongestion use case scenario. This research adopted an inductive approach, starting with informal observations of real-world port operations and a targeted literature review to identify patterns and challenges. The framework development was guided by the principles of transaction cost economics, resource-based view, and diffusion of innovations theories. MoSCoW method was used to prioritize features, while agile project management was adopted to ensure timely completion. Hyperledger Firefly and its connector framework were used as the middleware to facilitate blockchain integration, while chaincode developed using Go language was packaged and deployed to implement smart contracts. Raft orderer consensus mechanism was chosen to ensure resilience and fault tolerance. From a core functionality standpoint, the prototype allows initiation of smart contracts corresponding to functions such as creating and editing supply chain process-related documents, minimizing manual interventions and enhancing efficiency to reduce port congestion. It also offers live tracking of blockchain transactions, facilitating transparency and oversight, the permissioned nature of Hyperledger Fabric ensures security and robust access controls. Results of functional and performance testing conducted using Hyperledger Caliper, Prometheus, and Grafana, were satisfactory; this indicates the prototype's potential in alleviating bottlenecks in supply chains and quickly delivering benefits to key stakeholders such as port authorities, customs officers, shipping line representatives and logistics providers. In terms of limitations, the prototype is limited to basic functionalities and lacks advanced features required to meet operational and regulatory standards. Future improvements can focus on integrating AI for tasks such as predictive analytics and automated document verification, while technologies such as NFT-based schemas can enhance ownership verification and improve asset tracking.

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DEDICATION

I dedicate this work to my family for their unconditional support under all circumstances.

PUBLICATIONS

This thesis is based on previously published papers written jointly with my supervisor, Prof. Alauddin Al-Omary:

JOURNAL PAPERS

1. (Published) Alkhaldi, Bidah., & Al-Omary, Alauddin. (2023). Unified Framework for Integrating Blockchain into Supply Chain Systems. *International Journal of Blockchain Technologies and Applications*. 1. 78-88, doi: 10.18178/IJBTA.2023.1.2.78-88.
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CONFERENCE PAPER

1. (Published) Alkhaldi, Bidah., & Al-Omary, Alauddin. (2022). Frameworks for Integrating Blockchain and Supply chain: A Survey. In 2022 International Conference on Data Analytics for Business and Industry (ICDABI) (pp. 392-396). IEEE.

LIST OF ABBREVIATIONS

AI	Artificial Intelligence
BaaS	Blockchain-as-a-Service
DOI	Diffusion of Innovations
ECDSA	Elliptic Curve Digital Signature Algorithm
HTTP	HyperText Transfer Protocol
ICT	Information and Communication Technology
IEEE	Institute of Electrical and Electronic Engineers
IoT	Internet of Things
IP	Internet Protocol
IPFS	Interplanetary File System
JSON	JavaScript Object Notation
ML	Machine Learning
MSP	Membership Services Provider
NFT	Non-Fungible Token
P2P	Peer to Peer
PoW	Proof of Work
RFID	Radio Frequency Identification
REST	Representational State Transfer
RBV	Resource-Based View
SC	Supply Chain
SCAC	Standard Carrier Alpha Code
SCM	Supply Chain Management
TCE	Transaction Cost Economics

Chapter 1

Introduction

1.1 Overview

This chapter introduces the research context by explaining the current challenges faced by supply chains and the potential benefits of blockchain integration. This is followed by a brief discussion of current gaps in knowledge pertaining to the research topic. Following this, the core research problem, research objectives and research questions are discussed, thereby clearly outlining the aims of this thesis. Finally, the methodology deployed in this research is briefly explained and an outline of the thesis is provided.

1.2 Background

Supply chain systems are inherently dynamic due to several factors such as changes in regulatory policies, competitive landscape that demand cost efficacy, and environment-related logistic challenges. Changes occur frequently and sporadically, which lead to defects in the decision-making processes, requiring constant updates to mitigate errors. The density and variability of these systems make automation challenging, as frequent reconfiguration of components impacts cost-efficiency of operations. Regulations, influenced by the political landscapes of involved countries and their respective government agencies, often result in sudden changes to documentary requirements and enforce sweeping reforms to existing protocols and processes. Economic shifts impact supply and demand patterns, while logistical constraints affect the physical flow of goods, adding further challenges to Supply Chain Management (SCM). These

challenges are compounded by globalization, where Supply Chains (SC's) span multiple countries with varying regulations and economic conditions, making coordination and compliance increasingly difficult. Streamlining operations remains a persistent challenge due to external factors that hinder the efficient movement of goods. Thus, managing SC dynamics requires innovative solutions to address these issues effectively.

Blockchain technology has emerged as a solution for addressing many SC challenges. Its decentralized structure, distributed storage mechanism, consensus algorithms, and asymmetric encryption provide a secure, transparent, and immutable platform for recording transactions and sharing information (Batwa & Norrman, 2020). In logistics and SCM, where goods and services are transferred through intricate networks of partners such as retailers, distributors, airlines, third-party logistics providers, and last-mile delivery services, blockchain offers unprecedented visibility and coordination. Its consensus mechanisms ensure that all participants agree on the validity of transactions, reducing the risk of fraud and errors, while its immutability guarantees that once data is recorded, it cannot be altered, providing a reliable audit trail (Kamilaris, Fonts & Prenafeta-Boldó, 2019). The current reliance on isolated electronic silos for data storage often results in inefficiencies, delays, and a lack of real-time access to critical business information, thereby reducing productivity. By enabling direct peer-to-peer transactions and automating verification processes through smart contracts, blockchain can significantly reduce administrative costs and accelerate transaction times, these features position it as a powerful tool to enhance SC efficiency and transparency.

Treiblmaier (2018) emphasizes the urgent need for innovation in SCM to address persistent structural and managerial issues that hinder efficiency and adaptability. Blockchain is viewed as a disruptive

technology capable of catalyzing new strategies and theories, pushing the field toward greater automation and global distribution capabilities. As regulatory bottlenecks and other external pressures mount, there is a growing impetus to explore and adopt blockchain solutions to overcome these barriers (Oguntegbe, Di Paola & Vona, 2022). The growth of e-commerce and digital platforms has led to an explosion in the volume of transactions, both consumer-facing and business-to-business, necessitating robust systems that can handle large-scale data processing while ensuring accuracy and security. Blockchain's distributed ledger technology provides the scalability and reliability needed to manage these transactions .

The surge in digital transactions has increased the demand for transparency and security. Consumers and businesses alike demand assurance that their transactions are free from discrepancies and that their personal and financial information is protected from evolving cyber threats. Blockchain's inherent design promotes both transparency and security, making it an attractive option for securing and verifying transactions across consumer and business-to-business interactions (Saurabh & Dey, 2021). By encrypting all transactional and user data within a secure network, blockchain protects stakeholders while facilitating real-time access to information, consequently enhancing decision-making and operational efficiency. Therefore, the technology's features address the pressing needs for transparency and security in an increasingly digital supply chain environment.

Machine Learning (ML) enhances blockchain's potential by analyzing vast amounts of data to generate actionable insights for supply chain optimization. ML algorithms can identify patterns, predict trends, and recommend actions, such as determining the most efficient supply routes based on historical data or capitalizing on raw material price

fluctuations to improve cost efficiencies. Traceability, a key benefit of blockchain, is crucial for ensuring product authenticity and compliance, and frameworks like MOHBSChain have been developed to facilitate its widespread adoption despite existing challenges (Jabbar et al., 2021). Research demonstrates that blockchain can significantly improve customer satisfaction by providing accurate and timely data to stakeholders, thereby reducing delays and enhancing service levels (Acar & Kucukaltan, 2021). Studies also highlight blockchain's potential to transform SC functions, from provenance to security enhancement, supported by extensive literature reviews (Dutta et al., 2020; Queiroz, Telles & Bonilla, 2020). Blockchain applications within logistics are quite broad, covering clusters such as transport, finance, and information management (Issaoui et al., 2019). Thus, investments made towards making improvements is justified, as the adoption of blockchain can significantly enhance supply chain performance (Vanpoucke et al., 2017).

Despite its promise, blockchain adoption in supply chains is still in its early stages. While there is growing interest in leveraging smart contracts to automate processes and reduce manual intervention, developing a comprehensive integration framework that accommodates the rapidly changing requirements of global supply chains remains a daunting challenge. Blockchain integration into SCM promises to revolutionize the industry by addressing long-standing inefficiencies and enabling new levels of transparency, security, and automation. Refining frameworks like MOHBSChain to simplify integration can improve odds of widespread adoption, thereby paving the way for more resilient and responsive supply chains. Therefore, continued innovation is essential to overcome adoption barriers and realize blockchain's full potential in transforming SCM.

1.3 Gaps in Knowledge

The current literature on the integration of blockchain technology into supply chain services has made significant strides, but there are still several gaps and limitations that need to be addressed. Queiroz et al. (2020) focus on adoption drivers but overlook practical implementation challenges, Lim et al. (2021) emphasize theoretical benefits without real-world testing, and Kafeel et al. (2023) highlight scalability issues yet lack context-specific solutions. Blockchain technology has been heralded as a cutting-edge technology that can improve SC structure by increasing trust, efficiency, and transparency. However, it is not a panacea for all SC issues. There are several limitations associated with the use of blockchain in SCM. Although data on the blockchain is decentralized and immutable, which can increase trust among SC members, building this trust among all SC members remains a challenge (Ghode, Jain & Soni, 2022).

The appropriation of blockchain technology to meet the existing demands of different supply chains is time-consuming and results in costly projects due to the various requirements and specifications that need to be met for each iteration (Queiroz, Telles & Bonilla, 2020). The process of implementation is also viewed to be non-linear and prone to unintended project scope creep as demands from various stakeholders can arise as early as the planning and integration phase (Öztürk & Yildizbaşı, 2020). While technology is a boon for transparency and security, its degree of difficulty in terms of implementation requires immediate and focused attention, as the process is prone to be impacted by different variables that impact its effectiveness.

Blockchain technology can interface with and take advantage of other emerging technologies such as the Internet of Things (IoT), and Artificial Intelligence (AI) to provide an enhanced and secured supply

chain. However, the integration of these technologies is still in its early stages and faces several challenges, including data security, interoperability, and the complexity of managing multiple systems (Deloitte, 2023). Similarly, several blockchain frameworks have been proposed for SCM, such as Hyperledger Fabric for its permissioned network capabilities and VeChain for its focus on product traceability. These frameworks aim to address some of the challenges in SCM such as traceability, security, and efficiency. However, these frameworks are still in their early stages of development and adoption, and their effectiveness in real-world SC scenarios is yet to be fully validated. Besides framework development, validating the framework by developing a functional prototype is essential. While there is some existing research (Hijazi et al., 2023; Chen et al., 2023; Marchese & Tomarchio, 2021; Pelekoudas-Oikonomou et al., 2023) focused on developing blockchain prototypes, very few studies have developed a blockchain integration framework as well as complementary context-specific prototype for validation. This study seeks to close this gap by developing a Hyperledger Fabric-based prototype designed to optimize SC operations, which would serve as a guideline for SC organizations looking for a simple approach to integrate blockchain into their operations.

1.4 Research Problem

Human intervention remains to be one of the biggest bottlenecks in supply chain systems, as most procedures emphasize the need to verify documents to avoid any additional inconvenience caused by human error in checking paperwork or implementing policies. By extension, this also serves as a strong motivation to avoid any automated system that still requires human intervention as unintended results may occur, which are difficult to rectify due to multiple transactions being processed within

supply chain systems every minute. Keeping personnel updated with the latest policies, assuring accuracy in checking provided paperwork, and creating systems that would be able to address sudden increases in the volume of processed documents form part of the current context of supply chain systems. Automation of transactions through blockchain integration can help improve transparency, security and efficiency of existing SC networks.

To this end, this research proposes a unified framework for integrating blockchain technology into logistics and supply chain services, referred to as supply-blockchain framework. Hyperledger Fabric is a viable foundation due to its modular architecture, which supports rapid deployment and potential scalability across different logistics and SC contexts. Moreover, the perception of lengthy integration times and lack of support from key stakeholders are practical barriers that stand in the way of blockchain adoption (Yadlapalli, Rahman & Gopal, 2022). Therefore, it is critical to identify an ideal combination of blockchain platform, technical stack, and essential prototype features that can facilitate rapid integration of blockchain technology into logistics and supply chain services and enable key stakeholders to quickly reap its benefits.

1.5 Research Objectives

The motivation behind this research is to explore blockchain's potential utility in mitigating the inherent challenges and deficiencies pervasive in contemporary supply chain systems. These challenges include issues of transparency, security, efficiency, and innovation. Positioned as a decentralized, distributed, and immutable ledger, blockchain technology emerges as a promising solution capable of storing and validating transactions sans intermediaries, thereby fostering trust, traceability, and

automation within SC networks. While its aptness for logistics and SC networks is evident, the technology remains in its nascent stage, grappling with technical, organizational, and regulatory impediments to widespread adoption and implementation. Consequently, a pressing necessity arises for the formulation of a novel framework facilitating seamless integration of blockchain technology into logistics and supply chain services.

The effective integration of blockchain into logistics and SC services necessitates a holistic strategy that considers the distinct attributes and demands of SC's, the unique capabilities of blockchain technology, and their interplay. To accomplish this, developing a unified framework for integrating blockchain networks with critical components of existing supply chain systems in the shortest possible time is necessary. This will serve as a direct solution to the dynamic nature of the supply chain system and help improve the adoption process. The proposed model will also simplify the introduction of incremental updates to the blockchain framework by creating a modular approach for implementing features.

The aim of this research is to develop a unified framework for integrating blockchain into logistics and supply chain systems. This framework will serve as a pragmatic and efficient solution for integrating blockchain into supply chain systems. Besides detailing the framework's design and architecture, the study also intends to demonstrate its usefulness by theoretically applying it to a real-world case study. Following this, a functional prototype is developed based on the proposed framework, in order to exhibit its practical value in port congestion scenario. Furthermore, the study explores the framework's future implications and contributions to SCM. Following is brief list of research objectives:

- 1) To develop a novel blockchain integration framework for supply chains, in order to improve efficiency and simplify blockchain adoption
- 2) To quickly validate the framework, in order to shift the perception of lengthy integration times associated with blockchain adoption.
- 3) To determine ideal combination of blockchain platform, technical stack and critical features to efficiently develop a functioning prototype.

1.6 Research Questions

Based on the research objectives, the following research questions emerged to guide the direction of research.

- 1) What essential components should a blockchain integration framework have to improve supply chain efficiency and simplify adoption?
- 2) How can the framework be quickly validated to shift the perception of lengthy integration times associated with blockchain adoption?
- 3) What combination of blockchain platform, technical stack and critical features would be ideal to implement a functioning prototype?

1.7 Research Significance

This research holds the promise of significantly optimizing supply chain systems through the strategic integration of blockchain technology. By addressing prevalent challenges such as transparency, security, and efficiency, the proposed framework offers a robust solution that can fundamentally transform SC operations. The importance of this study lies

in its potential to simplify and accelerate blockchain adoption, thereby overcoming the perceived barriers of lengthy integration times and limited stakeholder support. Additionally, the development of a functional prototype serves as a practical demonstration of blockchain's value, enhancing stakeholder confidence and fostering widespread adoption. This research not only contributes to the theoretical understanding of blockchain's applicability in SC's, but also provides a pragmatic approach for real-world implementation, particularly in addressing issues like port congestion. It builds on recent studies, such as Yin and Ran (2021) that highlight the theoretical significance of blockchain in enhancing supply chain transparency, and Ran et al. (2024) that demonstrate its practical impact on reducing operational costs in logistics. Ultimately, the findings of this study are expected to drive innovation and operational improvements in SCM, paving the way for more resilient, transparent, and efficient SC networks.

1.8 Methodology

This research employs an inductive approach, starting with a review of existing research literature in the topic of study, in order to learn more about existing blockchain integration frameworks as well as the challenges involved in integrating blockchain into supply chain systems. Further analysis of this collected data revealed insights such as common components of existing blockchain integration frameworks as well as implementation challenges. Based on this, a theoretical framework for blockchain integration to improve efficiency and security of SC's was developed. The validity of the proposed framework was initially assessed through conceptual analysis, by applying it to a real-world case study. Following this, a fully-functional prototype based on this theoretical

framework was developed, and later tested for functionality and performance.

1.9 Thesis Outline

This thesis begins with a brief background of the research context, knowledge gap and existing problems, clearly laying a foundation for the research objectives. This is followed by an in-depth review of research literature of theoretical frameworks, key concepts and technologies pertaining to the research topic. The next chapter discusses the methodology adopted in this research. The design of the new blockchain integration framework is detailed in the next chapter. Following this, the validation of this framework is carried out by applying it to a real-world case study, and then developing a functional prototype. Next, the results of prototype development are explained through functional and performance testing, followed by a discussion of benefits to stakeholders. Finally, the thesis concludes with a discussion of potential areas of future work.

1.10 Chapter Summary

This chapter gives a brief background about contemporary supply chain systems, its current challenges, knowledge gaps and the potential that of blockchain technology to address inefficiencies caused by dynamic regulatory, economic, and logistical factors. It outlines research objectives to identify barriers to blockchain adoption, develop a novel integration framework, and create a functional prototype to demonstrate practical value. It also emphasizes research significance, as simplifying blockchain adoption can improve stakeholder confidence by addressing challenges like lengthy integration times. Besides covering potential benefits of the research such as improved transparency, security, and

efficiency in SCM also discussed, a brief outline of the thesis is also provided.

Chapter 2

Literature Review

2.1 Overview

This chapter presents an in-depth review of existing literature on contemporary supply chain systems, their challenges, and recent innovations. This is followed by a brief analysis of recent research interest in the topic to evaluate its research significance. Then, existing blockchain integrations frameworks used in SC's are reviewed, detailing key components, approaches and underlying data structures, which culminates in a comparison of existing blockchain integration frameworks. Following this, research specific to Hyperledger Fabric blockchain was conducted, focusing on prototypes developed based on Hyperledger Fabric. The role of smart contracts in SC automation was then reviewed in detail. After this, the benefits and challenges involved in blockchain integration were reviewed in detail. Finally, research pertaining to blockchain-as-a-service (BaaS) concept and blockchain integration with emerging technologies such as ML was reviewed.

2.2 Use of Blockchain Technology in Logistics and Supply Chain

Current SC systems face challenges in managing the integrity of the transport process and products because of fragmented data, multiple stakeholders, lack of reliable authenticity measures, and different protocols across the process (Jabbar et al., 2021). Advancements in

technology and the development of Blockchain technology have provided solutions to address these issues. Blockchain technology has facilitated the integration of SC data fragments to create a central system that allows end-to-end tracking and tracing (Song, Sung & Park, 2019). Tracking enables SC managers to observe the working path, while tracing allows them to monitor the step-by-step movement of a product. Traceability provides knowledge of the history and location of a product using a recorded identification (Jabbar et al., 2021). Traceability framework for blockchain follows the idea that data stored in blocks, under a block structure model, have its transactions recorded through so-called traceability tags that are meant to operate like Radio Frequency Identification (RFIDs) but with blockchain technology in conjunction with IoT as supporting components to improve the accuracy of such feature (Bhutta & Ahmad, 2021). This is important in creating a reliable provenance.

Blockchain technology enables customized traceability solutions for different industries according to their specific processes. Rather than relying on agency-to-agency transaction, one of the immediate goals of using blockchain in SCM would be to streamline the process and enable automation through processing and monitoring of documents and other related information, like how cryptocurrency public ledger operates (Ali et al., 2021). The use of blockchain to process digital documents and transaction records within a public ledger that is accessible to involved agencies and parties allows the framework to operate and establish a connection between the theoretical and operational frameworks. Effectively, blockchain can serve as the catalyst for resolving conflicts within guidelines and requirements across different countries' agencies that manage borders (Kamble, Gunasekaran & Sharma, 2020).

The movement of physical goods can be tracked virtually, while their associated documents can be seen and processed in real-time through blockchain's smart contracts. The use of smart contracts alleviates the conventional SCM practice of needing to present documents separately, which is typically associated with potential isolation periods for checking/ verification before entry of goods are allowed. For instance, in the manufacturing and processing industry, tracing begins at the source of ingredients to the end consumer, while in agriculture and fisheries, it begins with the planting of seed or birth of livestock to the market, and includes veterinary and nutrition information (Jabbar et al., 2021). Using Blockchain technology to create reliable provenance is gaining traction in pharmaceuticals and the food industry (Lucas, 2018). Blockchain technology has reduced SC costs, logistics paperwork, and tracing time. Before Blockchain, it would take days and weeks to go through paperwork to trace the origin of a product, but now it takes few seconds (Lucas, 2018). By making the physical representation of goods have its digital counterpart within the blockchain, the need to duplicate documents is entirely removed as inspections and other processes can also be omitted based on declarations, unless there is absolute need to conduct manual checks for safety and other concerns. As a form of disruptive technology, smart contracts are seen as the opportunity to integrate automation and ML that is currently not present in SCM practices (Batwa & Norrman, 2020).

Transparency and data integrity issues continue to be a concern in the current supply chain systems. Even after integrating digital solutions, such as cloud computing, data integrity continued to be a concern because digital solutions with centralized architecture, which are managed by a third party, face the risk of data tampering, security threats, and information disclosure. Similarly, even digital solutions with distributed

architecture can also experience data tampering despite their shared visibility (Lin et al., 2019). Blockchain technology addresses these issues by offering data immutability and transparency.

The decentralized ledger of blockchain technology makes transactions available to anyone with permission, thereby, increasing transparency in the SC. Data in the Blockchain is replicated on several nodes and verified through a consensus between the nodes making it immutable and tamper-free (Song, Sung & Park, 2019). The stakeholders involved in the SC are the nodes and are connected to a blockchain server. Every transaction in the ledger must be approved by consensus and recorded in the exact same manner on each ledger. Transparency allows people to see changes in real time. The distributed ledger also creates a record when a transaction is edited or deleted enabling others across the network to know when and by whom it was altered. Using Blockchain technology, SC managers can determine where an item is on the SC, where it was, and where it is going. These capabilities allow complete visibility between all stakeholders and creates trust in a manner that is impossible with the traditional supply chain.

Research into blockchain's potential for SC operations consistently highlights the technology's promise for enhanced efficiency and transparency. Boison and Antwi-Boampong (2020) present a detailed exploration of how a blockchain-based system with a distributed ledger could transform SCM. This research emphasizes a pragmatic, implementation-oriented approach, thereby outlining requirements for a custom blockchain solution for SCM. On the other hand, Irannezhad (2020) conducted a broader analysis, examining blockchain's potential to address challenges within the logistics and freight transportation sectors, thereby offering valuable perspectives on the hurdles and prospective advantages of blockchain integration across the entirety of the logistics

sector. Furthermore, blockchain's immutability is crucial in optimizing record-keeping. The tamper-proof quality of the distributed ledger mitigates the chances of errors and discrepancies, establishing a dependable audit trail. Moreover, they underscore the significance of consensus mechanisms in validating transactions and expediting approval procedures. Decentralizing authority diminishes the necessity for intermediaries, potentially eradicating bottlenecks in SC operations. This also underscores the challenge of information asymmetries, where stakeholders lack a unified, precise perspective of data. Blockchain's decentralized ledger holds promise in mitigating these disparities, enhancing coordination and visibility across the SC. Furthermore, it highlights blockchain's transparency, potential to refine resource allocation and diminish delays typical in maritime logistics. The technology enables real-time tracking of shipments, providing accurate and up-to-date information on the location and status of goods. This visibility allows logistics managers to optimize the use of resources such as ships, containers, and warehouse space by making informed decisions based on current data. For instance, if a shipment is delayed, the system can automatically notify relevant parties, enabling them to adjust schedules, reroute other shipments, or manage inventory levels accordingly. This proactive approach reduces idle time, minimizes bottlenecks, and enhances overall efficiency in maritime logistics operations.

2.3 Research significance of blockchain in supply chain context

There has been a steady increase in research studying the significance of blockchain technology specifically in the context of supply chains systems. The keyword combination “blockchain supply chain” with time

period filter between 2017 and 2023 yielded the following initial search results on Institute of Electrical and Electronic Engineers (IEEE) and ScienceDirect. A review of search results on IEEE.org shows that there were 2,163 search results using these keywords, ScienceDirect yielded a total of 7,386 results for the same search keyword.

Figure 2.1 below presents a graphical comparison of IEEE & ScienceDirect articles published in blockchain-supply chain context. The data reveals a consistent increase in the number of articles from both platforms over the years, indicating a growing interest in this research domain. However, while IEEE articles showed a slight decline in 2023, ScienceDirect witnessed an exponential rise, with the number of publications significantly surpassing those on IEEE. This disparity may be due to ScienceDirect's broader scope, covering disciplines like management science, economics, and engineering. In contrast, IEEE primarily focuses on the technical and engineering aspects of blockchain technology. The slight drop in IEEE articles in 2023 could be due to a shift in research focus or saturation of certain technical topics. Nonetheless, the overall upward trajectory underscores the increasing recognition of blockchain's potential in transforming SC operations and suggests that this area will continue to attract substantial research attention in the coming years.

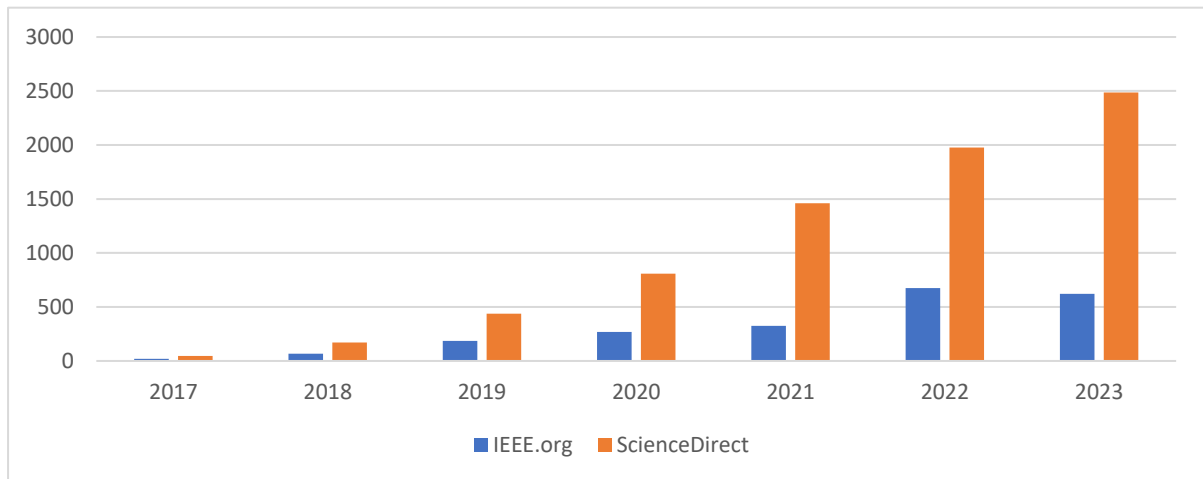


Figure 2.1 IEEE & ScienceDirect articles published in blockchain-supply chain context

2.4 Existing Blockchain Frameworks for Supply Chain Management

The two main aspects of proposed blockchain frameworks for SCM are currently a combination of traceability and application of contextualized processes for handling the SC. Traceability serves as the theoretical basis for creating a blockchain framework that would be able to address the existing gaps that hinder the possible application and adoption of a universal documentation and tracking system for processing cross-border permits.

The use of blockchain to process digital documents and transaction records within a public ledger that is accessible to involved agencies and parties allows the framework to operate and establish a connection between the theoretical framework and the application within the operational framework once the blockchain will be implemented. Essentially, the theoretical framework involving blockchain traceability may need modifications to be able to respond to the actual situation involving how documents are processed and what contents are needed to

be verified for the proposed framework to meet minimum standard requirements. Nevertheless, this serves as a key part of the blockchain framework for SCM as the intuitiveness of systems remain necessary given that not only businesses and regulators need access to the system but also individual consumers that may need to track their package or to ascertain the authenticity of imported or exported goods (Cui et al., 2019).

For the implementation of the proposed blockchain framework to work, a trusted environment that can collate data from involved parties is necessary for the framework to serve its purpose. Otherwise, it would be difficult to operationalize and manage the output provided by various stakeholders and involved parties that are subject to validation and verification across different participating state and government agencies. The study of Liu and Li (2020) proposes that a multi-chain approach that applies traceability would be the most appropriate for handling cross-border permits. In this case, three chains: IoT chain, Transaction chain, and Account chain are proposed to be used in order to meet the complex nature of collecting, verifying, and certifying information from various sources and involved parties. The data collected would be returned only as a transaction ID for accountability purposes, which allows protection and anonymity of involved parties without sacrificing the ease of monitoring a public ledger for all involved parties.

To make the multi-chain approach work, the IoT chain would act as the data collector wherein devices from various parties can transmit their documents to be stored in the said blockchain for processing and retrieval. The Transaction chain is where most of the operations would occur since it deals with the processes of verification through quality inspection and other alterations to the collected data. The transaction chain shall also be directly connected to the agencies or institutions

responsible for cross-border regulation as they are those with authority to conduct any inspection or approval. The Account chain would then act as the main storage for all information involving parties or enterprises involved, products that are processed for approval or inspection, and all other registered information related to cross-border trade. Detailed in the Account chain are also levels of authority for Enterprise, Consumer, and Regulator accounts as well as the certain variables they can access and edit.

2.4.1 Key Components: Traceability Tags and Smart Contracts

In assessing the whole blockchain framework, it is necessary to focus on integrating the concept of traceability framework to the proposed system. A traceability framework allows blockchain transactions to be tracked via traceability tags by integrating technologies such as IoT (Bhutta & Ahmad, 2021). The movement of a physical good and its associated documents can be seen and processed in real-time through blockchain's smart contracts, which alleviates the former SCM practice of needing to present documents separately and with possible isolation periods for checking/verification before entry of goods are allowed.

In essence, the key component of the traceability framework in conjunction with its integration with traceability tags and use of smart contracts enables the full automation of cross-border trade by linking all physical movement of goods with the blockchain system through reliable documentation (Agrawal et al., 2021). Most of the transactions are automated through smart contracts, which is another key component that allows the proposed framework to be feasible. By making the physical representation of goods have its digital counterpart within the blockchain, the need to duplicate documents become entirely removed as inspections

and other processes can also be omitted based on declarations, unless there is absolute need to conduct manual checks for safety and other concerns.

As a form of disruptive technology, smart contracts are seen as the opportunity to integrate automation and ML that is currently not present in SCM practices (Batwa & Norrman, 2020). While the technology may not be new, its implementation in use cases is presumed to allow SCM theories to evolve in line with newer and more efficient technology, particularly with use cases wherein processing of information is beyond current human capacity. Issues of corruption, human error, and difficulty of checking for compliance are among the many common issues to date that would likely go down in terms of priority once smart contracts are implemented to current SCM systems.

2.4.2 Multiple Blockchains to build a Trusted Environment

Multiple blockchains are necessary when the sources of data, authority to process, and right to view involves multiple parties with varying levels of access and capacity within the system. Traceability tags, which allows for real-time notification in the blockchain for changes in the location and handling of the goods, effectively help with data collection. However, the movement and management of data across multiple parties is made possible by the actual use of multiple blockchains that allows for the regulation of accounts and interconnection between numerous interrelated present and future systems related to cross-border permits.

Security systems for multiple blockchains and different layers of user accounts and respective access enable a so-called trusted environment to occur wherein a certain blockchain would hold and protect all user information. Use of multiple blockchains also allows a centralized chain to be separated from other blockchains that perform

different functions so that highly sensitive information is protected from unauthorized access without sacrificing the benefit of having a single point for storage and retrieval of vital information (Shakhbulatov et al., 2020), which is effectively part of the context of cross-border permits and the presence of numerous agencies and enterprises participating within the system. In this context, the choice between permissioned and permissionless blockchains is crucial. Permissionless blockchains, such as Bitcoin or Ethereum, are open to anyone, allowing unrestricted participation in the network. However, this openness can pose security and privacy risks, especially when dealing with sensitive trade data and regulatory compliance. On the other hand, permissioned blockchains, like Hyperledger Fabric, restrict access to authorized participants only. This controlled environment ensures that only trusted entities can join the network, validate transactions, and access specific data, thereby enhancing security and compliance. For cross-border operations, a permissioned blockchain is more suitable as it allows for fine-grained access control, ensuring that sensitive information is shared only with relevant parties while maintaining transparency and immutability for necessary data. By merging the different blockchains to form a single trusted environment, the system is able to perform its role and provide accessibility across multiple participating agencies without any restriction nor hindrance towards digitalizing the verification of documents.

In a multi-chain framework, the Account chain serves as the central point for storing and retrieving sensitive data and serves as a key component for making it possible to build a trusted environment despite multiple roles and external connections being made to the system as part of its requirements that are in line with the study's proposed framework for implementing blockchain to cross-border supply chains. Encryption, as part of the means to protect data stored in blocks, also helps the trusted

environment to operate with minimal risks as it expands and conducts numerous transactions within the IoT chain and Transaction chain. Users and other public entities may participate to check their data without another separate system necessary outside the multiple blockchain framework while unauthorized access is unlikely within the different blockchains as each block is encrypted using a hash code.

2.4.3 Data Structure for Management

While there is no elaborate means to handle processing outside of data structures followed in managing information transferred from one block to another, it is clear that the simplicity of the system and use of algorithm that mimics the actual processing of cross-border permits and other forms of logistics for goods makes the implementation highly intuitive. Regulation and certification of goods are among the many direct beneficiaries of simple data structures as it allows limited access to the right roles and enterprises (Ali et al., 2021). By allowing access only to those with the appropriate role, the blockchain can be used at a large scale without needing to overcomplicate the processing of data to uphold confidentiality. Information stored in blocks, if the system restricts access based on role, would mean that only the basic information can be traced by those without the appropriate authority.

Having a well-planned data structure also helps blockchain systems to manage the volume of goods for processing through the simplification of data transfer. Using proper classification helps reduce delays and costs brought by repetition of certain tasks. For example, the simplification of the process of validating documents by collecting all necessary information into the block and processing it through regulators only once allows for branching of tasks without risk of taxing the system through

unnecessary or repeated actions. As a result, the system is able to efficiently process multiple queries simultaneously as bandwidth is fully utilized without any wastage.

2.5 Comparison of existing Frameworks

Blockchain for SCM shares similarities in terms of testing smart contracts for the automation, which has served as a focal point for simplifying processes. While the traceability framework has been used in other studies, its combination with the multichain framework to build a trust environment for numerous enterprises and regulators remains to be a use case that can be explored further (Kamble, Gunasekaran & Sharma, 2023). This is because data structure and management of enterprise roles are not new to blockchain per se, but its application and contextualization to meet SCM use cases have proven to be simple yet effective.

The study of Liu and Li (2020) specifically points towards providing a specific model as well as alternative solutions that would enable the implementation of a blockchain framework that would focus on traceability, encryption, and transmissibility across different chains used for each government agency respectively. The idea of building on the concept of trust across border-to-border trade through the use of blockchain enables logistics to operate smoothly and minimize costs associated with delays, administrative costs, lost opportunities, and unoptimized routes for distribution.

Table 2.1 Comparison of Different Blockchain Frameworks for Supply Chain

	Security-based	Automated	Hybrid
Previous studies	Wang et al., 2020	Sharma et al., 2020	Liu & Li, 2020
Research Context	General supply chain management	Sustainable agriculture supply chains	Supply chain management with a focus on efficiency and balanced features
Focus	Maintain traceability and security of transactions; Allows transparency with clients and other users	Utilizes smart contracts and machine learning to process transactions	Enable efficiency and balancing of features despite possible shortcomings
Technical Stack	Encryption techniques	Machine learning algorithms and blockchain	Blockchain and IoT integration
Methodology	Heavy regulation of transactions to maintain security	Automating transactions and processes	Multi-chain approach for data management and security
Key features & benefits	Encryption; reduces risk of data leak	Establishes authority and eligible transactions	Simplification of system; establishes transactions
Limitations	Transactions are heavily regulated; Lengthened transactions to maintain encryption	Automation cannot handle very complicated transactions without extensive datasets.	Balance of features can cause unforeseen errors in terms of security and functionality

Table 2.1 above compares various blockchain frameworks for supply chains. In comparing the different common blockchain frameworks adopted for SCM, there are three common themes that emerge. First, security-based frameworks are usually adopted for cases wherein the focus is towards ensuring that data cannot be hijacked or altered while also allowing constant transparency throughout the blockchain network. This type of system is commonly used for transactions between different parties that have very sensitive information, and a variety of roles involved, which ranges from regulators to clients and common users (Wang et al., 2020).

On the other hand, automated systems are commonly adopted for blockchain frameworks that involve numerous transactions (Sharma et al., 2020). Automated systems make use of smart contracts, which are part of the functionality of blockchain networks that enable processing of transactions when certain criteria are met. Blockchain frameworks that focus on automation emphasize authority as it affects how the overall structure and taxonomy of the framework would be formed.

Another form of blockchain framework that is adopted for SCM involves a hybrid between functionality and security. Most proposed SCM blockchain frameworks follow a hybrid model as each one is made to fit their respective context and external environment. The purpose of adopting a hybrid model is to make use of most of blockchain's advantages and features (Liu & Li, 2020). However, it also involves heavy distinction between each iteration, which makes it difficult to replicate proposed systems.

2.5.1 Taxonomy of Blockchain Integration for Supply Chain Management

Blockchain frameworks for SCM tend to adopt a more centralized structure due to the need for a repository that would contain all of the sensitive and confidential information used to handle transactions (Ali et al., 2021). As a result of such tendency, the main repository also tends to have the highest authority and role. In some cases, the framework attempts to isolate the central repository from the other components to ensure that data is only retrieved from the repository to maintain a trusted environment and avoid vulnerabilities that is common from structures that extend across numerous IoT devices (Wang et al., 2020). To facilitate the alteration of the repository, a separate layer is allocated the authority to encode changes that come from trusted sources, such as regulators and other internal roles. Figure 2.2 presents a taxonomy pertaining to blockchain integration in the context of SCM.

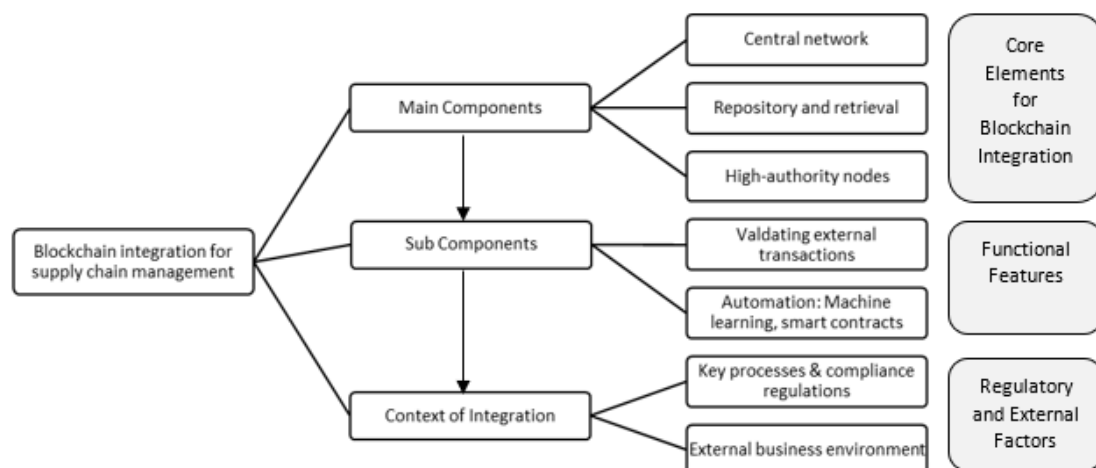


Figure 2.2 Taxonomy of Blockchain Integration for Supply Chain Management

Lower authority and priority are given to IoT devices and other nodes that attempt to access information as these often have roles that either transmit or retrieve information at a limited scope (Powell et al,

2022). In this way, the security of the system is preserved as these are the parts that usually involve several independent and unique users (Sharma et al., 2020).

Main components for blockchain frameworks involving SCM are the storage, processing, and retrieval layers that handle the movement, editing, and transfer of data within the system. For supply chain management, these are the main functions that need to be performed with the emphasis on security of information stored within the system. This is also the reason why most blockchain frameworks for SCM are centralized as key transactions are heavily guarded and limited to high authority roles and special layers.

Subcomponents of blockchain frameworks for SCM focus on functionality, which includes the implementation of traceability throughout the system. Automation and ML are also adopted as subcomponents as these assist in improving the transactions but are not mainly prioritized in previous iterations (Agrawal et al., 2021). While implementing smart contracts and ML as a core component would be ideal, there is inherent bias towards security over functionality in terms of supply chain management, which leads to stronger focus in preventing possible vulnerabilities in the main repository.

In terms of structure, both encryption and adaptability are considered as the drivers of integration and can also be considered as the most integral aspects of a blockchain framework's structure (Nasu, Kodera & Nogami, 2021). These ensure that both key processes and regulations are handled in a trustworthy manner while also allowing the blockchain framework to be adaptable to the external business environment that is prone to changes. However, other proposed structures focus on functionality, particularly towards traceability (Cui et al., 2019),

as this defines the purpose of using blockchain frameworks for SCM as opposed to other forms of technology.

In contrast, other studies have emphasized that simplicity and intuitiveness is actually the main design principle that should bind both functionality and context (Song et al., 2021). Simple structures for blockchain frameworks allow for better adaptation, easier incorporation of various features, and greater flexibility in adapting to changes based on expected needs. Focus on simplicity is also viewed as a necessary component in promoting acceptability and reliability as SC networks that seek to transition are likely required to meet various changing requirements that would require both main and subcomponents to be revised at a frequent basis (Khan et al., 2022b).

2.6 Hyperledger Fabric: Permissioned Blockchain

Hyperledger Fabric is an open-source blockchain network that prioritizes privacy and security, thereby making it well-suited to address the challenges faced by complex SC's such as port operations (Brotsis et al., 2020). The two key components of Hyperledger Fabric are the ledger and smart contracts. A ledger stores critical data about various digital assets, their current value, and entire history of transactions. A smart contract is a digital agreement that specifies the rules necessary for a digital transaction to be considered valid. On the other hand, chaincode refers to code that packages smart contracts for deployment (Khan et al., 2022a). Digital signing of transactions is facilitated by the chaincode's endorsement policy on Hyperledger Fabric. Consensus on Hyperledger Fabric is achieved by using an ordering service comprising of dedicated ordering nodes. That is, transactions are sent to endorsing peers, which execute them against their individual state and generate results along with

a digital signature, ensuring validity and agreement within the network. Once a transaction is considered valid by the endorsing peers, it is added to the ledger. Unlike other blockchains, chaincode execution on Hyperledger Fabric happens at the peer nodes, thereby separating it from the endorsing ordering nodes. This deterministic approach ensures that transactions made on Hyperledger Fabric are accurate and final (Harris, 2023).

Furthermore, Hyperledger Fabric allows for a modular pluggable approach to consensus mechanism, enabling selection of a consensus mechanisms tailored to specific needs (Mohammed, Abdulateef & Abdulateef, 2021). This flexibility yields several advantages. Firstly, it ensures tailored security and performance, as different mechanisms balance security, fault tolerance, and transaction speed differently. Secondly, the architecture's adaptability allows organizations to evolve their consensus mechanisms alongside changing needs. The ability to switch consensus mechanisms aligns with evolving regulatory demands pertinent to SC operations.

Unlike public blockchains that rely on Proof of Work (PoW) for consensus, require significant computational effort and associated mining fees, Hyperledger Fabric employs a permissioned model with pluggable consensus mechanisms such as Practical Byzantine Fault Tolerance (PBFT) or Raft (Nedaković et al., 2023). These mechanisms do not require mining instead, a set of known, trusted nodes (peers) validate transactions through a voting process, eliminating the need for transaction (gas) fees (Nedaković et al., 2023). This design is advantageous for enterprise applications like healthcare and SCM. In healthcare, for instance, frequent updates to patient records or insurance claims can be processed efficiently without incurring costs for each transaction, which would be prohibitive in a PoW-based system. Similarly, in SCM, where

daily transactions can number in the hundreds of thousands, the absence of transaction fees ensures cost-effectiveness and scalability. Moreover, the permissioned nature of Hyperledger Fabric enhances security by restricting participation to authorized entities, thereby protecting sensitive data while facilitating transparent and efficient operations. As Hyperledger Fabric allows for a modular consensus mechanism, a suitable consensus mechanism can be chosen based on project requirements (FasterCapital, 2024). Furthermore, the reduced cost is integral to their sustainability of SC systems, as the number of daily transactions can reach hundreds of thousands depending on the scale of operations. Besides the cost advantage, Hyperledger Fabric also facilitates reliability and transparency, which are crucial for sensitive SC operations.

The permissioned nature of Hyperledger Fabric provides essential privacy and access controls crucial for managing sensitive data and regulatory compliance in supply chains (Ravi et al., 2022). Unlike public blockchains, where every participant has full visibility into transactions, permissioned blockchains like Hyperledger Fabric grant access based on authorized roles. While Hyperledger Fabric's architecture prioritizes security, it also facilitates transparency to authorized users to track status of documents in real-time, fostering accountability and improving oversight (Rejeb et al., 2023). Robust security protocols, in line with industry-leading cybersecurity principles, safeguard sensitive supply chain data and mitigate risks inherent in digitalization. This controlled visibility is critical for secure SCM where sensitive trade data must be protected while still allowing for streamlined transactions and oversight.

2.6.1 Existing Hyperledger Fabric Prototypes for Supply Chains

Research leveraging Hyperledger Fabric for SCM has gained significant traction, offering enhanced security and transparency compared to traditional centralized systems. Marchese & Tomarchio (2021) introduced a Hyperledger Fabric-based prototype aiming to bolster traceability within agri-food SC's. Their study underscores the necessity of an integrated information system to ensure the quality and safety of food products. The prototype's decentralized approach to managing traceability information emphasizes blockchain's superiority over conventional systems, ensuring data authenticity sans a central authority. However, its narrow focus on the agri-food sector might curtail its immediate applicability across other supply chain segments.

Turjo et al. (2021) investigated Hyperledger Fabric's role in supply chain management, focusing on trust and transaction security. Their prototype, built with Python and Solidity, enabled peer-to-peer interactions through smart contracts, supporting secure transactions and an automated refund system. This approach aimed to improve efficiency and reliability in SC operations. However, the study lacked details on performance testing, raising questions about scalability and practical application. Further evaluation is needed to assess its real-world effectiveness.

Chen et al. (2023) focused on integrating blockchain technology specifically within the tea supply chain. Their Hyperledger Fabric prototype aimed to improve traceability and address challenges of authenticity and trust. By incorporating Elliptic Curve Digital Signature Algorithm (ECDSA) algorithm and Interplanetary File System (IPFS), the solution ensured secure identity confirmation and efficient data

storage. While effective in improving traceability within the tea industry, its direct applicability to other supply chain segments or industries remains a potential limitation. Further research could explore its adaptability and scalability in different supply chain contexts.

Hijazi et al. (2023) developed a prototype combining a Building Information Modelling (BIM) system with blockchain using Hyperledger Fabric, in order to improve trust and transparency in the context of construction supply chains. As unreliable data exchange was a major problem in construction supply chains, the prototype used JavaScript to develop smart contracts that would facilitate a unified reliable source of supply chain data delivery. A virtual scenario involving cladding attributes during the project handover stage was used to test the prototype, demonstrating the feasibility of the approach. The results underscored the potential of blockchain technology to enhance data reliability, traceability, and accountability in construction supply chains. Thus, these prototypes demonstrate the diverse applications of Hyperledger Fabric across different supply chain sectors.

Table 2.2 below compares the features of the blockchain-based prototypes discussed earlier. The prototype developed in this research offers distinct advancements over existing works that have developed blockchain-based supply chain solutions. Besides facilitating quick and robust integration, Hyperledger Firefly stack also provides access to intuitive graphic user interfaces through Swagger UI and Explorer UI to deliver better end-user experience. While other works have focused on specific supply chains pertaining to various industries, none of them have specifically focused on optimizing shipping port operations, thereby making this research's findings novel and valuable.

Table 2.2 Feature Comparison of Prototypes

	Marchese & Tomarchio, 2021	Turjo et al., 2021	Chen et al., 2023	Hijazi et al., 2023	Our prototype
Research Context	Agriculture & Food supply chain	General supply chain	Tea supply chain	Construction supply chain	Shipping port: document management
Technical Stack	Kubernetes, Docker, MongoDB	Python, Solidity	ECDS Algorithm, Interplanetary file system	JavaScript, REST API	Hyperledger Firefly, Go, JSON-based data structures
Features	Agri-food traceability, quality control automation	P2P with smart contracts, Secure transactions and refunds	Product traceability, anti-counterfeit	BIM integration, smart contracts for secure data delivery in construction supply chain	Document creation, editing, retrieval, real-time blockchain transaction tracking
Performance Testing	Not specified	Not specified	Hyperledger Caliper	Virtual business scenario with external validation	Hyperledger Caliper, Prometheus, Grafana

2.6.2 Hyperledger Fabric in BaaS context

Hyperledger Fabric supports a BaaS-centric approach in terms of simplifying the architecture needed when integrating blockchain frameworks to existing systems, which is necessary for the development of blockchain networks that are likely to specialize its features as the project progresses or matures (Kernahan, Bernskov & Beck, 2021). The

ease of integrating smart contracts and inherent benefits of a permissioned blockchain simplify the architecture needed to initiate the development of the blockchain network. Due to these advantages, large-scale BaaS projects tend to build upon Hyperledger Fabric as its base to cover several requirements immediately while creating specific features later on to address project-based requirements (Song et al., 2022). The inherent compatibility of Hyperledger Fabric helps reduce cost and shorten the time spent in building up BaaS-related projects.

Hyperledger Fabric, due to its modular architecture, allows for scalability of projects, particularly for those involving intensive data gathering, research, and data processing (Pešić et al., 2019). The utilization of Hyperledger Fabric in BaaS is strongly regarded for sustaining projects that often start small and are expected to grow with demand, which happens for both academic and industry practice. As Hyperledger Fabric is flexible and adaptable to various industries, it is often preferred whenever the scope of the project is not completely determined or is likely to expand over time.

2.7 Smart Contracts for Supply Chain Automation

The transformative potential of smart contracts in supply chain automation becomes apparent in a Hyperledger Fabric setting. These self-executing contracts minimize manual interventions and decision points, thereby enhancing transaction integrity and overall efficiency (Brotsis et al., 2020). Smart contracts offer extensive benefits, streamlining processes ranging from regulatory approval of shipped goods to compliance verification and initiating payments based on predefined conditions. In supply chains, smart contracts can automate the creation, approval, and tracking of documents, minimizing delays associated with

manual paperwork and enhancing overall efficiency (Ravi et al., 2022). This automation mitigates delays and cultivates a more dependable supply chain ecosystem for all stakeholders.

The potential of smart contracts to revolutionize SC operations through automation is conveyed by various studies. Alqarni et al. (2023) conducted an explorative study illustrating how blockchain-based smart contracts can undertake routine tasks such as document approvals, compliance checks, and payment initiation. This study underscores the potential decrease in manual intervention, streamlining processes and enabling workers to focus on higher-level responsibilities. This shift translates into a notable enhancement in overall supply chain efficiency. By securely embedding contract terms directly into the blockchain, Alqarni et al. (2023) demonstrated how smart contracts can autonomously execute agreements. The decentralized nature of blockchain ensures prompt compliance checks and instant document approval once predefined conditions are met. Furthermore, the immediate triggering of payments upon fulfilling obligations promises minimization of delays often encountered in traditional supply chain financial procedures.

The inherent tamper-resistant nature of blockchain and its integrated consensus mechanisms form an optimal framework for automating diverse supply chain processes (Turjo et al., 2021). The utilization of a peer-to-peer encrypted system in conjunction with smart contracts, thereby fortifying security and ensuring transactional integrity. Their research demonstrates how smart contracts can facilitate processes such as product returns and customer reimbursements in case of issues, thereby nurturing trust among participants across the entire supply chain.

Despite the allure of automation, Khan et al. (2021) underscore critical limitations and raises concerns that demand a balanced approach to smart contract integration, particularly for complex agreements that

require nuanced human judgment. While the study acknowledges blockchain and smart contracts' transformative potential across sectors, their widespread adoption faces hurdles. Legal uncertainties, inconsistent standards, privacy concerns, and a lack of tolerance for errors present challenges. Moreover, the intricacies of legal contracts often demand a degree of interpretation and flexibility that smart contracts may struggle to provide (Khan et al., 2021). This highlights the need for continuous oversight and adaptation to ensure smart contracts can effectively respond to regulatory shifts and unexpected complexities in intricate supply chains.

2.8 Transparency and Security provided by Blockchain Adoption

Transparency and security form the foundation upon which trust in digital transactions are built, particularly in the world of supply chains. Transparency, in this context, extends beyond visibility and encompasses creating an immutable audit trail of actions and decisions throughout a product's journey (Rejeb et al., 2023). A transparent record in the form of blockchain transaction provides stakeholders with a verifiable history, and reducing the likelihood of disputes arising from conflicting information (Afrin & Pathak, 2023). Furthermore, integrating real-time data fosters agility, as early warnings about bottlenecks or unexpected delays allow stakeholders to take remedial action, minimizing disruptions throughout the supply chain. Security remains paramount in digital transactions, as it ensures protection of personal data, trade secrets, and the integrity of records (Baddam et al., 2023). Striking a balance between security and usability is vital, which blockchain strives to deliver.

Transparency is embodied in digital transactions through the visibility of transactions and availability of transaction logs for end users

(Xu et al., 2021), which may also include real-time availability of said data, generation of audit trails, and presentation of digital certificates to certify the accompanying documentation. Validity forms a significant portion of transparency features as in some cases the products are not physically inspected and the accompanying paperwork is completed digitally. The different types of frameworks (Chod et al., 2020) that promote transparency in digital transactions focus on enabling accountability for all involved stakeholders, which includes vendors, buyers, and regulators (Gurzawska, 2020). These frameworks highlight interaction that allows for trust to be built based on sufficient means of monitoring and correction, such as the availability of documentation and real-time updates.

Security in digital transactions focuses on two main parts, namely: the protection of any personal data, and the immutability of records and transactions (Kumar & Mallick, 2018). Prevention of any unauthorized access is the main purpose of security, which is supported by features such as two-factor authentication and data encryption. Although an important aspect of security is that its implementation varies depending on the nature of transactions and the enforced regulations within an industry (Breaux & Antón, 2008). Sanctions form a large portion of security as the lack thereof may lead to potential litigation against the erring platform that handles digital transactions. While transparency can be implemented in the design with minimal updates moving forward, the same cannot be said for the purpose of security as the threat of cyberattacks and exploitation of loopholes constantly pose a risk to the trust built by digital transaction platforms (Verma et al., 2023).

In terms of digital transactions, the balance between transparency and security translates into allowing access to records for those with the necessary authority. Access to any confidential data should be limited to

parties involved in a specific transaction. Otherwise, any unintentional access can already be deemed a security breach within the system (Feruza & Kim, 2007). Even if transactions are not necessarily confidential, there is a risk incurred by companies to their respective supply chain when unintended access to data is granted. Hence, the balance between transparency and security often leans toward protection and prevention at the cost of access to quality-of-life features (Al-Turjman, Zahmatkesh & Shahroze, 2022). Nevertheless, supply chain systems remain open to technologies that can provide a high standard of security to enable transparency features with minimal drawbacks. Blockchain frameworks have become an integral part of the research and development efforts in supply chain systems due to their inherent design and functionality. However, their main issue lies in the difficulty of integrating existing systems, thereby forcing the adoption of a new framework (Nandi et al., 2020).

Furthermore, permissioned blockchains such as Hyperledger Fabric help improve privacy and security in blockchain-driven supply chain management systems. According to Ravi et al. (2022), permissioned blockchains tackle these key issues, by illustrating how Hyperledger Fabric bolsters privacy via access controls. In contrast to public blockchains that expose all transactions, permissioned systems limit access solely to authorized users, safeguarding sensitive port data. Using encryption in Hyperledger Fabric helps to protect sensitive supply chain data, by scrambling data during storage and transmission, making it illegible to unauthorized entities.

2.9 Challenges of Blockchain Adoption in Supply Chain

The adoption of blockchain technology is not a linear process but rather a complex and contextualized one that requires consideration of the

specific needs and demands of users, business partners, and government agencies (Agi & Jha, 2022). This means that even if blockchain frameworks are hypothesized based on the underlying context and the determined requirements, uncertainty remains due to the need for constant development to meet policy and regulatory changes. Moreover, there is no one-size-fits-all approach for blockchain integration. Each iteration would require frequent development due to constant changes in their political environment (Khan et al., 2022b). The set standards and components in the study are not exhaustive and may not be relevant nor applicable to other scenarios that have not been addressed or analyzed in the study.

The need to innovate SC practices involves a complex system of relationships that blockchain technology cannot address on its own. Integration of blockchain framework is viewed to be a combination of creating the necessary algorithm to handle various requirements while also ensuring that the functions meet the contextualized needs and demands of users, business partners, and government agencies (Oguntegbe, Di Paola & Vona, 2022). The intricate balance between developing a framework that would meet standards, satisfy requirements, and adapt to changes has been one of the viewed reasons as to why blockchain has not been implemented despite available technology. Moreover, blockchain is often criticized for expensive gas fees and an ecosystem dependent on numerous miners, which can be considered an unintended result of cryptocurrency's popularity. Criticisms highlight the lack of sustainability because of strong dependency on high costs to sustain the operability of the whole system, in conjunction with increasing costs as the system grows in scale.

Further study on blockchain integration needs to focus on how to make integrations more sustainable and adaptable as the logistics industry

demands more features to be implemented to meet new challenges in terms of distribution and cross-border trades. Understanding the intricacies of how iterations have sustained their operations is key in determining how to replicate successful implementations while also ensuring that the benefits of security, reliability, and accessibility remain present with minimal compromise (Shakhbulatov et al., 2020). By focusing on the common types of blockchain frameworks and how they were integrated, it would be possible to ascertain strategies that could be replicated, which would help provide further insights on how existing SCM practices could be revised to incorporate blockchain without intermittent interruptions.

Blockchain's digital ledger technology is viewed as the main incentive for its integration within supply chain systems. Both transparency and security are balanced by blockchain through consensus mechanisms that ensure the validity and reliability of transactions that allow for high confidence in providing real-time access to users. Integrations have allowed supply chain systems to be more transparent as their functioning becomes more trusted and reliable (Park & Li, 2021). However, blockchain integrations are not assured of success as these are prone to suffer from sustainability issues (Bodkhe et al., 2020). Therefore, the most crucial aspect of implementing blockchain would be the constant monitoring of its integration. Lengthy integration times and lack of support from stakeholders must be addressed before transparency and security are achieved within the beneficiary supply chain system.

The benefits provided by blockchain adoption are not immediate (Balasubramanian et al., 2021), which leads to the risk of investments made to these types of projects at risk of not meeting fruition. Recent blockchain implementations focus on modular integration as this allows benefits to be enjoyed at a sooner time, which reduces overall risk

(Drljevic, Aranda & Stantchev, 2020). However, modular approaches to integration do not necessarily ensure that transparency and security are assured (Sternberg, Hofmann & Roeck, 2021) as the process of blockchain integration is often complex, particularly in cases wherein existing systems are merged with a blockchain network (Alazab et al., 2021). Nevertheless, risks are taken as the difference that blockchain provide over existing digital transaction frameworks is their stability once the various components are established.

Despite numerous pieces of literature on blockchain integration and its benefits on supply chain systems, there is insufficient emphasis on the issues and limitations of the technology in its current method of adaptation for digital transactions. The appropriation of blockchain technology to meet the existing demands of different supply chains is time-consuming and results in costly projects due to the various requirements and specifications that need to be met for each iteration (Queiroz, Telles & Bonilla, 2020). The process of implementation is also viewed to be non-linear and prone to unintended project scope creep as demands from various stakeholders can arise as early as the planning and integration phase (Öztürk & Yildizbaşı, 2020). While the technology is a boon for transparency and security, its degree of difficulty in terms of implementation requires immediate and focused attention, as the process is prone to be impacted by different variables that impact its effectiveness.

Finally, there is a trade-off between security and functionality in terms of blockchain framework design. There are two opposing views: one that focuses on security and encryption to protect data and transactions, and another that focuses on functionality and traceability to enable transparency and efficiency (Song et al., 2021). Balancing these features can cause unforeseen errors in terms of security and

functionality, and simplicity and intuitiveness are important aspects to note when repurposing features and frameworks. It is important to direct attention to the persistent risks and essential mitigation tactics in blockchain-powered systems. Hacking and phishing are enduring cybersecurity menaces capable of jeopardizing the integrity of blockchain-driven port operations. The dynamic landscape of cyber threats necessitates ongoing vigilance from port authorities and stakeholders embracing blockchain. For instance, smart contract vulnerabilities could be exploited by malicious actors to manipulate transaction data or steal assets. If a smart contract contains a bug, an attacker might trigger unintended behaviors, leading to financial losses or data breaches. Additionally, phishing attacks targeting users' credentials or private keys could compromise the security of the blockchain network, allowing unauthorized access to sensitive supply chain information. These threats prompt the need for robust security measures, regular audits, and continuous monitoring to safeguard the integrity and confidentiality of the system. According to Al-Farsi et al. (2021), security protocols, regular audits, and consistent vulnerability patching are indispensable for safeguarding the security of systems utilizing blockchain technology. Therefore, addressing cyber threats is critical for the successful adoption of blockchain in SCM.

These challenges highlight the complexity and intricacy of integrating blockchain technology into existing supply chain management systems. The challenges faced by the study leads to findings becoming more exploratory as the need to test the determined standard for blockchain integration remains integral in determining if it would fit both SCM practice as well as the context of actual processes and regulations.

2.10 Blockchain integration with Emerging Technologies

While Blockchain technology has proven useful in addressing the shortcomings of the traditional supply chain, there is potential for increased efficiency when Blockchain is integrated with emerging technologies such as ML, AI, and IoT. Integrating Blockchain with emerging technologies can make supply chain operations more flexible and agile (Gohil & Thakker, 2021). The IoT is a system of interconnected computing devices and objects (things) that can exchange data with other devices over the internet without human intervention (Reyna et al., 2018). The things in IoT are usually provided with built-in sensors, unique identifiers, and an Internet Protocol (IP) to make them detectable on the internet. IoT is used in the digital supply chain to facilitate collaboration between stakeholders by exchanging data across various systems (Viriyasitavat, Anuphaptrirong & Hoonsoapon, 2019).

IoT offers operational benefits and revenue opportunities. Operational benefits are asset tracking, vendor relations, inventory management and forecasting, fleet management, and scheduled maintenance (Gohil & Thakker, 2021). Asset tracking is a key feature of the blockchain-IoT integration. All logistics activities can be tracked with the help of IoT and decentralized with the help of a blockchain server (Pureswaran, 2015). Decentralization helps stakeholders to efficiently manage their operations. The data from asset tracking allows supply chain managers to identify poor-performing vendor relations and to adjust production according to demand. IoT data can help managers to forecast demand and ensure manufacturing schedules match demand. In fleet management, IoT can be used to coordinate fleets to improve the speed of deliveries. Improving operational efficiency creates various revenue opportunities.

AI and blockchain increase automation and scalability to enhance connectivity and improve traceability in the supply chain. AI algorithms are used to perform calculations and real-time data analysis that can be used in decision-making. Since supply chains can be complex with several stakeholders, there is a large volume of data to process. Integrating AI helps to analyze this data, AI can use the data to make more accurate decisions than an individual would because of its ability to take all the data into account and discover patterns.

Applying AI can improve the supply chain by automating the process. AI-enabled scanners can scan documents including contracts and customer communications to identify patterns that can be used to optimize the supply chain. AI's ability to identify patterns and make predictions from analysis can be used to detect potential issues in advance (Salah et al., 2019). AI also uses data to improve inventory management by forecasting demands to give alerts about restocking and when and how much to order, based on previous statistics. AI-driven smart contracts enhance the effectiveness of the regular smart contract by analyzing past contracts and recommending changes for future contracts. Applying AI and Blockchain can help to improve the supply chain by automating the process, finding new sources of revenue, reducing the supply manager's workload, and increasing efficiency. AI's ability to use existing data to create different rule-based algorithms can be employed in planning strategies (Contreras-Cruz, Lopez-Perez & Ayala-Ramirez, 2017).

ML can also be integrated into Blockchain to improve supply chain processes. ML is a subfield of AI that enables computers to learn without explicit programming (Wong et al., 2021). It enables a system to learn from available data and modify its algorithm to improve performance. In supply chain management, it is used to enhance big data analytics (Wong et al., 2021). ML algorithms are applied in supply chain to explore

patterns from processed data. For instance, ML can analyze historical sales data to identify the ideal stock reordering level. Manufacturers use ML algorithms connected to the AI to reduce latency in the supply chain (Gohil & Thakker, 2021). Abbas et al. (2020) propose integrating ML and blockchain technology to combat counterfeit drugs, creating a smart system that leverages the strengths of both technologies. In this approach, ML algorithms analyze transaction data stored on the blockchain to identify patterns and anomalies indicative of counterfeit products. The blockchain ensures the integrity and immutability of the data, providing a reliable foundation for the ML model to learn from historical transactions of genuine and counterfeit drugs.

ML has been applied in different industries. In the healthcare industry, ML and Blockchain technology have been used to optimize several aspects including patient health management, information management, and insurance management. ML is important because it can find patterns in data that appears random to traditional statistical techniques, it can generate new insights, and can give directions (Tirkolaei et al., 2021).

ML is useful in the supply chain because it can handle nonlinear problems which are common in real-world SC situations. It can also deal with large volumes of unstructured data from different sources. ML has been used to address different issues of the SC. It has been used to design an automated SCM framework, to facilitate supplier selection, predict financial risk in the SC, categorize suppliers, and to predict SC risks (Zhu et al., 2016). It offers several advantages including sales and demand estimation, inventory control, transport and distribution management, production management, and supplier selection (Tirkolaei et al., 2021). The ability of ML algorithms to manage different areas of the SC makes it a valuable emerging technology in SCM.

2.10.1 Algorithms Used in Blockchain Integration

Various algorithms are used address the complexities of SCM in relation to logistics and agriculture. In the study of Wang et al. (2020), the use of an asymmetric encryption algorithm is used to add multiple layers to the security of data packets by segmenting the chain of verification private keys across each deal to limit unwanted access. This algorithm allows extended security levels by reducing the risk of hijacking parts of the data packets to gain access to the system, which is rendered ineffective without any access to the public key that decrypts the complete string for the segmented private keys. Heightened level of security is considered to be necessary for blockchain integration, particularly when it involves direct access to the public as well as having numerous roles involved. Ensuring that data accessed by regulators would not be tampered is essential in maintaining trust with the proposed blockchain system.

Another component in the aforementioned blockchain framework involves the use of a Hyperledger fabric framework that enables different layers of roles to limit access of each module and role within the system without hindering traceability. Modularizing the access of each node into different layers secures confidential information from being unintentionally leaked into other layers during the course of operations (Kayikci et al., 2022). A similar algorithm to the Hyperledger fabric framework (Lamken et al., 2021) could also be followed. However, the main difference is that the layers are interconnected and further modularized to ensure that each layer only conducts certain functions pertinent to the roles included in each layer. In the proposed algorithm, the system checklists the requirements and validates information with a central system to be able to conduct regulations autonomously.

When it comes to ML algorithms, the commonly used approach for SCM involves a learning system that handles the processing of datasets until such time that it yields the desired output. There are numerous varieties of learning systems, such as deep learning and clustering. However, the process of choosing the appropriate system involves addressing the context of the external environment, such as regulations and other specific conditions that need to be considered.

One of the most common implementations for ML algorithm involving the handling of regulations and promotion of transparency within SCM involves the use of “decision tree” (Sharma et al., 2020). This approach allows a basic checklist to be implemented that allows the blockchain network to verify data and process transactions in a simplified system. While the inherent limitation of the ML system prevents handling of highly complex problems, the system remains effective and foolproof in managing information based on clearly defined criteria.

2.10.2 Blockchain-as-a-Service (BaaS)

Blockchain-as-a-Service (BaaS) can help simplify the process of integrating blockchain technology into supply chain domains. BaaS providers use a cloud-based approach to facilitate swift development, hosting, and supervision of blockchain infrastructure. This approach reduces the entry threshold for entities seeking to harness blockchain advantages (Singh & Michels, 2018). Various entities within the supply chain such as regulatory bodies, shipping lines, and port authorities can utilize BaaS to concentrate on crafting bespoke smart contracts tailored to optimize desired processes. Research underscores the merits of BaaS for supply chains, citing cost-effectiveness, expedited deployment, and adaptability (Singh & Michels, 2018; Shi, 2019; Song et al., 2022).

BaaS can also serve as a cheaper alternative to facilitate in-house blockchain integration with existing services. By outsourcing the needed infrastructure, businesses can maintain operations and mitigate costs, leading to greater feasibility and success of blockchain integration projects (Onik & Miraz, 2019). Costs incurred for integrating blockchain networks come from the purchase of equipment to set up servers and the time spent in developing and testing the system. BaaS also utilizes the expertise of other businesses to reduce inherent risks that arise from project prioritization and resource allocation. Outsourcing the blockchain integration process allows a dedicated team to monitor and operate the service even as the project scope potentially grows, which is less feasible when the project is done internally due to numerous influences that strongly affect the implementation phase (Song et al., 2022). As a result, the integration becomes more cost-efficient as resource allocation is streamlined and the development process becomes more predictable through the expertise of an outsourced team.

While BaaS provides inherent advantages in terms of integration and scalability, one of its biggest downsides is its compromise in terms of control, privacy, and security. BaaS typically offers a pre-established architecture that is customized to align with the specific requirements of a project, thereby ensuring the infrastructure remains agile, well-organized, and easily accessible (Zheng et al., 2019). However, this benefit may also result in a compromise that impacts flexibility as niche and specialized requirements may not properly and sufficiently be covered by an outsourced development team. Control over how the architecture is developed, particularly for future-proofing, may require further collaboration to ensure that the project's objectives are met. Moreover, BaaS heavily relies on cloud-based technology to provide accessibility. Downtimes resulting from server outages are critical issues that cannot be

addressed internally and result in significant disruptions within the system (Onik & Miraz, 2019). Dependence on BaaS entails reliance on the capacity and capability of the service provider to ensure availability, which becomes a long-term risk to sustainability.

BaaS is usually used within a business setting, although there have been attempts to utilize its benefits in an academic setting for the purpose of research. In such cases, the examples of BaaS being used involve a stronger focus on healthcare research (Kleinaki et al., 2018) and data sharing (Cai et al., 2022) within a secure and cost-efficient network. Overall sustainability has been one of the main drivers for using BaaS for nonprofit ventures, which has led to potential adaptation in government-related projects as the benefits become more highlighted. However, prudent evaluation is necessary to consider deploying BaaS for supply chain applications, particularly concerning vendor lock-in and data sovereignty concerns.

2.11 Chapter Summary

This chapter reviewed research literature discussing the use of blockchain technology in supply chains, underlying technologies such as traceability tags and smart contracts, their key benefits and challenges. The rising research significance of this topic was acknowledged by quantitatively assessing the increased number of research publications in the research domain over the past few years. This was followed by a brief review and comparison of existing blockchain integration frameworks, their strengths and weaknesses. The impact of managerial and organizational aspects of blockchain implementation was also considered. Furthermore, various approaches to improving security on such systems such as data structure and using multiple blockchains to build a trusted environment were covered. Finally, research discussing the potential for blockchain's

integration with other emerging technologies such as AI and IoT was also reviewed.

Chapter 3

Methodology

3.1 Research Design and Rationale

This research adopts an inductive research approach to achieve its objectives, aligning with a design that derives theories and frameworks from specific observations and patterns identified during the study. Inductive research, as defined by Saunders et al. (2024), focuses on building theory from empirical data, making it ideal for emerging topics with limited prior research. The research purpose is exploratory, aiming to generate new insights into blockchain integration in supply chains where existing models are inadequate. The research strategy employs qualitative methods, including observation and literature analysis, to uncover underlying patterns and develop a novel framework. This approach is particularly valuable for addressing innovative areas, as it allows for flexibility and the creation of new theoretical constructs based on real-world evidence. According to Thomas (2021), inductive research excels in contexts where theoretical foundations are nascent, while Haque (2022) highlights its suitability for dynamic fields like blockchain applications. Saunders et al. (2024) further emphasize that inductive methods foster deep understanding through iterative data analysis, ensuring the framework emerges organically from the data. Figure 3.1 below outlines the inductive design approach adopted by this research.

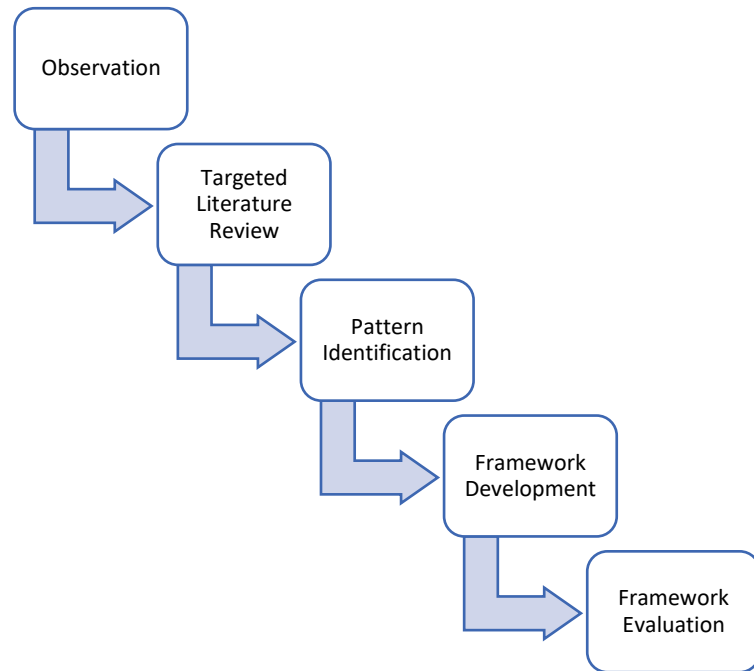


Figure 3.1 Inductive Research Design Approach

3.2 Observation

Observation in an inductive research design approach allows data to be collected empirically from real-world settings without preconceived theories or hypotheses guiding their observations. This phase is crucial for gathering detailed, nuanced information about phenomena as they naturally occur. A host of methods such as direct observation, interviews, and surveys can be used to collect data, ensuring that they remain open to emerging patterns and themes. The goal is to build a comprehensive understanding of the subject matter based on the data collected rather than testing existing theories. This approach allows for the development of new theories grounded in actual observations and experiences. For instance, in qualitative research, observation can help identify recurrent patterns or concepts that become the basis for theoretical development (Patton, 2015). This study used personal observations backed by research findings to make relevant observations. Observation of current supply

chain systems was carried out to identify the challenges they face, and how blockchain integration can alleviate those challenges. It involved conducting informal observations of SC operations in port logistics, identifying issues such as data fragmentation, delays in document verification, and lack of transparency, while also observing how blockchain prototypes demonstrate real-time tracking and secure data sharing.

3.3 Targeted Literature Review

A survey of research literature pertaining to blockchain integration in a supply chain context was conducted to identify common factors challenges, and knowledge gaps. A targeted literature review approach helped to efficiently obtain high-quality and pertinent information. A targeted literature review approach focuses on efficiently obtaining high-quality and pertinent information by employing a systematic and selective search strategy (Snyder, 2019). Following this, a search strategy comprising of specific keywords and phrases was developed to capture the most relevant and recent research. The initial search criteria included research articles published in journal articles within the last five years, which was then narrowed down by manually reading through abstracts to screen for relevant articles. The review process involved reading abstracts, conclusions, and key sections to gather insights efficiently.

3.4 Pattern Identification

The next step was to seek patterns in the data collected, by analyzing the articles to extract key information about the features, components, challenges, and advantages of the blockchain frameworks. It was found that benefits of blockchain such as security, efficiency and transparency are realized through immutable ledgers and smart contracts. Common

blockchain integration challenges included technical complexity, scalability issues, and resistance to change from traditional systems. Various potential blockchain platforms were identified and considered, including Hyperledger Fabric and Ethereum, each framework had specific benefits and limitations relevant to supply chain applications.

To identify these patterns, the study employed a systematic review of research papers published on the topic. The process involved searching for relevant papers using carefully designed queries on Google Scholar, followed by title screening and abstract screening for relevance. After that, full text review of the shortlisted papers was conducted to detect recurring concepts such as blockchain's role in enhancing security or addressing scalability, ensuring robust identification of patterns in existing research. Identifying these patterns led to the development of a framework that optimizes blockchain's features for supply chain efficiency and security, thereby serving as an efficient and reliable solution to integrate blockchain technology into existing supply chain management systems.

- Search Query (Hyperledger Fabric OR Ethereum + "integration" + "supply chain") ~ 8100 papers
- Title screening phase ~ 2420 papers
- Abstract screening ~ 450 papers
- Full-text review ~ 190 papers

3.5 Framework Development

Framework development was guided by a synthesis of several theoretical perspectives. Transaction Cost Economics (TCE) underpinned the design, aiming to streamline supply chain operations by automating processes and minimizing manual intervention (Ketokivi & Mahoney, 2020). Resource-Based View (RBV) theory positioned blockchain as a strategic

asset, capable of conferring competitive advantage through heightened supply chain efficiency and security by leveraging inimitable resources (Nandi et al., 2020). From a technology perspective, blockchain's decentralized ledger offers unique data immutability; from a capability perspective, it enhances organizational skills in secure data management; and from a performance perspective, it improves operational efficiency and reduces costs through automated processes. Finally, Diffusion of Innovations (DOI) theory guided the framework's development with a focus on quick organizational and user adoption, acknowledging the importance of factors such as relative advantage, compatibility, complexity, trialability, and observability in technology adoption (Call & Herber, 2022). The framework uses smart contracts for process automation and rule enforcement, a permissioned blockchain ledger for secure and tamper-proof record-keeping, and a simple user interface for streamlined management and reducing resistance to change, thereby aligning with TCE's efficiency goals, RBV's emphasis on strategic resources, and DOI's focus on adoption facilitation.

3.6 Framework Evaluation

3.6.1 Conceptual Analysis

The reliability of the proposed framework was first evaluated by applying it to a real-world case study. This approach is referred to as conceptual analysis, wherein the theoretical framework is systematically applied to existing real-world data to assess its practical applicability and explanatory power (Ridder, 2017). When applying a theoretical framework, it is critical to select a well-documented case study that reflects real-world conditions, using secondary data sources for analysis (Yin, 2018). A detailed analysis evaluates the framework's effectiveness

in addressing the complexities of the case study, providing insights into its practical applicability (Reay & Jones, 2016). This approach relies on using secondary data such as existing documents, reports, or studies rather than primary data collection. The focus is on validating the framework conceptually by applying it to a documented case rather than through empirical fieldwork. More specifically, this method allows for the examination of the framework's ability to address specific challenges within the case, providing a deeper understanding of its utility in real-world contexts. Furthermore, conceptual analysis aids in bridging the gap between theory and practice, offering insights that can inform both further theoretical development and practical implementation (Suddaby, 2014). This approach is particularly useful in the early stages of theoretical development, where the goal is to test and refine a conceptual framework before conducting more extensive empirical research. It ensures that the framework is robust and applicable to real-world situations, even if primary data collection is not feasible at this stage. Through this process, the framework's robustness is tested, ensuring that it can be effectively applied in similar scenarios across various settings.

3.6.2 Prototype Development

A prototype was then developed based on the concepts outlined in the framework, in order to validate the framework's usefulness and reliability. This helps to translate abstract ideas into a tangible form that can be tested and evaluated. Prototype-based validation approach involves developing a working prototype based on a theoretical framework to test its practical applicability, usefulness, and reliability in a specific context. Therefore, a specific use case scenario was chosen to clearly define the features necessary in the application context, thereby ensuring that the features of the prototype align with practical needs and

challenges. Developing a prototype involves selecting the most appropriate technology stack for a given use case scenario, which includes identifying a suitable blockchain platform, middleware for integration, coding language for smart contracts, consensus mechanism and user interface. The prototype essentially helps to validate whether the theoretical framework can be successfully implemented in real-world scenarios, assessing both its strengths and limitations. Prototype-based validation often is an iterative process where the prototype is refined based on performance and functional results (Lauff, Kotys-Schwartz & Rentschler, 2018). Applying it to a specific use-case scenario helps to ensure that the prototype addresses typical user needs in a supply chain context, making the validation process more focused and relevant.

3.6.3 Prototype Testing

The prototype developed based on the supply-blockchain framework was subjected to functional and performance testing to ensure a holistic evaluation. Functional testing of the prototype involves checking to verify that all features are functioning as intended, which also indicates proper smart contract execution. Various datasets were entered into the prototype to check various scenarios to confirm that the system performs its intended functions. Performance testing helped to assess the prototype's efficiency under different load conditions and its potential for scalability. This evaluation was performed using Hyperledger Caliper, while the raw data from the performance testing was visualized using a combination of tools such as Grafana and Prometheus. Carrying out performance testing helps to evaluate if the prototype could properly handle anticipated transaction volumes and operational demands. Based on the outcomes of functional and performance tests, it would be possible to identify potential areas for future improvements.

3.7 Chapter Summary

This chapter describes the methodology used to develop and validate the supply-blockchain framework for integrating blockchain technology into logistics and supply chain services. The methodology follows an inductive research approach, involving observation and backed up by a targeted literature review. This is followed by theoretical framework development and evaluation of the framework using conceptual analysis as well as prototype development. The developed prototype is finally subject to functional and performance testing, in order to evaluate its functional and technical capabilities.

Chapter 4

Framework Development

4.1 Approaches towards Blockchain Framework Development

Project management is critical component in the approach towards implementing a blockchain framework. The process of integrating a new framework and replacing the old system or merging both systems into a single framework requires proper allocation of resources and prioritization of tasks (Al-Mazrouai & Sudevan, 2020). The purpose of project management is to ensure that goals are being met during the adoption phase without any additional implications to time, cost, and quality. In blockchain framework development, the same principles apply as multiple external factors could impact the completion of the project,

particularly in supply chain systems that encompass a multitude of geopolitical and logistical aspects.

There are three main phases to be considered for blockchain framework development in the context of supply chain systems, namely: framework creation, framework integration, and framework adjustment (Gozman, Liebenau & Aste, 2020). Creation focuses on the development of architecture, data structuring, and intended dependency across various systems that would be involved with the blockchain framework. Integration focuses on the concessions made to the architecture to fit the needs of the system as well as, the adjustments needed to be implemented during blockchain adoption (Janssen et al., 2020). Lastly, adjustment is made based on how goals and standards are met to be able to realign the purpose and function of the created and implemented blockchain to fit the needs of the supply chain system, including any optimizations or calibrations required as the framework expands or changes its overall structure (Collomb, De Filippi & Klara, 2019).

4.2 Essential Requirements and Specifications

The continuous operations required for supply chain systems create multiple challenges that need to be addressed, as the development of any new feature or framework is forced to be compartmentalized to be able to meet the constant demand for processing documents while also introducing innovations and features (Helo & Shamsuzzoha, 2020). Supply chain systems require a modular approach rather than a complete overhaul of the existing system (Jayaram & Vickery, 2018), as the acceptance of sudden changes is very unlikely across various involved parties. Integration of changes tends to take time across different segments due to the complexity of relationships and procedures. More often than not, change is introduced slowly to allow regulators, suppliers,

and other users to adjust to new policies and ensure that the documents of products already in transit are still acceptable within the currently transitioning system. In addition, existing frameworks also need to be tested as it is being modified to ensure that changes produce only the intended results (Yadav et al., 2020). Deviations from standard procedure and updated policies, particularly for regulatory functions within supply chain systems, create a domino effect throughout the system. Hence, frameworks that are adopted are ideally made to maintain a standard procedure to ensure predictability during operations.

The essential requirements and specifications of blockchain frameworks stem from the context of their priority functions, which are defined by a combination of the identified case's technological need, current operational framework, political climate, existing regulations, and intended purpose (Jayaram & Vickery, 2018). The development of blockchain frameworks requires an analysis of these factors to identify the exact specifications required to address both the existing issues of supply chain systems and the blockchain architecture needed to address future development. Technological needs and operational framework are particularly important as they highlight how the blockchain could be integrated with various existing technologies, such as IoT and RFID. On the other hand, certain specifications are often dictated based on the political climate and existing regulations as these involve embargos, trade restrictions, product quality specifications, identification of the origin of goods, and other limitations or requirements for handling logistics within the supply chain system.

4.2.1 Theoretical concepts underpinning framework development

To address requirements specified earlier, the proposed framework is designed based on four key theoretical concepts including decentralized data structure, distributed storage mechanism, consensus agreement algorithms and asymmetric encryption. The concept of decentralized data structure is utilized in the framework to ensure transparency and security, this is crucial for supply chain integrity as it facilitates a robust and transparent ledger system (Azzi, Chamoun & Sokhn, 2019). The distributed storage mechanism further enhances security by eliminating data centralization, lowering the risk of single point failure (Chiu, Meng & Jensen, 2021). This aspect allows blockchain-integrated supply chain systems to be more resilient to data breaches and cyber-attacks. The use of consensus agreement algorithm further ensures that supply chain systems are reliable and consistent, since all the nodes in the network agree on the validity of a transaction (Ma, 2021). Lastly, asymmetric encryption safeguards transactions against tampering and unauthorized access.

4.3 Framework Development Process

Developing a novel and unified supply-blockchain framework for integrating blockchain into supply chain systems helps to address several issues such as the lengthy period before perceived benefits are enjoyed and the costly transition towards blockchain. This framework fosters a modular approach toward developing multiple features. It involves integration of the following stages:

- i. Agile model of project management
- ii. Core integration framework adapted from MOHBSChain model

4.3.1 Agile Method of Development

The agile method of development is ideal for addressing supply chain system software as it enables modular improvements to the existing system while also enabling a secured environment for testing before changes are pushed into the live service (Zhu et al., 2021). In the context of supply chain systems that are likely to run non-stop, the use of the agile method is crucial as it allows for continuous servicing that mitigates the risk of backlogs due to delayed processing of documents and system downtimes. The approach toward adopting the agile method involves the ability to simultaneously test introduced features at the cost of higher resources for troubleshooting and bug-fixing (Udokwu, Anyanka & Norta, 2020). While beta testing and quality assurance are possible strategies before committing changes to the live service, there is still an expectation that costs will be incurred for addressing any unforeseen issues that may arise.

As a type of project management, the agile method also allows for the prioritization of key features based on existing needs and demands (Faruk et al., 2022), which leads to effective incremental progress as main issues are partially or fully resolved within sprints. Unlike other project management strategies, the agile method allows feedback loops to be faster to roll out improvements quicker. In the process of integrating blockchain into supply chain systems, the agile method enables blockchain technology to be utilized to address primary issues, which builds up the impact of the technology and its features on the identified project.

4.3.2 Development of a Core Integration Framework

The unpredictability of political and economic conditions requires that framework development be suited for multiple types of scenarios that

could be encountered. While blockchain is inherently flexible due to its large capacity to handle multiple functions, it also needs to be guided by key features that enable it to perform its intended role and purpose (Biswas et al., 2018). To ensure that blockchains remain useful while also being adaptable to various changes, developing a core framework is viewed as ideal for enabling greater flexibility as it allows features, policies, and other related systems to be repurposed whenever sweeping changes are implemented. The main benefit of this approach is that it enables scalability for supply chain systems that are likely to constantly develop and adapt to their external environment.

A core framework also limits issues regarding transferability and compatibility when new technology is expected to be implemented, as it enables a modular approach to be incorporated that is likely to be able to accept multiple features and allow modification of each one separately (Riasanow et al., 2021). Lack of interdependence among the features also allows the developed framework to function more consistently as the inclusion, revision, and removal of features would have minimal impact on the overall operations.

The core integration framework has been adapted from the MOHBSCChain model that is intended for use in logistics and supply chain systems, due to its simplified centralized architecture that enables multiple connections with various external devices (Shinkar & Thankachan, 2022). MOHBSCChain provides the advantage of maintaining security and combining it with functionality to meet the stringent demands of supply chain systems brought about by an ever-changing environment and strict requirements to meet regulations and specifications.

From a functional perspective, the MOHBSCChain model's advantage is that it clearly delegates and clusters trusted and non-trusted

devices to funnel interactions into certain layers wherein security can be strengthened while maintaining the accessibility of the system to external devices (Bellandi et al., 2021). The delineation between each segment of the framework also identifies key points where security needs to be improved to ensure that data is immutable and reliable (Shinkar & Thankachan, 2022). Moreover, the MOHBSchain model also enables an easier way of monitoring operations and identifying errors within the system by allowing transactions to be compartmentalized and limited within each respective portion. This allows hotfixes to be more reliable and effective as portions of the system are segmented and easily identifiable, which benefits the agile method as it allows for shorter testing periods before the actual release of changes (Jayashree, Srinivasan & Babu, 2022).

While MOHBSChain model has many advantages, it is also quite complex to implement. Therefore, the supply-blockchain framework developed in this research only utilizes MOHBSChain model's core features. Figure 4.1 below presents a graphic representation of the proposed framework, the core blockchain ecosystem is surrounded by two layers. The first layer provides services such as storage and retrieval, processing of the transaction, operation of the consensus mechanism for verification, and processing of blockchain transactions through the use of smart contracts. The first layer is patterned in a way that it contains the core functions needed for the blockchain to operate. This is also the reason why the first layer is prioritized in terms of development and integration.

The second layer involves additional features that improve the security and functionality of the framework, while still retaining core features necessary to operate and maintain the blockchain network. Thus, prioritization of new features implementation can depend on the changing

needs of a SC organization. For example, if security is the main concern, then developing dynamic encoding and control of access for regulators and other users can be prioritized over other updates. But, if the focus is on end-user experience, then developing access channels for viewing transactions and automating purchases through an app or website linked to the blockchain network can be prioritized. Development of channels to connect with external devices improves accessibility, while a backup server helps to strengthen the reliability of processed data. These components are less prioritized, as they involve expanding the framework to other connections, which not only increases security risks but also requires more resources to complete.

Figure 4.1 illustrates the proposed supply-blockchain framework adapted from the MOHBSCChain model for blockchain integration. The framework features a central blockchain core, surrounded by concentric layers divided into quadrants, each detailing functional components. The innermost layer includes smart contracts for automating purchasing, processing transactions, a consensus mechanism for validation and layered access for regulators, forming the core operations. The second layer enhances functionality with dynamic encoding of hashes, transaction transparency, and storage and retrieval, the latter incorporating cloud storage levels that include object storage for unstructured data like archival documents, block storage for high-performance real-time transactions, and file storage for hierarchical documentation. External components such as a backup server for redundancy and external devices including RFIDs, cloud storage, and other networks, connect via arrows, ensuring reliability and interoperability. This design prioritizes security and efficiency, which is in line with the MOHBSCChain model's centralized architecture. The

inclusion of cloud storage levels bolsters data management, supporting scalability and adaptability for various SC needs.

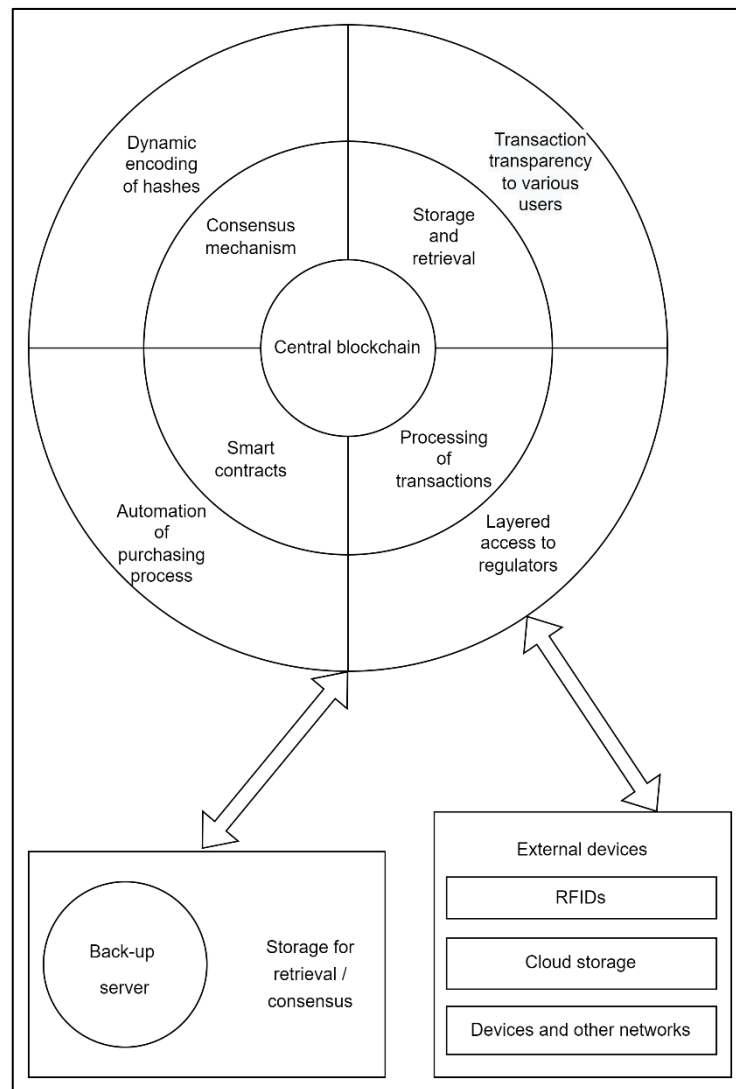


Figure 4.1 Proposed Supply-Blockchain Framework

The particular approach is quite beneficial to an agile method of development as it fills the gaps in security that are expected to occur as incremental changes may inadvertently result in security loopholes within the system. Moreover, it also establishes a clear hierarchy of prioritization among the different components of the system that should be developed, which allows for a clear pathway toward assigning sprints for each time period (Jayashree, Srinivasan & Babu, 2022). The hierarchy serves an important role as it facilitates a way to inherently structure data that

would be processed, stored, and accessed from the central blockchain and its various layers.

4.4 Integrating Change Management for Blockchain

Adoption

The process of integrating change management into existing systems has been characterized by the numerous online platforms that are present across various supply chain systems (Xu & Choi, 2021). Change management, in the context of blockchain integration, involves pursuing strategies and building architecture that is more acceptable to involved parties by either minimizing changes or improving the quality of life across different sectors.

Resistance from various stakeholders must be expected as supply chain systems revolve around transparency, accountability, and stability (Balci & Surucu-Balci, 2021). Risk is also incurred whenever changes are made, particularly due to unforeseen results and unfamiliarity with the technology. Hence, the process of creating and integrating the blockchain framework tends to require a buy-in period wherein stakeholders are made aware of how the framework's technology operates. One of the biggest factors affected by risk would be the presence of strict policies within supply chain systems, which would have accompanying sanctions when specifications are not met (Collomb, De Filippi & Klara, 2019). In this regard, change management needs to follow strict adherence to the core principles and specifications while also ensuring that the process of integration would remain stable throughout the integration process.

4.5 Delivering Transparency through Blockchain

Integration

Blockchains have generally been adopted due to their capacity to promote transparency within the system (Centobelli et al., 2022). Due to the nature of logistics and supply chain systems that seek to provide pertinent data to respective users in a timely and accurate manner, blockchain integration can enhance predictability across multiple regulatory bodies that a package may pass through. Hence, its reliable implementation through blockchains has attracted attention to how existing systems could incorporate strategies that maximize such benefits (Reddy et al., 2021).

As a core feature of blockchain, transparency builds trust among users that data remains immutable. Users of varying roles and authority are able to monitor transactions and access role-relevant data to aid in decision-making and enable the predictability of conducted processes (Tandon et al., 2020). In cases wherein automation is sought, transparency also serves as a means of audit without interference, as data could not be scrubbed from ledgers within a blockchain's secure system (Yadav et al., 2020). End-users, such as businesses that import or export their goods, are examples of stakeholders that benefit from transparency as they are able to hold government agencies accountable for delays. Another benefit of transparency is that it allows for accurate forecasting as data involving approval of transactions, time taken to deliver goods, and other relevant data are accessible.

Transparency also promotes accountability within the blockchain framework as it allows irregularities or loopholes to be detected based on the visibility of all conducted transactions. As supply chain systems tend to deal with various roles and levels of authority, then it would be practical to have backup systems that are used to validate existing data

(Mishra & Maheshwari, 2021). Thus, by facilitating transparency, the proposed blockchain integration framework can enhance efficiency, informed decision-making quicker problem resolution, and secure access to data for all stakeholders involved.

4.6 Managing Risk within Supply Chain Systems

Risks in implementing and adopting blockchain frameworks impact the sustainability of the supply chain systems due to their inherent capacity to stall the transport of goods and potentially lead to spoilage or damage (Kano, Tsang & Yeung, 2020). Sweeping changes are likely to cause confusion and disrupt the operations of supply chain systems. Avoiding risks is considered to be a necessary step in blockchain framework development, as the severity and volume of transactions handled are likely to cause a significant impact on day-to-day functions. Mitigation is conducted by pursuing framework development that not only fits the context of SCM but also builds upon features that fit the particular needs of various stakeholders (Hellani, Sliman & Samhat, 2021). The overall approach to mitigating risk would be to ensure stability and regularity of operations even as changes within the system occur.

To initiate the process of integrating blockchain frameworks without disrupting the existing system, it is found that the approach should gradually transition the current operations while maintaining a fully functioning system that provides day-to-day service. New features are then tested before being released once the migration process to a new framework has been completed (Helo & Shamsuzzoha, 2020). In developing these new features, the goal is to ensure that these are complementary to the existing supply chain environment and industry needs otherwise, it leads to unnecessary risks that could disrupt the

system. Furthermore, the preservation of continuous service allows for greater flexibility in realigning proposed changes as each component that is sought to be integrated is tested for a limited period of time, which enables adjustments to be made in comparison to previous performance or operations.

A system of checks and balances is necessary to proactively mitigate risk within the supply chain system due to its complex nature resulting from various roles, processes, and transactions involved. Hence, the use of a secure consensus mechanism is found to be critical in ensuring data transparency and validity (Hellani et al., 2021). While trust within the digital ledger is acquired through the reduction of uncertainty, there must still be extensive measures to ensure that hashes are not vulnerable to tampering across all data points. Therefore, the proposed blockchain integration framework can help regulations to be more reliably enforced, as long as the system remains reliable for all involved parties.

4.7 Chapter Summary

The chapter outlines various approaches used for blockchain framework development, encompassing various stages including framework creation, integration and adjustment. The essential requirements for a blockchain integration framework to be successfully applied to a supply chain context were clearly specified. Key theoretical concepts underpinning the framework such as distributed storage mechanism, decentralized data structure and consensus algorithms were discussed. The framework development involved agile project management approach and adapting the core aspects of MOHBChain model. Finally, the role of change management in blockchain integration and the need for facilitating transparency as well as mitigating risks in supply chains were discussed.

Chapter 5

Framework Validation

5.1 Application of Theoretical Framework to Case Study

The framework was applied to a real-world case study through conceptual analysis, as it is critical to test the proposed framework to identify how it functions and differs from existing solutions. The case study used for the application of the proposed framework is “*The Struggle is Real: Insights from a Supply Chain Blockchain Case*” (Sternberg, Hofmann & Roeck, 2021). The case study’s scenario involves a contemporary situation wherein the application of blockchain theory is sought for a specific project but social and systemic factors, such as an inter-organizational structure, a distortion in the cost-benefit analysis, and the strong presence of tension throughout the internal and external environment, are found to hinder the implementation of blockchain frameworks. The proposed framework seeks to address resistance towards the adoption of blockchain technology by making the benefits more prevalent. Moreover, by following an agile project model, most of the issues provided in the case study could be addressed in a timely manner, which are further discussed in the latter portion of this study.

5.1.1 Proposed Project Flow

In the proposed project flow, the main focus is to integrate the blockchain into the supply chain system while also adding greater priority to both feature development and correction of system requirements to meet set standards. The triggers for developing new features involve interventions from any stakeholder, existing systems not meeting the expected results, and seeking improvement to the supply chain system operations (Alazab

et al., 2021). Figure 5.1 below shows a block diagram detailing the key steps involved in the project flow.

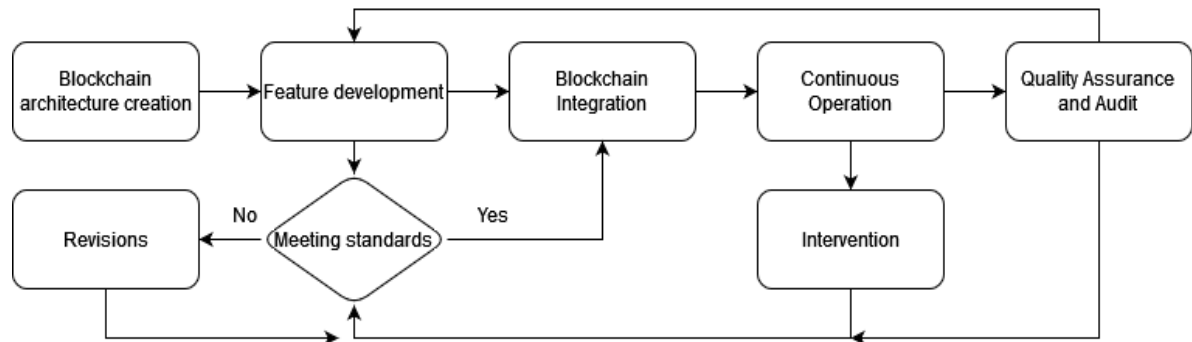


Figure 5.1 Block diagram of the Project Flow

The blockchain architecture creation starts the process as it involves the most planning among the different steps of the project. The data structure, the interconnection between different networks, the security measures for encrypting hashes and the type of consensus mechanism are all decided during this phase, as these are the rudimentary steps needed to operate the blockchain framework (Zhang et al., 2019). Afterward, the project would then follow development cycles wherein sprints would be conducted to prioritize tasks based on current conditions. These features are then integrated into the blockchain system after pre-testing to ensure that the features are in line with the project specifications and standards. However, alternative solutions arising from interventions and quality assurance may lead to revisions of existing or proposed features within the blockchain to ensure that the supply chain system is able to adapt to its conditions.

In this case, the rationale for following the proposed project flow would be to ensure regularity during actual operations. Blockchain would serve as a means to improve security and reliability throughout the supply chain system, but its features are incrementally introduced to ensure that

the integration process does not disrupt daily processes, transactions, and operations (Valle & Oliver, 2021). Ideally, the gradual integration of the blockchain and its new features would serve as a means to reduce tension by allowing the stakeholders to familiarize themselves with the new system at a slower pace (Shepherd et al., 2020).

5.1.2 Key Implementation Strategies

The project would be implemented in three main phases, which involve conceptualization, integration, and adaptation. The three phases follow the pattern provided in the proposed project flow. Figure 5.2 details the actions corresponding to each phase of the project.

Phase 1: Conceptualization	Phase 2: Integration	Phase 3: Adaptation
• Develop Blockchain architecture • Develop core features • Ensure standards are met with the first iteration • Prepare alternative solutions/strategies for proposed features	• Test features that were developed before committing to the supply chain system • Execute agile project sprints per time period • Record information on identified issues and bugs for new features	• Evaluate the efficiency of existing features and operations • Identify alternative solutions to encountered interventions

Figure 5.2 Project Phases

Conceptualization involves all the planning tasks that would enable the creation of the blockchain architecture and its initial features. In this phase, the overall idea of how the blockchain framework would fit the supply chain system is already prepared. This phase is meant to ensure that all aspects of the blockchain framework are in line with the necessary requirements and specifications before they are integrated into the current system (Pournader et al., 2020). The requirements include functional needs such as the ability to process transactions securely, non-functional

constraints like system performance and scalability, as well as domain-specific needs such as regulatory compliance for logistics and supply chain operations. These requirements guided the development of the system, its core features and standards adherence. Moreover, any contingency plans and foreseen issues are also discussed and identified in this phase.

Integration involves the incremental process wherein the project follows the agile method as changes are slowly introduced into the system. The Supply-Blockchain model shall slowly be implemented during the integration phase, which may also involve major changes to the current system used for operations. However, the main focus of this phase is not only to integrate the project into a new system, but also to allow various stakeholders to be more accepting of the change. Transitions are aimed at giving more time for stakeholders to familiarize themselves not only with the new system but also with its accompanying features (Alkaabi et al., 2020).

Adaptation involves the continuous development process that will maintain the quality of the whole system and ensure that any internal and external changes are correctly responded to. The adaptation phase is a response to the issues in the case study that were not addressed by having a more proactive stance on possible changes that impact the supply chain system. In relation to continuous development, prioritization is also part of the adaptation phase, which is tied to the goals of the implemented blockchain framework.

To ensure that the system has minimal issues regarding prioritization, the MoSCoW method is used as a means to identify the greatest to least priority features and components for the blockchain system (Burgess & Sunmola, 2021). The MoSCoW method was chosen over other prioritization techniques such as Kano model or Weighted

Shortest Job First, due to its distinct advantages. First, it offers fast usage and time efficiency, enabling rapid decision-making in agile environments (Miranda, 2022). Second, it provides clear prioritization categories (Must Have, Should Have, Could Have, Will Not Have), which simplify communication among stakeholders. Third, it supports flexibility, allowing adjustments as project needs evolve. Fourth, it enhances stakeholder alignment by making priorities transparent and actionable (Miranda, 2022). These advantages are in line with the agile sprints and dynamic requirements of the blockchain integration, ensuring focus on critical features while addressing the case study’s systemic and social challenges. Consequently, the method optimizes resource allocation and mitigates resistance during implementation.

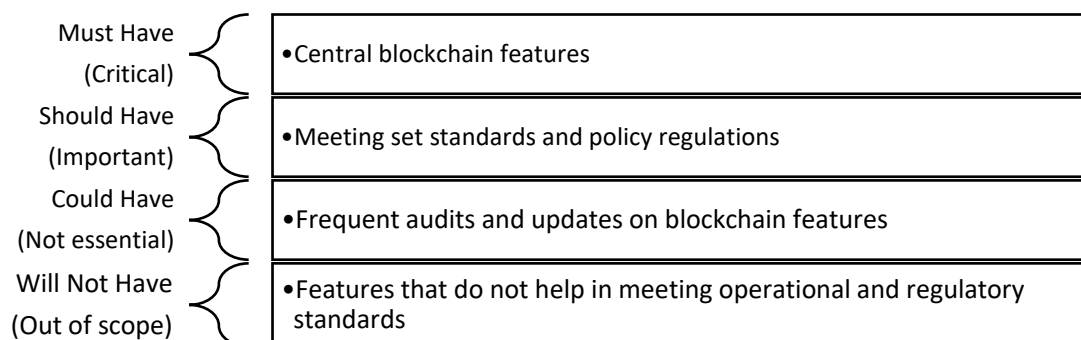


Figure 5.3 Application of MoSCoW method to Case Study

Figure 5.3 illustrates the application of the MoSCoW method to prioritize features for the blockchain framework in the case study, categorizing them based on their criticality to operational and regulatory needs. The “Must Have” category, encompassing central blockchain features, represents critical requirements essential for the framework’s functionality, such as secure transaction processing and data integrity, without which the system fails to operate. The “Should Have” category, including meeting set standards and policy regulations, denotes important requirements that enhance system reliability and compliance but are not

immediately critical for launch. The “Could Have” category, covering frequent audits and updates on blockchain features. The “Will Not Have” category, comprising features that do not help in meeting operational and regulatory standards.

As the case study involves numerous issues during and after the implementation of the blockchain framework, the proposed strategy is to maintain focus on the central blockchain system and develop external linkages to expand the network, similar to how the MOHBSChain model operates. In this way, the blockchain architecture is clearly determined and would remain intact even after new features are introduced as a response to various needs and demands. This system would also allow agile sprints to be more targeted as to what features and changes should be prioritized.

5.1.3 Difference in Approach

The method of solving the problems in the identified case study would be through the revision of how the project is managed and how blockchain is introduced and integrated with existing supply chain systems. The proposed project framework emphasizes the timeliness of updates and the gradual process of blockchain adoption to mitigate tension with existing and future stakeholders within the supply chain system as these are viewed to be among the main reasons why blockchain frameworks tend to have issues and lead to having less impact than expected (Vu, Ghadge & Bourlakis, 2021).

One of the main differences in approach would be the focus on building upon the central blockchain and its features, which aims to address organizational immaturity. A central blockchain reduces overall complexity during the start of the implementation phase as it is designed to allow fewer disruptions and minimal transition needed from the old to

the new system. Moreover, urgent issues involving lack of knowledge or training on the use of the new system could immediately be added as a priority task in the agile method as sprints are conducted during set periods but are open to being changed depending on the immediate needs (Wamba, Queiroz & Trinchera, 2020). Compared to the original approach used in the case study, the use of a central blockchain limits the immediate need for additional infrastructure as it allows the system to operate with the least possible resources needed for the blockchain framework to function. As a result, dependencies are limited during the implementation phase, which also limits the overall complexity of the project and allows for greater focus on improving key features in the early stages and slowly building improvements after the central blockchain has been integrated into the system.

External resistance is considered to be a constant threat to the implementation and operation of blockchain integration into supply chain systems due to its large scope and impact. In the case study, the focus on external resistance involved industry stakeholders, rival businesses, and an overall lack of commitment, which are often considered to be behavioral in nature but could be addressed through the use of direct involvement in the intervention step as well as the quality audits that force new specifications to be made in relation to the supply chain system's operation (Queiroz & Wamba, 2019). The introduction of a new step as a part of the integration process as well as, the operations of the supply chain system is viewed to be integral in reducing tension from external resistance by building trust through continuous engagement. Unlike the approach in the case study, this proposed strategy of including interventions across different stages allows for active participation and the provision of insights from various stakeholders to maintain a clear goal for the project's direction as it matures over time.

Lastly, the perceived obstacles are handled directly through the agile method as operational efficiency can be improved through prioritization of key features and tasks while increasing complexity is addressed by the incremental growth of the project and its required technology. The project phases are meant to allow for proper planning of requirements before blockchain integration, reassessment of priorities during the blockchain implementation phase, and reassessment of goals during the adaptation phase to allow the various stakeholders to have ample opportunities to intervene and ensure that expectations are being met.

5.1.4 Significance of Proposed Framework

The proposed framework helps to address gaps and limitations in existing frameworks. The agile model of project management allows for a modular and incremental approach to blockchain integration, which can reduce the time and cost of the project, as well as the complexity and scope creep (Faruk et al., 2022). The model also enables prioritization of key features and tasks based on the current needs and demands of the supply chain system and allows for feedback loops and adjustments to improve the quality and effectiveness of the blockchain solution (Wamba, Queiroz & Trinchera 2020). It can also mitigate the resistance and tension from various stakeholders by involving them in the project and demonstrating the benefits of blockchain technology in a timely manner.

The core integration framework adapted from the MOHBSChain model provides a simplified and centralized architecture for the blockchain network, which can increase the security and reliability of the data and transactions (Bellandi et al., 2021; Shinkar & Thankachan, 2022). It also enables scalability and flexibility of the blockchain solution by allowing for the addition of external features and devices that can

enhance the functionality and accessibility of the blockchain network (Riasanow et al., 2021). The framework can also address the challenges of interoperability and compatibility with other existing technologies and systems, such as IoT, smart contracts, and AI, by creating a modular and adaptable structure for the blockchain network (Zhang et al., 2019).

5.1.5 Implications & Limitations of Proposed Framework

The proposed framework intends to provide an improved experience to supply chain companies while handling a blockchain integration project, leading to multiple implications related to improved timeliness and availability of resources to address obstacles encountered. The proposed framework utilizes the agile model for project management, thereby serving as a timely response to the common issues identified and experienced during blockchain integration.

Through the use of the proposed framework, there would be a better understanding of how entry-level barriers to blockchain adoption could be addressed based on an understanding of the technological, managerial, and behavioral aspects involved during the process. While the proposed framework does not guarantee to be a panacea that would resolve all issues, it is viewed as a means to delve further into the process of increasing both blockchain adoption and blockchain integration effectiveness within supply chain systems.

The limitation of the study is that it involves the theoretical application of the Supply-Blockchain framework to the identified case study. In practice, however, it is expected that multiple other factors such as geopolitics, administrative and logistical challenges would have a significant impact on an operational level, particularly when proposed changes are introduced. Moreover, each case study is viewed to be unique and independent of the other hence, there are multiple scenarios that

could not be covered by the study. The focus on identifying each factor would not be possible without a significant amount of data for further analysis, which is not part of the scope of this study, but is deemed to be relevant nonetheless.

5.2 Prototype Development

A prototype was developed based on the unified supply-blockchain framework, in order to demonstrate the practical application of the developed theoretical framework. It aimed to demonstrate how blockchain technology can improve the transparency and security of supply chain transactions, especially in the context of port decongestion. This prototype was implemented using Hyperledger Fabric and utilizes a stack called Hyperledger Firefly, which provides access to tools such as the Hyperledger Firefly API and simplifies the process of connecting to blockchain networks (Hyperledger Foundation, 2024). It provides access to tools such as FireFly API to facilitate blockchain transactions. Compared to other implementations of Hyperledger Fabric, the goal of this prototype is to use Hyperledger Fabric to operate decentralized applications. This allows for digital signing of transactions, controlled access to authorized personnel, and intervention of end users to fix anomalies, thereby helping to speed up operations and reducing port congestion.

5.2.1 Use Case Scenario

The use case scenario that the prototype seeks to address is port congestion. Port congestion persists as a significant obstacle in global supply chains, hindering the smooth movement of goods. Cumbersome document management processes, often prone to human error and exposed to security risks, are at the core of these delays (MacLennan,

Lewis & Roman, 2024). Yet, shipping and port operations form the most crucial part of most supply chains enabling transfer of good and materials on a global scale. Any product with a global customer base has to pass through a port, in order to be shipped to the intended market. However, this critical node in the supply chain is engulfed in constant delays and slowed document processing and shipment tracking. The Centre for Strategic and International studies reports that slow manual administrative processes result in shipping delays, disrupting the entire supply chain (Benson & Judd, 2021). Simple tasks like bill processing take an average of 42 days to reach the invoicing company (Hellenic Shipping News, 2021). Blockchain technology, with its emphasis on immutability, distributed ledgers, and secure data handling, presents a compelling solution to optimize these essential supply chain operations (Dutta et al., 2020; Epiphaniou et al., 2020). Some shipping companies and ports such as Port of Koper and Abu Dhabi ports have initiated pilot programs involving blockchain integration in shipping and port management (Marine Insight News Network, 2019). However, most ports around the globe are yet to use this technology.

Blockchain integration in supply chains allows better communication between suppliers and producers and reduces human error. Besides that, it also facilitates automation using smart contracts to reduce lengthy wait times. The nature of transactions in ports requires strong alignment with transparency and security. Goods shipped to and from ports must be well-documented as they can involve tariffs and quality requirements imposed by the importing country. Since these restrictions encompass economic and health-related concerns, the documents must be free from tampering. While processing digital transactions for ports, blockchain technology allows for the immutability of records through its security features and transparency through its

public ledger. This helps to address port requirements such as approval of entry of goods, certification of the contents of packages, and proof of payment of taxes among others.

As a guiding principle, both transparency and security are maintained throughout the operation of the blockchain network. In a shipping port scenario, transparency not only encompasses availability of transaction details, but also the accessibility of said information through front-end applications for increased visibility. This allows real-time viewing of any uploaded documents and their approval status. In theory, transparency builds trust and accountability among authorities and service providers, as any error is audited and can be tracked. Besides that, security goes hand-in-hand with transparency as transactions made by an organization would only be viewable to those given permission, despite having a public ledger for all transactions. The segmentation also allows for any personal data such as customer info to be protected.

In the port congestion scenario considered, the prototype development and integration of the blockchain network does not necessarily require direct installation within ports or offices of regulatory bodies. Instead, it can be deployed into cloud systems that currently host the existing supply chain management system of the port, thereby allowing them to gain access to the blockchain network's benefits. Agile model was followed to plan, design, develop, test, deploy and review development of this prototype, in order to reduce risks and ensure timely completion.

Furthermore, MoSCoW method was used to prioritize requirements for the prototype, ensuring essential features are implemented first (Kravchenko, Bogdanova & Shevgunov, 2022). In terms of functionality considered, integration of Hyperledger Fabric with Firefly was a fundamental requirement, while the ability to create and edit

smart contracts was also essential to facilitate basic functionality. Invoking a smart contract does not require any programming knowledge from end-users, as the invoke function automatically triggers the chaincode corresponding to creating or editing a smart contract. Having a user interface to keep track of changes made to the smart contract was a useful feature initially considered, and eventually realized using Explore UI. However, advanced features such as demand forecasting using AI services and tracking using IoT integration were not considered, due to their complexity, time constraints and costs involved. Figure 5.4 shows the application of MoSCoW method to prioritize functions expected from the prototype.

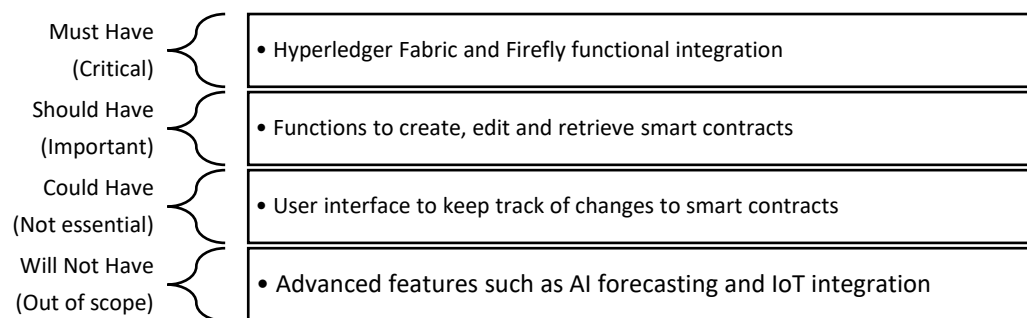


Figure 5.4 MoSCoW prioritization of prototype functionality

5.2.2 Prototype stakeholders

The prototype has the potential to deliver a range of direct and indirect benefits to various stakeholders throughout the supply chain, from producers to consumers (Irannezhad, 2020). More specifically, one of the primary beneficiaries of this technology is the regulatory sector, as it allows for automation of repetitive tasks. Bottlenecks in ports often result from either high volume of documents or special issues encountered in time-consuming cases. Since approval can be automated based on a predetermined checklist, it can free up regulators and allow them to focus on more complex cases that require manual intervention. This not only

speeds up the approval process but also improves the accuracy of regulatory compliance.

Shipping companies also directly benefit from blockchain implementation in ports, as it speeds up timely delivery and improves transparency. The enhanced tracking capabilities provided by the prototype can reduce the likelihood of lost or misplaced shipments, offering real-time updates on package status. Apart from this, another benefit to shipping companies is the reduction of costs resulting from schedule disruptions and increased transit times. By streamlining documentation and minimizing errors, the prototype can help companies optimize their routes and schedules. Additionally, improved data accuracy and transparency foster better relationships with clients and partners, potentially leading to increased business opportunities and satisfaction. This may also positively impact investor confidence in shipping and logistics companies that integrate blockchain technology.

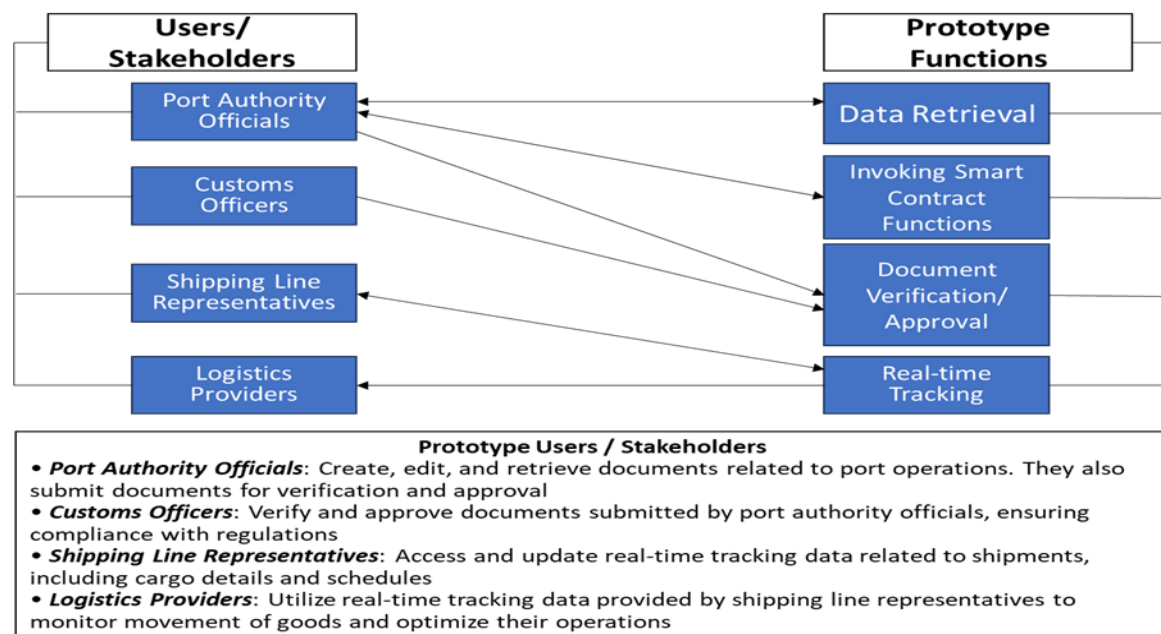


Figure 5.5 Block diagram detailing prototype functionality and users

Figure 5.5 presents a block diagram detailing various functions of the prototype corresponding to its potential users. The cumulative effect

of the value delivered to these stakeholders improves overall efficiency, reliability, and trustworthiness of the SC. The advantages gained from the prototype are as follows:

- 1) Enhanced transparency in transactions, enabling real-time tracking and visibility for stakeholders like regulators and shipping companies.
- 2) Increased security through blockchain's immutable records, reducing risks of tampering and errors in port operations.
- 3) Improved operational efficiency by automating repetitive tasks, such as document approvals, thereby reducing port congestion.
- 4) Strengthened stakeholder trust and accountability, fostering better relationships among suppliers, manufacturers, and consumers.

5.2.3 Hyperledger Firefly Architecture

The architecture of the prototype depicts the connection between the technical stack, central blockchain, and smart contracts, thereby encompassing core components that allow the prototype to connect with the blockchain network in a meaningful way. Once key requirements were identified, a review of case studies, existing tools and their technical feasibility was conducted to identify the most suitable blockchain platform and technical stack, which helped to develop a high-level technical architecture of the prototype. The choice of technical stack is the most critical part of the development process, as it involves choosing a set of tools and programs necessary to allow core transactions to occur.

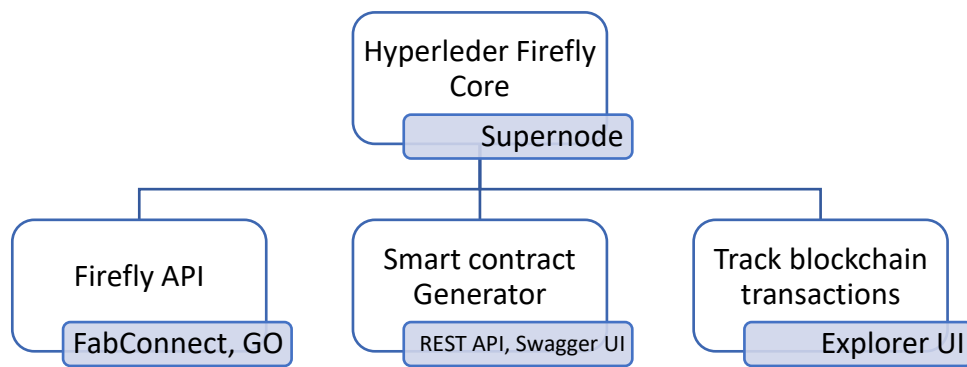


Figure 5.6 Hyperledger Firefly Architecture

Figure 5.6 outlines the key component of Hyperledger Firefly architecture. The architecture comprises of Hyperledger Firefly (see Appendix A for more details) stack, which is essentially a supernode comprising of APIs and other tools. FabConnect API allows for integration with public or enterprise blockchains, enabling the prototype to work with existing systems and ensuring transparent transaction management. It also acts as the hub connecting the Hyperledger Fabric blockchain with other system components. While chaincode is developed using Go language, all transactions are processed within the Hyperledger Fabric framework using channel-based privacy for permissioned access. The encrypted data is transferred to Hyperledger Firefly for further handling by other APIs, besides providing access to interfaces such as Swagger UI for end users to interact with the prototype and Explorer UI for transaction tracking.

As the scenario considered involves decongesting ports, the data types include those typically used in supply chain systems, along with the introduction of the approval status of documents that comes from regulators. The key intended function of this prototype is to create, edit and retrieve smart contract-based documents within a blockchain framework, where “documentation” refers to digitally signed, immutable records of port-related transactions, such as bills of lading, customs

declarations and shipment approvals, stored securely on the blockchain. However, as numerous transactions may have to be handled in real time, the prototype will also be able to use Representational State Transfer (REST) API to automate transactions. The next step is prototype development to validate its viability as a solution to practical barriers identified, which will be discussed in the next section. The agile model of plan, design, develop, test, deploy and review was duly followed during the development of the prototype, in order to reduce risk of delay and ensure timely completion.

5.2.4 Prototype Development Process

A linear process was followed during prototype development to realize basic functions required to exhibit its potential to optimize document management in congested ports. The five main steps involved in the prototype development process include: (1) setting up the environment and technical stack, (2) connecting to the central blockchain, (3) creation of smart contracts, (4) automation of verification processes, and (5) processing of transactions. These steps encompass development of the prototype architecture that will connect with the blockchain and handle transactions, as well as the user interface needed to get inputs from end-users to carry out functions. Figure 5.7 below represents the process involved in prototype design and development. Following are steps involved in the process:

- 1) Setting up the environment – Install WSL (Windows Subsystem for Linux) and set up the technical stack (Docker, Hyperledger Fabric and Hyperledger FireFly).

- 2) Initializing Hyperledger FireFly – Set up FireFly as a blockchain middleware to orchestrate transactions, manage off-chain data, and enable API-driven interactions with Hyperledger Fabric.
- 3) Setting up a Hyperledger Fabric network and configuring Raft consensus mechanism – Initialize the Fabric network, define ordering nodes using Raft, and configure peers and policies.
- 4) Creating smart contracts (chaincode) for Hyperledger Fabric – Develop Fabric chaincode in Go, language, ensuring it aligns with business logic requirements of supply chains.
- 5) Packaging the developed chaincode, and preparing it for deployment on the Fabric network.
- 6) Deploying packaged contract – Install chaincode on peer nodes, approve it through Fabric governance processes, and commit it to a Fabric channel.
- 7) Creating a contract interface – Expose smart contract functions through FireFly's API layer, making them accessible for applications.
- 8) REST API integration to allow APIs to interact with deployed smart contracts, enabling seamless communication between blockchain and external systems.
- 9) Configure Swagger UI for API testing and FireFly Explorer for network monitoring and end-user interaction.

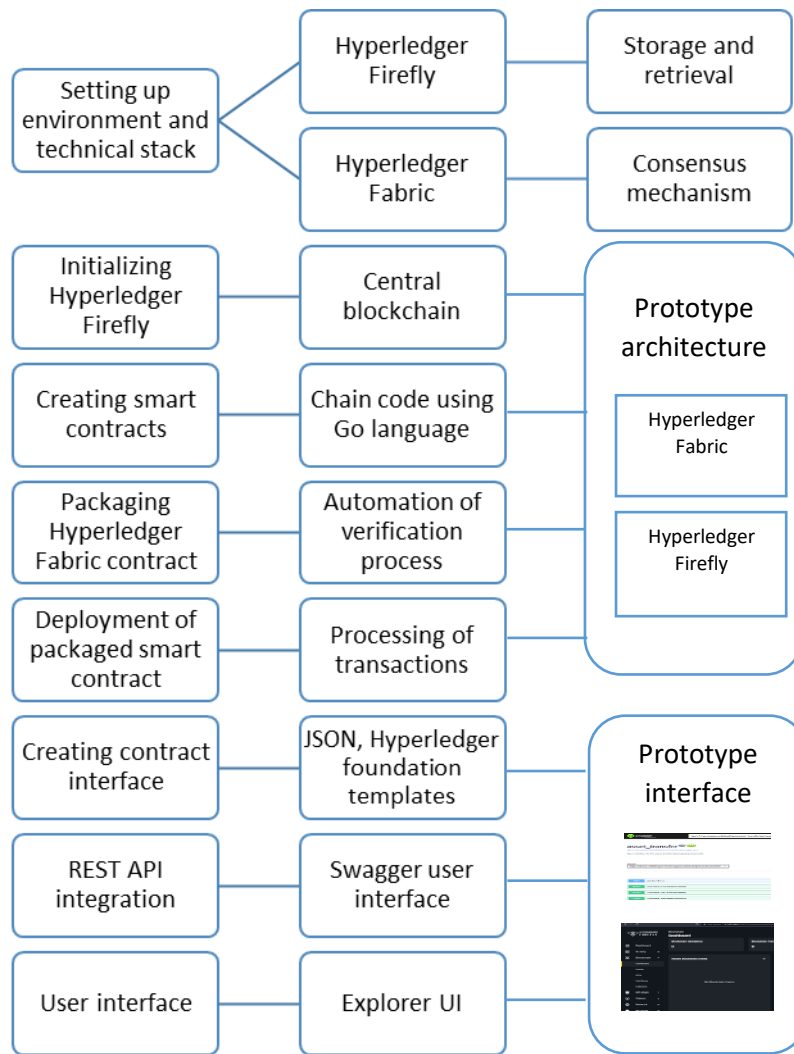


Figure 5.7 Prototype development and deployment process

The chaincode for deploying smart contracts was developed using Go language by customizing basic templates provided by the Hyperledger Foundation to fit the case scenario (GitHub, 2024). Furthermore, a FireFly Interface document was created using JavaScript Object Notation (JSON) based data structures, which enables Hyperledger Firefly to comprehend and interact with the chaincode developed (GitHub, n.d). The next step was to package chaincode via the command line interface, in order to automate the verification process. This is followed by deployment of the chaincode, which allows blockchain transactions to be processed.

Upon successful deployment, a contract interface was created using the Sandbox UI provided by Hyperledger Firefly. Smart contract functions can generate events that Hyperledger Firefly listens to, enabling notifications to users or triggering of HTTP requests for further action. Once the contract interface is registered, it provides access to the REST API and associated user interfaces. Swagger UI allows end-users to invoke various functions (see Appendix E) of the prototype such as creating, editing and retrieving port-related documents are implemented. Furthermore, Explorer UI provides a snapshot of transactions carried out.

5.3 Components of Supply-Blockchain Framework used in Prototype

5.3.1 Central blockchain

The central blockchain comprises of Hyperledger fabric, due to the efficiency and security that it provides. It was also chosen for its suitability for enterprise environments and its support for complex smart contracts. Hyperledger Fabric's contribution to blockchain integration is its sustainability resulting from requiring no gas fees for its operations. For supply chain systems, the reduced cost is integral to their sustainability as the number of daily transactions can reach hundreds of thousands depending on the scale of operations. However, this does not mean that all operational costs are reduced by blockchain implementation. Operational costs are still incurred as Hyperledger Fabric still needs servers that host nodes and operate the consensus mechanism, similar to other blockchain networks (Jamil et al., 2019).

The use of Hyperledger Fabric in existing literature has showcased how it differentiates itself from other popular blockchain frameworks such as Ethereum. As Hyperledger Fabric is considered to be a

permissioned blockchain, it specializes in protecting information from unauthorized access by segmenting the public ledger's visibility depending on a user's authority. Nevertheless, the segmentation done for security does not limit the connectivity of Hyperledger Fabric as it can still connect with other blockchains. Hyperledger Firefly was used as middleware to facilitate integration between the blockchain and existing supply chain systems, enabling effective communication and data exchange (Hyperledger Firefly, 2023).

Previous implementations that have used Hyperledger Fabric for supply chain systems emphasize the use of smart contracts as part of the framework's scalability (Putri, Hariadi & Wibawa, 2020). Smart contracts are strongly embedded within the implementation Hyperledger Fabric and serve as a means to enable scalability by reducing the need for human intervention in programmed decisions and repeated transactions. As a result, the risk of human errors in numerous transactions is prevented without prejudice to the architecture allowing for the required authority to approve certain categories of transactions. Chaincode written in Go language was used in the prototype to implement smart contracts that automate various supply chain processes (see Appendix C).

Privacy by design is promoted within the Hyperledger Fabric framework due to its inherent focus on channel-based privacy and Membership Services Provider (MSP) (Ma et al., 2019). Unlike other blockchain frameworks, these features of Hyperledger Fabric make it optimized for the purpose of supply chain digital transactions as less time and resources need to be dedicated to roll out these essential features. Channel-based privacy also modularizes transactions by providing independent ledgers for each channel to prevent unauthorized access to any transaction made within the blockchain network.

5.3.2 Processing of Transactions

When a transaction is initiated on firefly through the asset manager SwaggerUI, an *invoke* or *query* request is sent to Hyperledger fabric blockchain through Fabconnect (see Appendix D). Fabconnect is essentially a connector or a medium of connection between Hyperledger fabric and Hyperledger firefly, which forwards all the invoke requests from firefly to fabric, and responds by sending back an output to firefly. In a port congestion scenario, all the ports are occupied by various supply chain organizations. When these organizations and their corresponding containers are added to the Hyperledger fabric network, they can essentially be tracked and given priority based on the routes taken and type of verification needed.

5.3.3 Automation of verification process

Automation of verification process is implemented on an organization level using smart contracts. Whenever a transaction is initiated, the smart contract receives information about the organization that is trying to initiate the transaction, as well as data relevant to the organization towards which the transaction is being initiated. If the organization has given relevant permissions for both, then the smart contract approves the transaction and corresponding changes are made. For a user to get registered as an organizational entity, they have to initiate a request to register them as an organizational entity. This feature to register a third-party entity as an organization will grant all access to features and access privileges to organizations that wish to use the proposed framework. While the prototype does not implement this feature, this just demonstrates the ability to expand the functionality of the prototype as needed. In such a scenario, every organization will be given their own

user UI and separate ports, so that they can be differentiated and uniquely identified.

5.3.4 Consensus mechanism

In simple terms, consensus is a way of making sure that everyone agrees on the same information and the same order of events in a network comprising of different participants. Consensus is important for blockchain networks because they are decentralized, meaning that there is no central authority or leader to decide which is true or false. Hyperledger Fabric allows different participants to join a network and transact with each other using smart contracts. Hyperledger Fabric uses a modular and flexible approach to gaining consensus, which enables it to be configured to suit different needs and scenarios. Hyperledger Fabric does not have a single component or algorithm for reach a consensus but allows for a consensus mechanism to be chosen based on the operational context and needs. Raft orderer was the consensus mechanism used in the prototype to achieve consensus. Three main services are involved in the consensus mechanism, which include endorsing, ordering and validation services.

Endorsing service is responsible for checking and executing transactions proposed by users or client applications, it also takes care of sending back results and signatures to the clients, by adopting an endorsement policy that specifies the number of endorsing participants needed for a valid transaction (GitHub, 2023). *Ordering service* takes care of receiving transactions from different clients and batching them into blocks and delivering them to peers (nodes) in the network, by adopting an ordering policy that defines the criteria for ordering transactions to make sure that all peers get access to the same sequence of blocks. *Validation service* carries out the task of checking if transactions in a

block as per the updated ledger and endorsement policy, as well as updating the ledger accordingly.

By using these services and policies, Hyperledger Fabric achieves consensus in a way that is scalable, flexible, and customizable. Different participants can have different roles and permissions in the network, and different types of transactions can have different requirements for validation and ordering. Hyperledger Fabric also allows for pluggable implementations of these services, meaning that different algorithms or protocols can be used depending on the needs of the network.

5.3.5 Storage and retrieval

The blockchain is directly invoked through rest API to validate transactions and documents. This can be considered as primary storage where all the required data is retrieved directly from the blockchain by providing the container number. Alternatively, GetAllDocuments function can be used to access all the documents on the blockchain. The benefit of using this storage is that the information available is always updated, reliable and verified by all other members on the blockchain network. Besides that, it also provides security, since an organization check is performed to confirm whether a given organization has permissions to access the data. Apart from this, there is another form of data that contains all the information about changes made to these documents, which will be discussed in the following section.

Firefly is a web-based UI that contains all the transactions history and all the access information on an organization level. As observed earlier, there is a need for storing data pertaining to all the transactions, apart from the actual document data itself. This ensures security and prevents data from being accessed or manipulated by unregistered users

in an organization. Firefly UI offers various features to access all the data and transactions that occurred in the past in an easily understandable format. Thus, authorized users can refer to past transactions and understand all the changes made throughout the lifetime of a document.

5.3.6 Datasets

Various datatypes are used by the prototype to help convert or resolve all the physical package information and the data needed for verification and authorization. They contain all the necessary information to carry out the process of customs clearance and routing a container at a shipping port. The parameters were chosen in such a way that comprehensive information about a container is available to resolve port congestion (see Appendix B). In more practical terms, the function of a smart contract is to get all the relevant information about a container using a reference number (i.e. container number in this prototype) to authorize, verify, dispatch and control port traffic efficiently. SCAC stands for standard carrier alpha code is a unique 2-4 letter code used to identify transportation companies, while container number is used to identify a specific container that may be owned by any transportation company. Declaring the datatype helps to standardize the procedure of accumulation of all the information at one place and ease access of the data, which can eliminate a lot of physical work or data management.

Datasets used by the prototype are categorized into the following: *Chassis Number, Comment, Container Number, Discharge Port, Export Booking, Export SCAC, Import Delivery, Import SCAC, Loading Port, Reference Client, Reuse Date, SCAC code, Seal Number and Shipping Line* (Avantida, 2023). These datasets have been used in the smart contract to allow automation of transactions. These datasets can also be categorized based on their relevance to the supply chain system. The most

universal dataset is *Comment*, which involves special instructions and other specific details involving a specific package. Comments may include information related to items to indicate if they are perishable, fragile, or contain harmful chemicals to assure that necessary preparations can be taken.

In terms of logistics, there are two main modes of transportation that need to be taken into consideration, namely container ships and delivery vehicles. For decongesting ports, the main focus shifts to container ships as these have a greater impact on the volume of goods entering and being stored in ports. However, the direct delivery of packages to hubs and user locations from shipping containers also needs to be tracked as these relate to the monitoring of a package's arrival at the designated address. Datasets such as *Discharge Port*, *Loading Port*, *Export SCAC*, *Import SCAC*, and *SCAC code* help in determining the responsibility of shipping lines to transfer, load, and/or unload packages that have arrived or will leave the designated ports. The designation of SCAC code for service providers helps monitor the efficiency rate of each service provider to identify current gaps and bottlenecks in both import and export.

To support the forecasting of the expected volume of goods entering and leaving ports, datasets such as *Shipping Line*, *Reuse Date*, *Export Booking Date*, and *Import Delivery Date* provide reasonable timelines with respect to arrival and departure timelines for shipping containers to and from designated ports. These datasets directly impact port decongestion as the flow of packages within ports can be directly monitored through these data, which allows for the coordination of service providers and port authorities to improve overall efficiency in shipping from ports to delivery hubs and vice versa.

The *Container Number* and *Seal Number* correspond to the package's identifying code and security code, which is necessary for real-time tracking of the package's location and delivery status. Its counterpart for container ships would be the *Chassis Number*, which serves as the identifying number for each vessel. This dataset enables accountability and transparency within the blockchain network, particularly for end users to track and confirm receipt of a package. Furthermore, the *Reference Client* dataset allows users to know the service provider responsible for the delivery of a package.

5.4 Chapter Summary

This chapter begins with theoretical validation of the proposed framework by applying it to a real-world case study through conceptual analysis. This is followed by practical validation of the framework through prototype development. The entire process involved in the design and development of the prototype is detailed. This begins with the use case involving port decongestion and key stakeholders of the prototype. A discussion of rationale for blockchain network and technical stack choice was duly included. The development and deployment of the prototype was explained in detail. Various aspects of the design of the prototype such as key features prioritization using MoSCoW method, choice of programming language used in the smart contracts, datasets as well as the consensus mechanism used in the prototype were also covered.

Chapter 6

Results and Discussion

6.1 Functioning of Prototype

The prototype functionality allows end-users to create, update, delete, and retrieve documents related to port operations, while successfully recording these transactions onto the blockchain ledger. This core functionality is in line with the objective of streamlining processes susceptible to bottlenecks, as identified by Boison and Antwi-Boampong (2020), who emphasized the need for pragmatic blockchain solutions in SCM. Besides streamlining these processes, which is a recurring theme in SC literature (Treiblmaier, 2018), this system facilitates the management of documents pertaining to regulatory approvals, shipment manifests, and inspection reports. In terms of design and usability, Hyperledger Fabric Gateway APIs provide a secure mechanism for interacting with the blockchain, while Swagger UI offers a user-friendly interface for API testing. Authorized end-users can trigger actions via REST APIs that interact with smart contracts, ensuring seamless execution and blockchain transaction registration. This user-friendly approach is crucial for wider adoption of blockchain solutions, as noted by Khan et al. (2022b) regarding the need for accessible, user-focused solutions.

The deployed chaincode enables automation of document workflows, which is consistent with Batwa and Norrman's (2020) view of smart contracts as opportunities for integrating automation, lowering reliance on manual processes, and minimizing the risk of human error. Furthermore, Hyperledger Explorer provides a visual representation of blockchain transactions, enhancing transparency and accountability. This addresses a key demand in digital transactions, as highlighted by Xu et al.

(2021) concerning visibility and transaction logs. Figure 6.1 below depicts the processes involved in invoking a smart contract corresponding to the creation of a new document. From a researcher's perspective, the successful implementation of these functionalities indicates a tangible step toward realizing the potential of blockchain in enhancing operational efficiency and transparency in port operations. The system's design prioritizes user interaction and process automation, directly tackling some of the practical challenges hindering blockchain adoption in real-world SC scenarios.

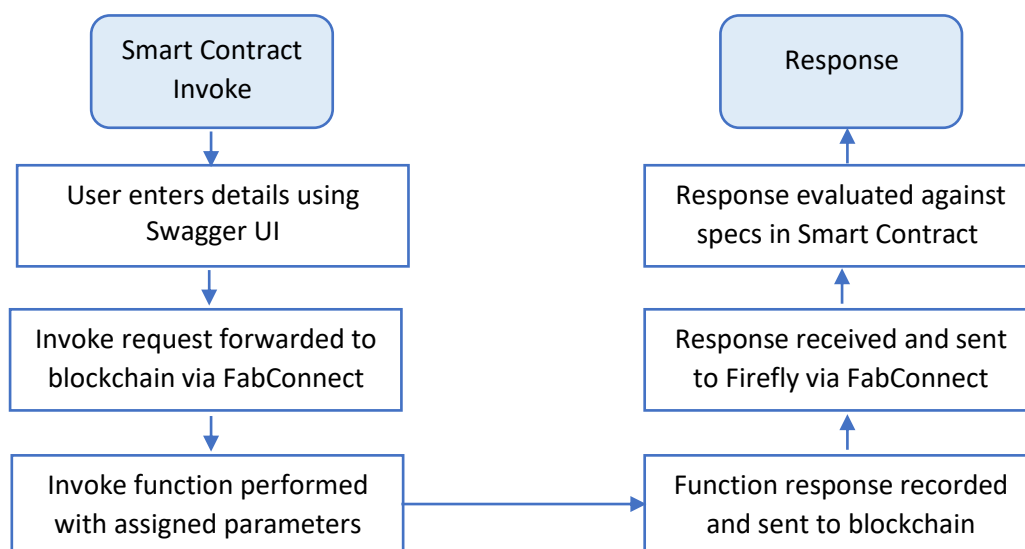


Figure 6.1 Smart contract - invoke function

When a smart contract function is invoked by the user through Swagger user interface, it is forwarded to the blockchain through FabConnect and relevant functions are performed as per user inputs. Figure 6.2 shows Swagger UI being used to access the CreateDocument function.

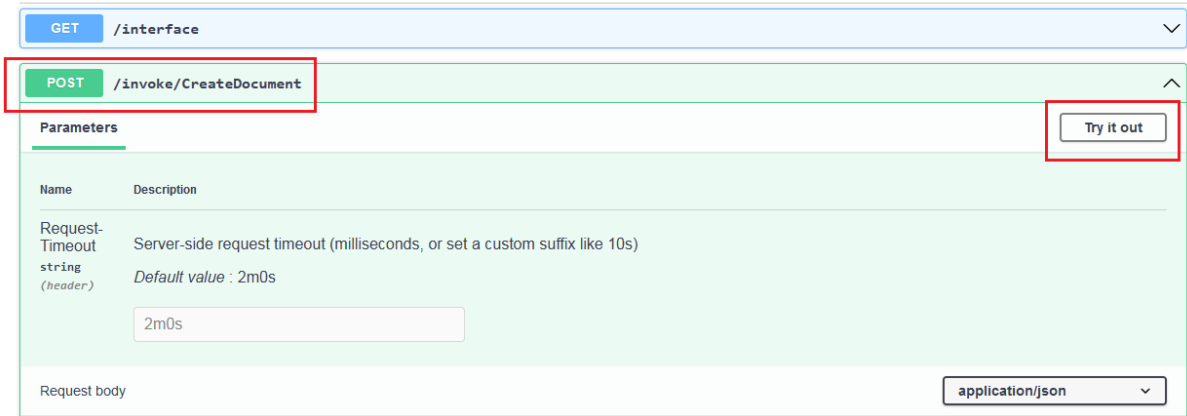


Figure 6.2 CreateDocument function accessed through Swagger UI

Following this, the response is evaluated and a consensus reached by Hyperledger Fabric, while it is recorded and stored by Hyperledger Firefly on to the central blockchain ledger. However, in the event of a user entering incorrect data outside of the acceptable parameters (e.g. incorrect container number), the smart contract invoke function fails. Figure 6.3 shows the Hyperledger Firefly Explorer user interface, which allows for monitoring of the blockchain's transactions, as it displays both successful and failed attempts. The central blockchain contains the stored data and also processes any changes initiated by an authorized user.

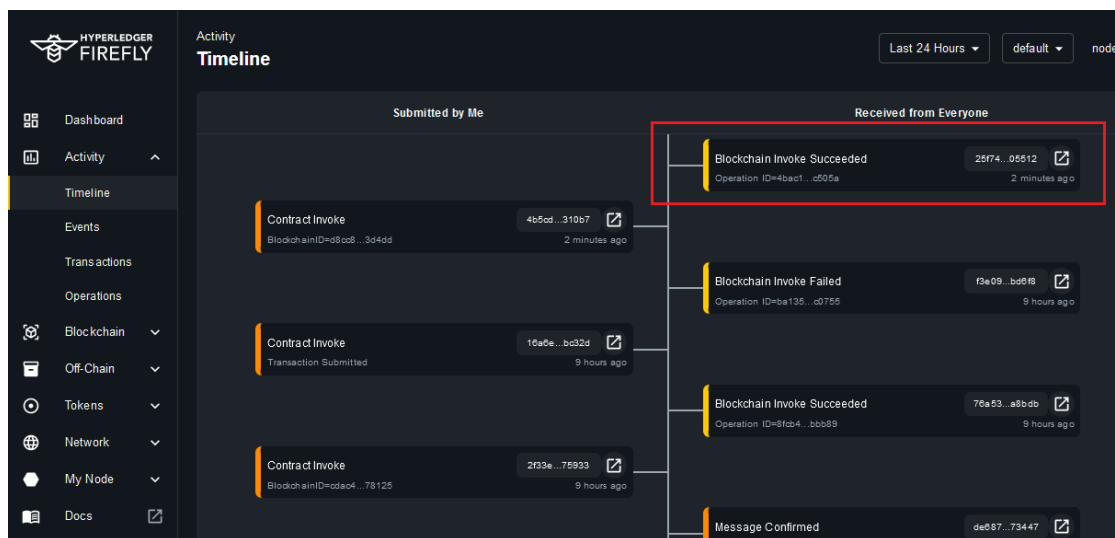


Figure 6.3 Hyperledger Firefly UI

Authorized users can keep track of changes made to the blockchain ledger using the Firefly UI. The system ensures the security and privacy of transactions by using channel-based privacy and MSP features of Hyperledger Fabric. This aligns with existing research that emphasize that permissioned blockchains like Hyperledger Fabric are crucial for managing sensitive data and regulatory compliance (Ravi et al., 2022). Besides that, it also enhances transparency and accountability of the transactions by using the public ledger and the consensus mechanism of Hyperledger Fabric. This combination of security and transparency inherent in the prototype's architecture addresses key concerns identified in the literature regarding blockchain's dual role in fostering trust and data protection within supply chains (Song et al., 2019). Therefore, the prototype effectively integrates user accessibility with robust backend operations, showcasing a practical application of blockchain technology capable of meeting the demand for both efficiency and security in port operations.

6.2 Functioning of consensus mechanism in prototype

While Hyperledger Fabric allows for a modular approach, the specific consensus mechanism used in this prototype is Raft orderer. This choice was made due to its resilience and fault tolerance (Harris, 2023). When the Create Document function is invoked, the following processes take place to reach a consensus.

- An HTTP request is sent to the /invoke endpoint of contract API, specifying the function name (create document) and the input parameters for the function, while credentials and signature are provided for authentication and authorization.
- FireFly validates this request and forwards it to the endorsing service of Hyperledger Fabric, which is responsible for checking

and executing transactions proposed by authorized users. The endorsing service follows the endorsement policy, which defines how many and which participants need to endorse a transaction for it to be valid.

- The endorsing service sends the request to the selected endorsing peers, which are nodes that have a copy of the smart contract and the ledger. The endorsing peers execute the create document function on their local copy of the ledger and produce a result as well as signature (i.e. endorsement). This endorsement is then sent back to the endorsing service.
- The endorsing service collects all the endorsements and checks if they satisfy the endorsement policy. If it does, it assembles them into a transaction proposal and sends it to the ordering service of Hyperledger Fabric, which is responsible for receiving transactions from different clients and batching them into blocks and delivering them to peers in the network. The ordering service follows the ordering policy, which defines how the transactions are ordered and who can participate in the ordering process. The ordering service ensures that all peers receive the same sequence of blocks.
- The ordering service sends the transaction proposal along with other transactions in a block to the validation service of Hyperledger Fabric, which is responsible for verifying if the transactions in a block are valid according to the endorsement policy and current state of the ledger. The validation service also updates the ledger with the new transaction and rejects any invalid ones.
- The validation service sends a confirmation message to FireFly, indicating whether the transaction was accepted or rejected. FireFly

then sends a confirmation message to the user, along with any relevant information such as transaction ID, block number, etc.

- FireFly also listens for events generated by the smart contract on Hyperledger Fabric, such as document created. FireFly translates these events into a standardized FireFly format (e.g. `blockchain_event_received`) and then broadcasts them to other nodes in the FireFly network. It is possible to subscribe to these events to receive notifications about changes in the ledger.

6.3 Performance Testing

Performance testing of the prototype was carried out using a combination of tools including Hyperledger Caliper, Prometheus and Grafana. Hyperledger Caliper was first set up to run performance tests, in order to measure latency and transaction throughput. Following this, the performance data generated by Caliper during the testing was extracted using a monitoring tool called Prometheus, which helps to gather metrics using an HTTP pull model. This extracted data was then sent via a push gateway to an analytics application called Grafana, which helps to generate graphs of the real-time data. This approach to performance testing ensures that authentic performance data is gathered and represented visually. Figure 6.4 shows the performance metric report generated by Hyperledger Caliper.



Caliper report

Basic information

DLT: fabric
Name: basic-contract-benchmark
Description: test benchmark
Benchmark Rounds: 1

Summary of performance metrics

Name	Succ	Fail	Send Rate (TPS)	Max Latency (s)	Min Latency (s)	Avg Latency (s)	Throughput (TPS)
readAsset	13318	0	223.4	0.07	0.01	0.01	223.4

Figure 6.4 Performance Metric Report

The report indicates a high success rate for transactions, as zero failed transactions were recorded. Furthermore, a throughput of 223.4 transactions per second with an average latency of 0.01 seconds indicates fairly good performance. The performance testing was conducted on a Core i5 system with 7.4 GB of usable memory. The testing process involved the creation of assets, which refers to writing new objects to the contract, which corresponds to peaks in memory and CPU consumption. Figure 6.5 below shows the testing results, indicating that the prototype consumed only 1 – 2.5% of CPU resources. Furthermore, Figure 6.6 indicates memory utilization showing that the prototype utilized between 115 – 135 MB of memory during the tests.

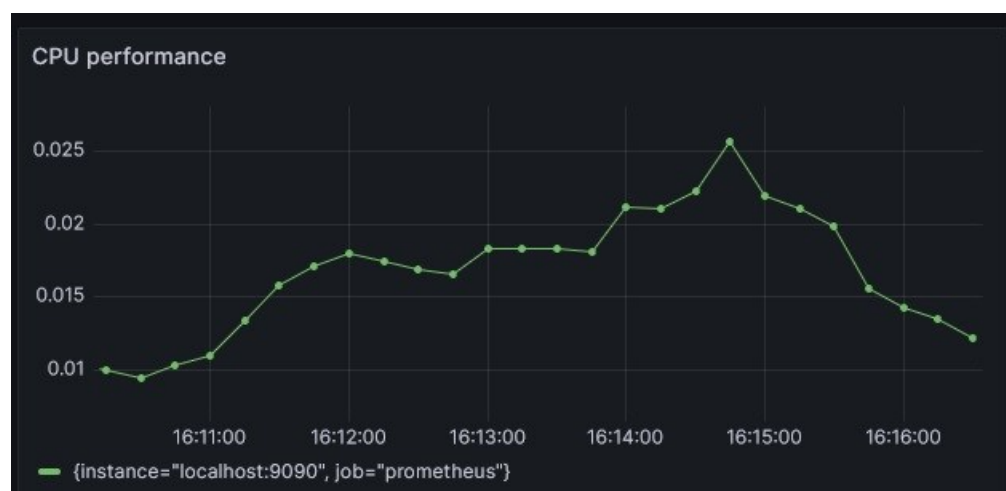


Figure 6.5 CPU Utilisation Graph

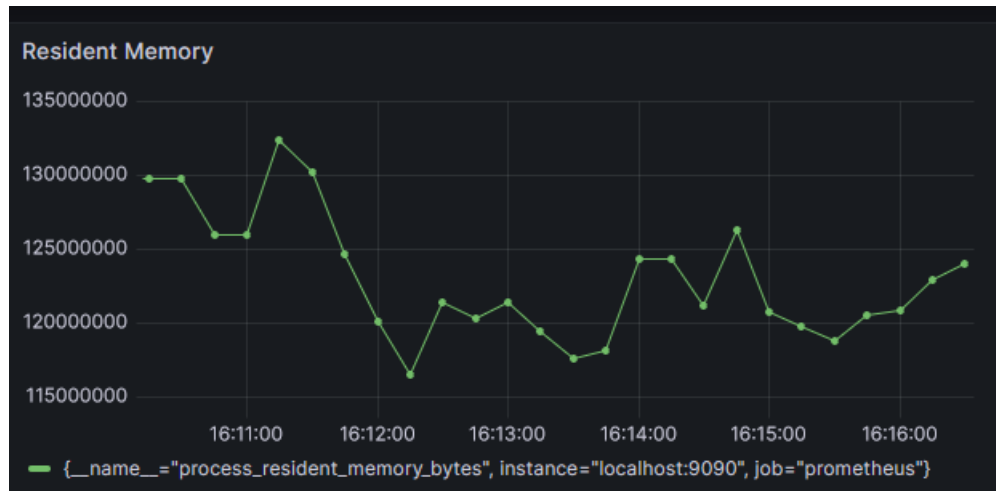


Figure 6.6 Memory Utilisation Graph

During the performance testing, a scenario involving two users simultaneously using the prototype was simulated to evaluate the total number of transactions submitted versus the number of successful transactions. Figure 6.7 shows a graph comparing submitted transactions versus finished transactions. This test indicated a peak throughput of 130 transactions per second, with a high success rate of almost all transactions being successfully finished.

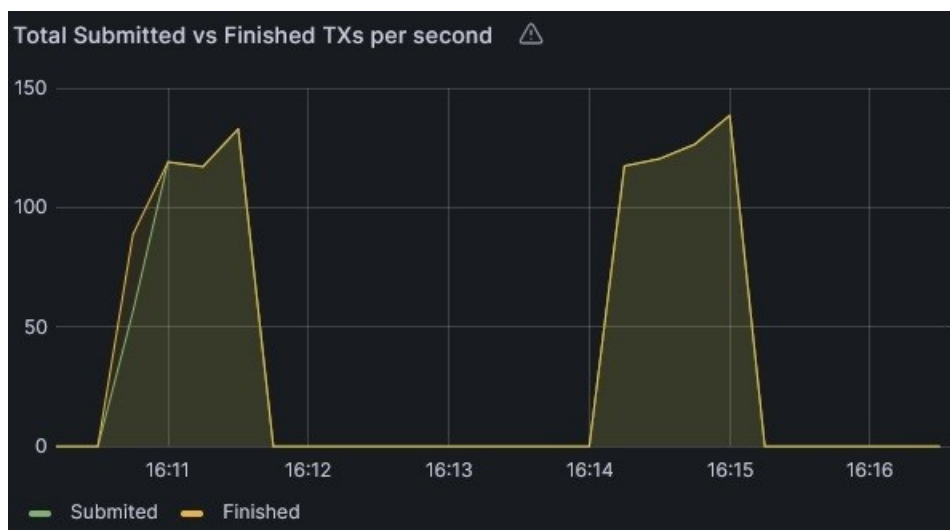


Figure 6.7 Submitted vs. Finished transactions performance graph

6.4 Evaluation of prototype

The decision to develop the prototype based on Hyperledger Fabric network and Hyperledger Firefly technical stack was instrumental in realizing blockchain integration within a short span of time, without compromising the key benefits of security, efficiency, immutability and transparency. Results of performance testing indicate relatively good performance metrics in terms of throughput and efficient resource utilization. It is hoped that this efficient approach would encourage supply chain organizations to integrate blockchain into their operations, dispelling fears of long integration times and delayed realization of benefits, thereby gaining the support of key stakeholders (Yadlapalli et al., 2022). Furthermore, this approach serves as a secure alternative to BaaS providers for supply chain organizations, as it keeps operations in-house and addresses data sovereignty concerns (Song et al., 2022). While the core functions implemented such as creating, editing, deleting and retrieving documents may seem simple on the surface, they can be applied to a number of port operations such as shipment manifests, inspection reports and regulatory approvals to optimize and automate a wide range of processes. The features included in this prototype target port decongestion by considering all critical datasets involved, thereby improving efficiency in processes related to document processing.

6.5 Prototype Limitations

The developed prototype currently addresses core functionalities and serves as a way to validate the framework. Therefore, it has only implemented basic functions as a proof of concept, rather than implementing all features necessary in an operational supply chain management system. While the results of performance testing and initial setup were quite satisfactory, real-world performance may vary based on

transaction volume and system demand. Future iterations could focus on more extensive scalability testing under varying load conditions and exploring resource auto-scaling mechanisms. While the prototype's UI is relatively easy to use, it may still present a considerable learning curve for new users as well as require expertise for initial deployment and management, which may be a barrier for organizations with limited in-house blockchain expertise .

In terms of the technology used, Hyperledger Fabric has a few inherent limitations such as a complex architecture and its network is not entirely fault-tolerant. While Raft consensus enhances fault tolerance, complete resilience requires careful network design and redundancy planning. Hyperledger Fabric also has relatively fewer APIs and SDKs, resulting in a lack of use cases compared to popular alternatives such as Ethereum. This was noticed in the process of integrating with existing port system, where the number of available APIs for interoperability were somewhat limited compared to more widely adopted blockchain platforms. While the architecture promotes scalability and no gas fees, it is still necessary for the system to operate with a sufficient number of nodes to allow transactions to be processed within the blockchain network. The prototype setup required a minimum number of nodes to achieve the performance metrics observed, implying that scalability benefits are contingent on maintaining an adequate node infrastructure, which has resource implications

While Hyperledger Fabric is cheaper to run than other networks, it is expected that costs will be relatively high as the use of blockchain is inherently resource-intensive. Despite the absence of gas fees in Hyperledger Fabric, operational costs related to infrastructure, maintenance and specialized personnel are still considerable and need to

be factored into a comprehensive cost-benefit analysis for long-term deployment.

6.6 Chapter Summary

This chapter details the functioning of the prototype developed in this research. It goes on to outline how the prototype development process is aligned with theoretical concepts of the proposed supply-blockchain framework. It also includes a discussion of testing functions of the prototype such as creating, editing and retrieving port-related documents. Following this, the performance testing of the prototype using Hyperledger Caliper was explained, and the underlying process involved such as gathering performance testing data using Prometheus, as well as generating data visualizations using Grafana was also covered.

Chapter 7

Conclusion and Future work

7.1 Conclusion

The integration of blockchain technology into logistics and supply chain operations is deemed revolutionary, promising enhancements in trust, efficiency and transparency. This research discerned substantial gaps within existing literature specifically, the complex and costly nature of blockchain implementation, compatibility issues with other technologies, and the security and privacy concerns intrinsic to blockchain networks. To address these gaps and limitations, this research proposed a unified supply-blockchain framework for integrating blockchain into logistics and supply chain services. This proposed framework builds upon and

simplifies the foundational elements of MOHBSChain, by allowing modular pre-defined contract templates for faster and more reliable deployment, which addresses the first research question. This framework strives for pragmatic and efficient resolutions, attuned to the diverse requisites of distinct supply chain systems, while harnessing the potential of smart contracts.

Applying the framework to a real-world case study helped to evaluate its theoretical underpinnings and theoretically validate the framework, which addresses the second research question. Developing a prototype for a port congestion scenario after determining the ideal combination of blockchain platform and technical stack helped to assess practical validity and implications of the proposed framework. The inference is unmistakable, as blockchain offers substantial advantages for logistics and supply chain services, contingent upon a holistic, tailor-made, and adaptable integration strategy. The framework encapsulates this importance, charting a promising trajectory for future research and operational implementations in this domain.

The results of this research demonstrate Hyperledger Fabric's potential to facilitate blockchain integration to alleviate inefficiencies in port document management. Hyperledger Fabric's permissioned nature along with Firefly's seamless integration facilitated creation of a solution meeting the security, transparency, and access control needs of various stakeholders. While chaincode developed using Go language was used to deploy smart contracts, Raft orderer consensus mechanism was deployed to facilitate resilience and fault tolerance necessary to carry out uninterrupted port operations. This combination of blockchain platform and technical stack helped to swiftly develop a functioning prototype, which addresses the third research question. Hyperledger Fabric's

modular architecture also offers significant flexibility for future adaptations and feature expansions.

Based on functional and performance testing, the prototype shows promising results in streamlining port document processes. However, in the context of real-world high-volume port operations, it's vital to recognize that blockchains have inherent limitations in terms of scalability. Future research can explore potential optimizations like off-chain data storage or alternative consensus mechanisms, to strike a balance between efficiency, security and scalability using simulation tools like BlockSim to model and analyze different scalability solutions.

Hyperledger Firefly builds upon the advantages of Hyperledger Fabric in shortening the time needed for BaaS integration to address existing problems. In the case of port decongestion, the choice of architecture based on Hyperledger Fabric and Firefly has allowed for a scalable prototype that meets the requirements of digitalizing shipping documents processed, approved, and verified by regulators. The modularity of Hyperledger Fabric as the basis for developing the prototype has proven to be useful in providing opportunities for the system to be tweaked to meet different demands and requirements that benefit various stakeholders.

The proposed framework explores the idea of standardizing how blockchain integration and adoption could be conducted not only for supply chains but also for other industries. The focus on addressing issues from a holistic perspective make this framework novel, and is an important aspect of capturing attention and building trust toward blockchain technology, particularly for other industries that need to heavily commit to changes for the transition to be successful. By providing both project management strategies and proposed blockchain architecture to support the implementation process, the proposed

framework delivers an initial blueprint to interested parties, this allows them to become aware of implicit factors that need to be taken into consideration for blockchain technology adoption, especially conventional industries that are usually late adopters of technology. Integrating agile approach into the supply-blockchain framework helped improve efficiency of blockchain integration, particularly for shortening the period needed to enjoy the perceived benefits.

7.2 Future Work

Future improvements to the prototype can potentially facilitate automation of approval processes based on predefined rules and compliance checklists, while IoT integration can facilitate real-time location tracking. For automating approval processes, rule engines like Drools or TensorFlow Decision Forests could be employed (Jin et al., 2021; Zarei & Faridnia, 2024). For IoT integration, platforms such as Azure IoT Hub or AWS IoT Core can be utilized to manage and integrate IoT devices (Alkhoori et al., 2021). While this research serves as a foundation showcasing feasibility of a Hyperledger Fabric-based solution to address challenges in congested ports, future efforts can explore incorporating cutting-edge blockchain technologies such as Non-Fungible Token (NFT) schemas, which can help improve traceability and ownership verification. This could be achieved using NFT standards like ERC-721 or ERC-1155, and platforms such as OpenZeppelin to implement and test NFT functionalities (OpenZeppelin, n.d.).

Future studies may also focus on the impact of the proposed framework for blockchain integration, particularly during the integration and implementation process. The unified supply-blockchain framework aids integration but does not emphasize key features required for greater effectiveness and impact. Once the overall initial success rate for

blockchain integration increases due to common issues being resolved more often, certain complex issues are expected to arise during deployment, which would require further improvements to the core framework to adapt to changing needs and demands of the supply chain environment.

In relation to the modularity of the prototype, future work that can be carried out to expand SCM features is quite expansive. Various features could be implemented to make the system more robust. One directly beneficial feature to stakeholders would be the automated review and approval of documentation using smart contracts. Since regulatory functions tend to follow a checklist, an algorithm for automating the review process of contracts with minimal human intervention is possible. It could be developed and tested using tools like IBM Watson Assistant or Google Dialogflow for natural language processing and rule-based automation within smart contracts (Rizk et al., 2020). Furthermore, automation deployed for the review process can also be augmented to create a tracking system that allows for increased transparency and visibility of package condition and status not only to shipping companies but also to consumers as well. The emphasis on improving the efficiency of ports remains an ever-evolving challenge, which can be addressed through the innovation and efficiency provided by AI and blockchain technologies.

Future research on blockchain frameworks for SCM could explore replicating best practices across existing processes or integrating innovations within the blockchain framework. Digitalization of supply chains through blockchain technology is viewed as the means to innovate existing practices, which means that theories and concepts arising from the technology is expected to be replicable and transferrable to other supply chain problems.

Another possible aspect for future studies would be to assess if it would be possible to arrive at an ideal framework that contains common features and strategies that are likely to fit existing practices and promote sustainability by being adaptable to various changes. Developing a basic yet robust framework that meets all essential needs and requirements of parties or users involved within a supply chain network would be essential to make blockchain integration more accessible to the public, which in turn would help push for more features to be included in newer iterations. The development of a basic framework would also help in standardizing the process of testing, thereby easing the process of integrating other allied technologies such as RFID and IoT into blockchain without compromising security, functionality, and accessibility for all users. For standardization and testing, frameworks like the NIST Blockchain Technology Program or Hyperledger Cello for on-demand blockchain network deployment could be explored to improve reliability and security (Sah et al., 2021; NIST, 2021).

7.2.1 Potential for AI integration

There are several opportunities to integrate AI and improve SCM as a whole, well beyond port decongestion. The confluence of AI and blockchain technology within supply chains enhances operational capacities, promoting sustainable development and facilitating data monetization (Tsolakis et al., 2023). This synergy is fortified by the establishment of AI marketplaces, leveraging blockchain for seamless buying and selling of AI services. Furthermore, their collaborative potential extends to the development of crowdsourced predictive models for investment management platforms (European Investment Bank, 2021). For instance, AI could be used to improve demand forecasting based on the volume of transactions made across different timeframes.

Studies have shown that AI applications have slowly leaned toward cloud computing to allow forecasting and business planning based on actionable data (Charles, Emrouznejad & Gherman, 2023). These trends could also be applied to supply chain management, particularly for port decongestion as the volume of transactions is susceptible to various social, economic, and political factors that are difficult to quantify. Tools such as Prophet or ARIMA models in Python could be used for time-series forecasting of transaction volumes, potentially leading to advancements in predictive SCM (Ensafi et al., 2022).

AI and blockchain also synergize well in RFID-driven contractual bidding for cartons (Berg, 2018). The integration of AI and blockchain technology presents an unprecedented opportunity for businesses to elevate supply chain performance. Blockchain provides a robust foundation for data recording across endpoints, complemented by AI's proficiency in data matching (Nethravathi et al., 2022). Leveraging blockchain to track and secure contracts, coupled with AI automating their execution, can enhance the efficiency and trustworthiness of supply chain processes in the near future (Sherin et al., 2023).

While this study does not deploy AI due to time and resource constraints, it briefly reviewed a few studies, existing applications, beta test features or prototypes that currently use AI in a blockchain-supply chain context. Alibaba managed to seamlessly fuse AI and blockchain on its Blockchain as a Service platform, revolutionizing supply chain logistics (Alibaba, 2023). This innovation optimizes order tracking, enhancing efficiency. Walmart, likewise, leverages AI and blockchain for superior food safety (Sristy, 2021), augmenting traceability and reducing trace time. DHL's Global Trade Barometer utilizes AI and blockchain (DHL, 2023) for predicting trade flows, collecting data that refines decision-making, operational efficiency, and anticipates supply chain

challenges. The data collected helps in making informed decisions, improving operations, and identifying potential issues in the supply chain.

The integration of AI and blockchain in supply chains can facilitate expansion of operational performance horizons, catalyze sustainable development and data monetization. This approach was empirically studied in the tuna fish supply chain in Thailand to identify respective end-to-end operations, observe material and data-handling processes, and envision the implementation of AI and blockchain (Tsolakis et al., 2023). This Thai tuna supply chain study's initial phase involved mapping business processes and system-level interactions to comprehend the governing material, data, and information flows, paving the way for a comprehensive understanding of the combined implementation of AI and blockchain in the supply chain.

The Abu Dhabi National Oil Company, in a pioneering move, has crafted a blockchain-infused automated system employing both blockchain and AI to streamline transactions, thereby reducing the temporal and financial burdens associated with manual processes (Kramer, 2021). Collaborative efforts from Maersk and IBM were made to integrate AI into maritime domain, but these efforts were with an untimely end due to insufficient client traction, as it was a bit ahead of its time. More recently, TradeLens, a global trade digitization platform conceived for modernizing the maritime domain, is a testament to the potent fusion of blockchain technology and supply chain dynamics, championing enhanced transparency and traceability (Ahmed & Rios, 2021).

AI-based modelling is a key component in building automated, intelligent, and smart systems, and can play a significant role in developing intelligent systems in various real-world applications including SCM (Sarker, 2022). Explainable Artificial Intelligence (XAI)

is an emerging field which is particularly relevant to high-stake decision-making environments (Rizzo et al., 2022). XAI provides a theoretical framework for explaining theoretical models, with properties of faithfulness and plausibility. The application of this framework simplifies how various parameters in a specific case scenario are conceptualized by AI. Therefore, such tools have a lot of potential to advance theory by applying AI techniques to analyze and synthesize data, generate and test hypotheses, and discover new patterns and insights (Tsolakis et al., 2023).

AI tools can thus apply theoretical models to case studies and to real-world scenarios across various fields. It can construct predictive models that anticipate future outcomes based on past data, a feature that can be harnessed in case studies to foresee trends, behaviors, and events. AI's ability to discern patterns and trends in extensive datasets, often overlooked by human analysts, is particularly beneficial in case studies with substantial data. For instance, Lee et al. (2021) used AI to predict performance outcomes by analyzing learning behaviors, while Yan (2023) explores the huge influence of AI in predicting financial performance, channels, and service methodologies. These instances highlight the versatile utilization of AI, showcasing its adaptability in addressing specific challenges within various domains including SCM.

Moreover, AI can simulate various scenarios and optimize results based on specific criteria, a valuable tool in case studies where decision-making is paramount. AI's capacity to analyze text data, interpret images and videos, and elucidate the findings of intricate models in a comprehensible manner further enhances its applicability in case studies. AI's potential lies in enhancing security, efficiency, and productivity within business landscapes marked by volatility, uncertainty, complexity, and ambiguity (Charles, Emrouznejad & Gherman, 2023). Notably, the supply chain is a significant beneficiary, experiencing improvements in

information and process resilience, faster delivery of products, and increased traceability.

7.3 Chapter Summary

This chapter summed up how the research successfully achieved its research objectives of developing a novel framework for blockchain integration in a supply chain context, applying it theoretically to a real-world case study, and finally validating it by developing a functional prototype for a specific use case. Taking a holistic perspective towards addressing various blockchain integration challenges in a supply chain context and facilitating quick deployment makes this framework novel. Finally, future work recommendations as well as several improvements through the integration of IoT, RFID and AI were suggested.

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APPENDICES

Appendix A. Information about chosen Technical Stack

Hyperledger Firefly

It is a developer toolkit used to simplify the creation of full stack decentralized applications. Firefly was chosen for deployment of the prototype, as it allows easy access to the smart contract and other blockchain features. A command line interface is typically used to interact with blockchain or deploy a frontend interface to test the prototype, whereas firefly acts as a medium between frontend node application and blockchain. This helps to simplify the process of creating a prototype based on the proposed architecture without much complexity. The key advantage of building a prototype on Firefly is that there is a lot of flexibility to make updates to the project. It also helps to speed up the process of building an actual working decentralized application from the skeleton of the prototype.

Hyperledger Fabric

This is a permissioned blockchain unlike Ethereum and other public blockchains where all the data or transactions are available and can be accessed by anyone in the network. Hyperledger Fabric is developed to build enterprise grade blockchain applications where all the users in the network are controlled by the application owner, while a transaction between one organization and another organization is performed through a private channel. Thus, the actual data/ parameters of the transactions are unknown to other users in the network unless they are given explicit access to the transactions. Hyperledger firefly communicates with fabric and returns the output to the client. As supply chain systems contain huge number of files that are confidential, automating the transactions will help

reduce port congestion, while keeping the data secure and confidential. This is the main criteria underlying the prototype developed for the proposed supply-blockchain framework using Hyperledger fabric.

Go Language

Go programming language is used to write the smart contract and also package it with the peer of Hyperledger fabric, to deploy in Hyperledger firefly. Although Hyperledger Fabric supports Go, JavaScript (NodeJS) and Java, Go language was chosen since Hyperledger was initially built for Go, while later updates were made to accommodate NodeJS and Java. Go is a simple, feature-rich, flexible and easily understandable language to develop smart contracts for developing web3 or decentralized applications.

Appendix B. Datatypes used in Smart Contract

- **Chassis Number:** This parameter identifies the specific chassis used to transport the container and helps in tracking the movement of containers, thereby reducing the time spent searching for a particular container in congested ports.
- **Comment:** This parameter provides additional information about the container or shipment, such as special handling instructions, which can help in streamlining the port operations and reducing the time taken to process the containers.
- **Container Number:** This parameter uniquely identifies the container and helps in tracking its movement through various stages of the shipping process, thereby reducing the likelihood of delays due to lost or misplaced containers.

- **Discharge Port:** This parameter identifies the port where the container is scheduled to be offloaded, enabling better planning and management of terminal operations and reducing the time taken to unload and process containers.
- **Export Booking:** This parameter provides details about the booking for the container's export, such as the shipping schedule, which helps in coordinating the movement of containers and reducing congestion at the port.
- **Export SCAC:** This parameter identifies the SCAC code of the shipping line responsible for exporting the container, enabling better coordination between the shipping line and the port authorities to reduce congestion and delays.
- **Import Delivery:** This parameter identifies the delivery location for the container's import, enabling better planning and coordination of terminal operations and reducing the time taken to process containers.
- **Import SCAC:** This parameter identifies the SCAC code of the shipping line responsible for importing the container, enabling better coordination between the shipping line and the port authorities to reduce congestion and delays.
- **Loading Port:** This parameter identifies the port where the container was loaded onto the vessel, helping to track the movement of containers, and enabling better coordination between the port authorities and shipping lines to reduce congestion and delays.
- **Reference Client:** This parameter provides details about the client who has booked the container, helping to streamline port

operations by enabling better communication and coordination between the port authorities, shipping lines, and clients.

- **Reuse Date:** This parameter identifies the date on which the container is scheduled to be reused, helping to manage the container inventory and reduce congestion at the port.
- **SCAC Code:** This parameter provides the SCAC code of the shipping line responsible for the container, helping to coordinate the movement of containers and reduce congestion at the port.
- **Seal Number:** This parameter identifies the seal number used to secure the container, enabling better tracking and management of container movements and reducing the likelihood of theft or tampering.
- **Shipping Line:** This parameter identifies the shipping line responsible for the container, enabling better coordination between the shipping line and port authorities to reduce congestion and delays.

```
type Document struct {  
    ChassisNumber string `json:"chassisNumber"`  
    Comment       string `json:"comment"`  
    ContainerNumber string `json:"containerNumber"`  
    DischargePort string `json:"dischargePort"`  
    ExportBooking  string `json:"exportBooking"`  
    ExportSCAC     string `json:"exportScac"`  
    ImportDelivery string `json:"importDelivery"`  
    ImportSCAC     string `json:"importScac"`  
    LoadingPort    string `json:"loadingPort"`  
    ReferenceClient string `json:"referenceClient"`  
    ReuseDate      string `json:"reuseDate"`  
    SCACCode       string `json:"scacCode"`  
    SealNumber     string `json:"sealNumber"`  
    ShippingLine   string `json:"shippingLine"`  
}
```

During the process of prototype development, containers are identified based on their unique container number, and thus documents are created for each container number. When a user requests creation of a document, the following form is generated.

```
{
  "input": {
    "chassisNumber": "CH12345",
    "comment": "This is a test comment.",
    "containerNumber": "CONT12345",
    "dischargePort": "Abu Dhabi",
    "exportBooking": "EXP123",
    "exportScac": "MSC",
    "importDelivery": "2023-04-15",
    "importScac": "MAEU",
    "loadingPort": "Shanghai",
    "referenceClient": "REF123",
    "reuseDate": "2023-05-01",
    "scacCode": "CMA",
    "sealNumber": "SEAL12345",
    "shippingLine": "Maersk"
  },
  "options": {}
}
```

Document datatype maps all the given inputs to the datatype structure, and stores the data in an array. Every function in the smart contract follows this datatype to understand the document and also make changes or display document.

Appendix C. Chaincodes corresponding to Prototype Functions

Invoke functions to make changes to data stored on the blockchain

C1. CreateDocument: This function is designed to create a new document on the blockchain.

```

// CreateDocument issues a new document to the world state with given details.
func (s *SmartContract) CreateDocument(ctx contractapi.TransactionContextInterface, scacCode
string, shippingLine string, dischargePort string, loadingPort string, containerNumber string,
exportBooking string, reuseDate string, referenceClient string, comment string, importDelivery
string, importScac string, exportScac string, chassisNumber string, sealNumber string) error {
    exists, err := s.DocumentExists(ctx, containerNumber)
    if err != nil {
        return err
    }
    if exists {
        return fmt.Errorf("the Document %s already exists",containerNumber)
    }

    asset := Document{
        SCACCode:    scacCode,
        ShippingLine: shippingLine,
        DischargePort: dischargePort,
        LoadingPort:  loadingPort,
        ContainerNumber: containerNumber,
        ExportBooking: exportBooking,
        ReuseDate:    reuseDate,
        ReferenceClient: referenceClient,
        Comment:      comment,
        ImportDelivery: importDelivery,
        ImportSCAC:   importScac,
        ExportSCAC:   exportScac,
        ChassisNumber: chassisNumber,
        SealNumber:   sealNumber,
    }
    assetJSON, err := json.Marshal(asset)
    if err != nil {
        return err
    }

    return ctx.GetStub().PutState(containerNumber, assetJSON)
}

```

C2. UpdateDocument: This function is designed to update an existing document on the blockchain using container number.

```
// UpdateDocument updates an existing Document in the world state with provided parameters.
func (s *SmartContract) UpdateDocument(ctx contractapi.TransactionContextInterface, scacCode
string, shippingLine string, dischargePort string, loadingPort string, containerNumber string,
exportBooking string, reuseDate string, referenceClient string, comment string, importDelivery
string, importScac string, exportScac string, chassisNumber string, sealNumber string) error {
    exists, err := s.DocumentExists(ctx, containerNumber)
    if err != nil {
        return err
    }
    if !exists {
        return fmt.Errorf("the document %s does not exist", containerNumber)
    }

    // overwriting original asset with new asset
    asset := Document{
        SCACCode:    scacCode,
        ShippingLine: shippingLine,
        DischargePort: dischargePort,
        LoadingPort:  loadingPort,
        ContainerNumber: containerNumber,
        ExportBooking: exportBooking,
        ReuseDate:    reuseDate,
        ReferenceClient: referenceClient,
        Comment:      comment,
        ImportDelivery: importDelivery,
        ImportSCAC:   importScac,
        ExportSCAC:   exportScac,
        ChassisNumber: chassisNumber,
        SealNumber:   sealNumber,
    }
    assetJSON, err := json.Marshal(asset)
    if err != nil {
        return err
    }
    return ctx.GetStub().PutState(containerNumber, assetJSON)
}
```

C3. DeleteDocument: This function is used to delete an existing document using container number.

```
// DeleteAsset deletes an given asset from the world state.
func (s *SmartContract) DeleteDocument(ctx contractapi.TransactionContextInterface, scacCode
string) error {
    exists, err := s.DocumentExists(ctx, containerNumber)
    if err != nil {
        return err
    }
    if !exists {
        return fmt.Errorf("the Document %s does not exist", containerNumber)
    }

    return ctx.GetStub().DelState(scacCode)
}
```

Query functions sends a query to the blockchain and requests for information

C4. GetAllDocuments: This function is used to retrieve all the documents on the blockchain.

```
// GetAllDocuments returns all assets found in world state
func (s *SmartContract) GetAllDocuments(ctx contractapi.TransactionContextInterface)
([]*Document, error) {
    // range query with empty string for startKey and endKey does an
    // open-ended query of all assets in the chaincode namespace.
    resultsIterator, err := ctx.GetStub().GetStateByRange("", "")
    if err != nil {
        return nil, err
    }
    defer resultsIterator.Close()

    var assets []*Document
    for resultsIterator.HasNext() {
        queryResponse, err := resultsIterator.Next()
        if err != nil {
```

```

        return nil, err
    }
    var asset Document
    err = json.Unmarshal(queryResponse.Value, &asset)
    if err != nil {
        return nil, err
    }
    assets = append(assets, &asset)
}
return assets, nil
}

```

C5. ReadDocument: This function is used to read a particular document by using its container number.

```

// ReadDocument returns the document stored in the world state with given ScacCode.
func (s *SmartContract) ReadDocument(ctx contractapi.TransactionContextInterface, scacCode
string) (*Document, error) {
    assetJSON, err := ctx.GetStub().GetState(containerNumber)
    if err != nil {
        return nil, fmt.Errorf("failed to read from world state: %v", err)
    }
    if assetJSON == nil {
        return nil, fmt.Errorf("the document %s does not exist", containerNumber)
    }

    var asset Document
    err = json.Unmarshal(assetJSON, &asset)
    if err != nil {
        return nil, err
    }

    return &asset, nil
}

```

C6. DocumentExists: This function is used to check if a document corresponding to a container number exists on the blockchain or not.

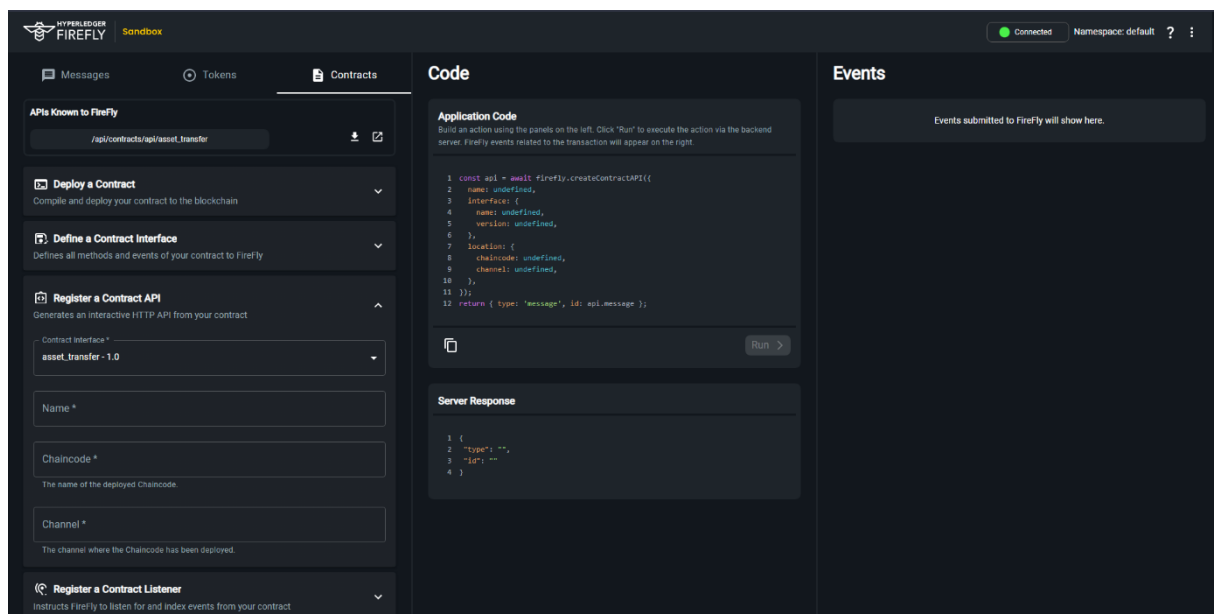
```
// DocumentExists returns true when Document with given ID exists in world state
func (s *SmartContract) DocumentExists(ctx contractapi.TransactionContextInterface, scacCode
string) (bool, error) {
    assetJSON, err := ctx.GetStub().GetState(containerNumber)
    if err != nil {
        return false, fmt.Errorf("failed to read from world state: %v", err)
    }

    return assetJSON != nil, nil
}
```

Appendix D. Interfaces of the Prototype

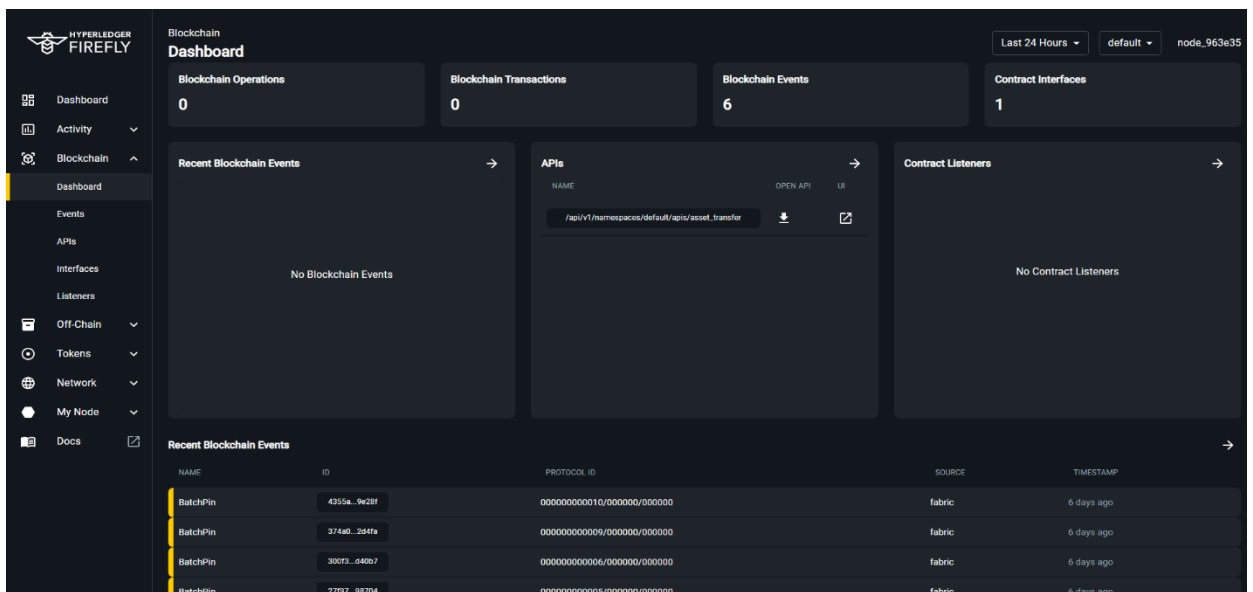
D1. Sandbox UI

This user interface is used for sending public and private messages across the blockchain, and to deploy contract interfaces and register API.



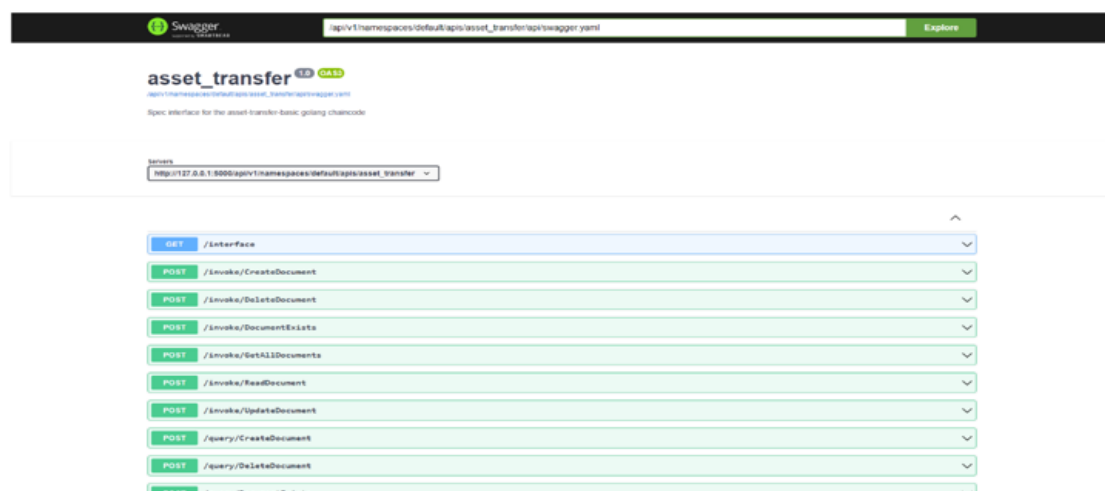
D2. Firefly Dashboard User UI

This is where a user can access all the blockchain transactions that occur within an organization as well as on a global level. For example, whenever the document pertaining to a specific container is created, updated or deleted, this data is updated in ledgers across organizations, thereby allowing these transactions to be accessed from anywhere.



D3. Asset Transfer API

The interface helps to interact with the smart contract.

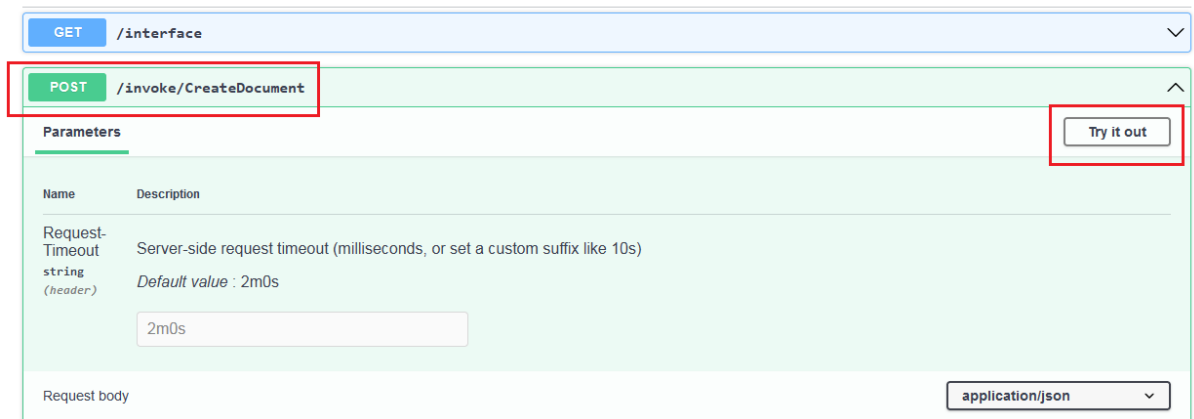


Appendix E. Prototype Functions

Go to Swagger UI (Asset Transfer API) to interact with the prototype

Function #1: **CreateDocument**: This function allows creation of documents that are required for the verification of containers. Creating this document helps to reduce port congestion, as automation of the process reduces the time involved in carrying out manual work.

- Go to **Post/invoke/CreateDocument** and click on the arrow button to expand
- Click on **Try it out**



GET /interface

POST /invoke/CreateDocument

Try it out

Parameters

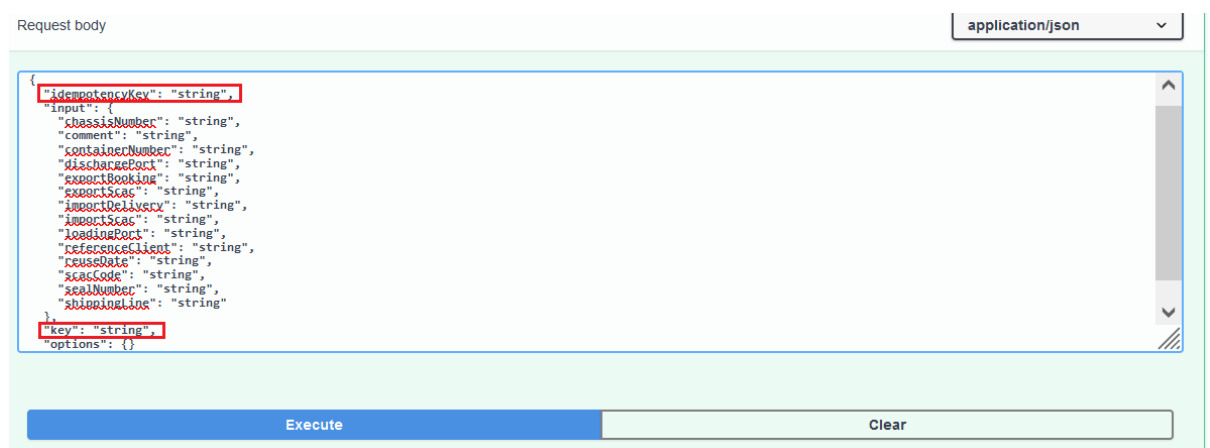
Name	Description
Request-Timeout	Server-side request timeout (milliseconds, or set a custom suffix like 10s)
string (header)	Default value : 2m0s

2m0s

Request body

application/json

- Now inside Request body, remove (delete) the following:
 - "idempotencyKey": "string"
 - "key": "string",



Request body

application/json

```
{
  "idempotencyKey": "string",
  "input": {
    "chassisNumber": "string",
    "comment": "string",
    "containerNumber": "string",
    "dischargeDoc": "string",
    "exportBooking": "string",
    "exportISAC": "string",
    "importDelivery": "string",
    "importISAC": "string",
    "loadingPort": "string",
    "releaseStatus": "string",
    "releaseDate": "string",
    "statusCode": "string",
    "sealNumber": "string",
    "shippingLines": "string"
  },
  "key": "string",
  "options": {}
}
```

Execute Clear

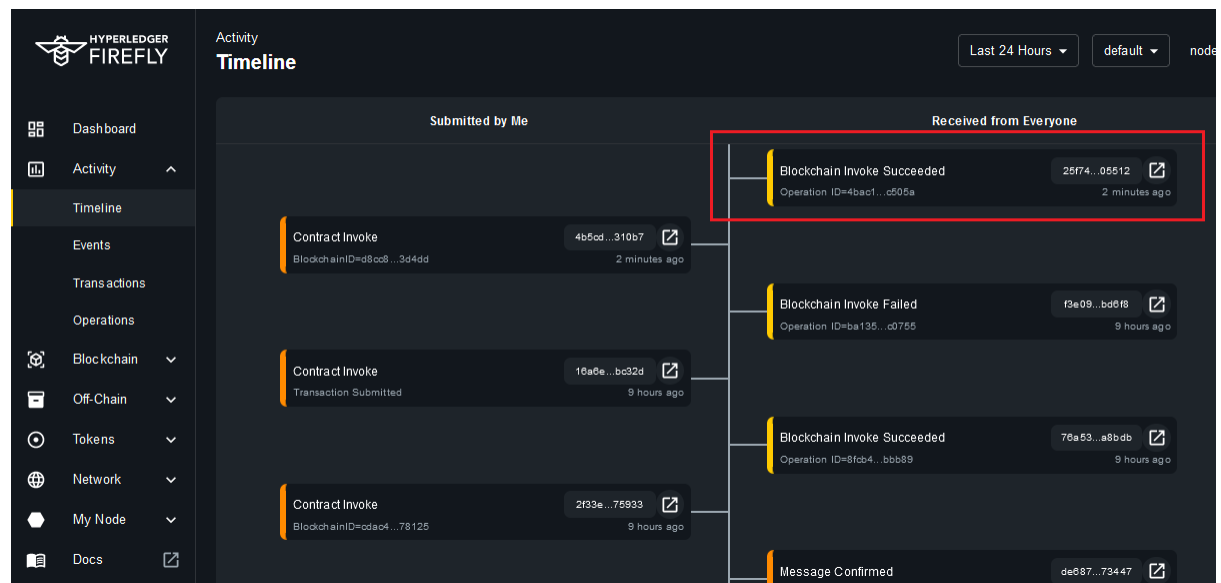
- **Enter the data** for the document (such as shipping container, etc.) in the Request body and Click **Execute**

When a smart contract function is invoked by the user through Swagger user interface, it is forwarded to the blockchain through FabConnect and relevant functions are performed as per user inputs. Following this, the response is evaluated and a consensus reached by Hyperledger Fabric, while it is recorded and stored by Hyperledger Firefly on to the central blockchain ledger. However, in the event of a user entering incorrect data outside of the acceptable parameters (e.g. incorrect container number), the smart contract invoke function fails.

Response

In response to the invoke request, a new document is created with the data entered, and can be viewed in the Response body.

This recently completed transaction can be also verified on the Firefly Activity Dashboard UI:



Function #2: **ReadDocument**: This function allows a user to get information regarding a particular document using container number as a parameter. Whenever an authentication or verification needs to be performed, the particular document can be directly accessed by entering the container number, instead of searching for it in the whole ledger.

- Go to **Post/invoke/ReadDocument** and click on the arrow button to expand
- Click on **Try it out**
- Now inside Request body, remove (delete) the following:
 - "idempotencyKey": "string"
 - "key": "string",

- **Enter the container number** of the document that needs to be viewed, and Click **Execute**

POST

/invoke/ReadDocument

Parameters

Cancel

Reset

Name	Description
Request-Timeout string (header)	Server-side request timeout (milliseconds, or set a custom suffix like 10s) 2m0s

Request body

application/json

```
{
  "input": {
    "contentType": "string"
  },
  "options": {}
}
```

Execute

Response

The document (and its details) corresponding to the entered container number are displayed:

Code	Details	
200	Response body <pre>{ "chassisNumber": "12345", "comment": "container info", "containerNumber": "12345678", "dischargePort": "1234", "exportLoading": "5678", "exportscac": "1234", "importDelivery": "1234", "importscac": "5678", "loadingPort": "1234", "referenceClient": "1234", "reusate": "01012024", "scacCode": "1234", "sealNumber": "5678", "shippingLine": "1234" }</pre>  Download Response headers <pre>access-control-allow-credentials: true access-control-allow-origin: * content-length: 321 content-type: application/json date: Mon, 01 May 2023 15:48:47 GMT vary: Origin</pre>	
Responses		
Code	Description	Links
200	Success	No links

Function #3. **GetAllDocuments**: This function allows access to all the documents that exist on the blockchain. When a user wants to go through all the containers that are active, this function can be used.

- Go to **Post/query/GetAllDocuments** and click on the arrow button to expand
- Click on **Try it out**
- Now inside Request body, remove (delete) the following:
 - "idempotencyKey": "string"
 - "key": "string",
- Click **Execute**

POST /query/GetAllDocuments

Parameters Cancel Reset

Name	Description
Request-Timeout string (header)	Server-side request timeout (milliseconds, or set a custom suffix like 10s)

Request body application/json

```
{
  "input": {},
  "options": {}
}
```

Execute Clear

Response

All the documents on the blockchain and their corresponding information are displayed in the response body.

200

Response body

```
[
  {
    "chassisNumber": "1234",
    "comment": "Container info",
    "containerNumber": "12345678",
    "dischargePort": "1234",
    "exportBooking": "5678",
    "exportscac": "1234",
    "importDelivery": "1234",
    "importscac": "5678",
    "loadingPort": "1234",
    "referenceClient": "1234",
    "reuscha": "40812004",
    "scacCode": "1234",
    "sealNumber": "5678",
    "shippingLine": "1234"
  },
  {
    "chassisNumber": "1234",
    "comment": "1234",
    "containerNumber": "1244567",
    "dischargePort": "1234",
    "exportBooking": "1234",
    "exportscac": "1234",
    "importDelivery": "1234",
    "importscac": "1234",
    "loadingPort": "1234"
  }
]
```

Response headers

```
access-control-allow-credentials: true
access-control-allow-origin: *
content-length: 628
content-type: application/json
date: Mon, 01 May 2023 16:03:52 GMT
vary: Origin
```

Responses

Code	Description	Links
200	Success	No links

Function #4. **DocumentExists**: This function is useful to check whether the document corresponding to a container exists on the blockchain or not. For example, if user wants to check if a container is in use or empty, this function can be used.

- Go to **Post/query/DocumentsExists** and click on the arrow button to expand
- Click on **Try it out**
- Now inside Request body, remove (delete) the following:
 - "idempotencyKey": "string"
 - "key": "string",
- **Enter the container number** of the document that needs to be checked if it exists, and then Click **Execute**

Request body

application/json

```
{  "input": {    "containerNumber": "1"  },  "options": {}}
```

Execute

Responses

Response

If the document corresponding to the entered container number exists, the message “**true**” is displayed in the Response body. However, if the document does not exist, the message “**false**” would be displayed.

Responses

Curl

```
curl -X 'POST' \
  'http://34.93.27.189:5000/api/v1/namespaces/default/apis/asset_transfer/query/DocumentExists' \
  -H 'accept: application/json' \
  -H 'Request-Timeout: 2m0s' \
  -H 'Content-Type: application/json' \
  -d '{
    "input": {
      "containerNumber": "1"
    },
    "options": {}
  }'
```

Request URL

http://34.93.27.189:5000/api/v1/namespaces/default/apis/asset_transfer/query/DocumentExists

Server response

Code	Details
200	Response body true Response headers <pre>access-control-allow-credentials: true access-control-allow-origin: * content-length: 5 content-type: application/json date: Thu, 20 Jun 2023 10:27:24 GMT</pre>

Function #5. **UpdateDocument**: This function allows a user to update information in an existing document. For example, if a container has finished its delivery and ready to be used for another delivery or any other parameter has to be changed, this function can be used.

- Go to **Post/invoke/UpdateDocument** and click on the arrow button to expand
- Click on **Try it out**
- Now inside Request body, remove (delete) the following:
 - "idempotencyKey": "string"
 - "key": "string",
- **Enter the container number** of the document that needs to be updated, along with details of parameters that have to be updated, and then Click **Execute**

Parameters

CancelReset

Name	Description
Request-Timeout	Server-side request timeout (milliseconds, or set a custom suffix like 10s)
string (header)	2m0s

Request body

application/json

```

{
  "input": {
    "chassisNumber": "dudu",
    "comment": "dud",
    "containerNumber": "1",
    "dischargePort": "dsdas",
    "exportBooking": "sdsad",
    "exportScac": "sdsad",
    "importDelivery": "sdsad",
    "importScac": "sdaas",
    "loadingPort": "dudfas",
    "referenceClient": "sdsd",
    "reuseDate": "dsdas",
    "scacCode": "string",
    "sealNumber": "string",
    "shippingLine": "string"
  },
  "options": {}
}

```

Execute

Response

The parameters of the document are updated with the new details entered.

Code

Details

202

Response body

```

{
  "id": "f2392154-3772-46fc-a78e-793d448a7647",
  "namespace": "default",
  "tx": "a5a8d08-c25c-4d08-bf2b-60feb13754ba",
  "type": "blockchain_invoke",
  "status": "Pending",
  "plugin": "Fabric",
  "input": {
    "input": {
      "chassisNumber": "dudu",
      "comment": "dud",
      "containerNumber": "1",
      "dischargePort": "dsdas",
      "exportBooking": "sdsad",
      "exportScac": "sdsad",
      "importDelivery": "sdsad",
      "importScac": "sdaasx",
      "loadingPort": "dudfas",
      "referenceClient": "sdsd",
      "reuseDate": "dsdas",
      "scacCode": "sdsd",
      "sealNumber": "sdsad",
      "shippingLine": "sdf"
    }
  },
  "interface": "1d7c169f-d912-4b00-a5ff-0018ccb1632c",
  "key": "Org1MSP:x509::CN=org_92db8d,OU=client::CN=fabric_ca.org1.example.com,OU=hyperledger FireFly,OU=org1.example.com,L=Raleigh,ST=North Carolina,C=US",
  "location": {
    "chainCode": "asset_transfer",
  }
}

```

Download

Response headers

```

access-control-allow-credentials: true
access-control-allow-origin: *
content-length: 1839
content-type: application/json
date: Thu, 20 Apr 2023 19:33:17 GMT
vary: Origin

```

Responses

Note: these recent changes can also be verified by using ReadDocument or GetAllDocuments function.

Function #6. **DeleteDocument**: This function enables a document on the blockchain to be deleted. If a container has been delivered successfully, or is not going to be used anymore for any reason, the corresponding document can be deleted. This will indicate that there is an empty space

in port, which can help in dynamically allocating ports to solve port congestion.

- Go to **Post/invoke/DeleteDocument** and click on the arrow button to expand
- Click on **Try it out**
- Now inside Request body, remove (delete) the following:
 - "idempotencyKey": "string"
 - "key": "string",
- **Enter the container number** of the document that needs to be deleted, and Click **Execute**

POST /invoke/DeleteDocument

Parameters

Cancel Reset

Name	Description
Request-Timeout	Server-side request timeout (milliseconds, or set a custom suffix like 10s)
string (header)	2m0s

Request body

application/json

```
{
  "input": {
    "containerNumber": "string"
  },
  "key": "string",
  "options": {}
}
```

Execute

Response

The document corresponding to the container number entered is now removed from the blockchain.

202

Response body

```
{
  "containerNumber": "12345678",
  "key": "string",
  "options": {}
}
```

Response headers

```
access-control-allow-credentials: true
content-length: 911
content-type: application/json
date: Tue, 20 May 2023 09:22:23 GMT
vary: Origin
```

Responses

Code	Description	Links
200	Success	No links

Note: ReadDocument, GetAllDocuments and DocumentExists can also be used to check if the document has been deleted. The successful execution of the function can also be verified on the Firefly Activity Dashboard UI.

ملخص الدراسة

لا تزال الاختناقات وانعدام الكفاءة التشغيلية في سلاسل التوريد قائمة على الرغم من الابتكارات التكنولوجية، وذلك بسبب القضايا الهيكلية والإدارية. يقدم تكامل blockchain حلاً قابلاً للتطبيق لهذه المشكلات طويلة الأمد من خلال تقديم دفاتر مقاومة للتلاعب ومعاملات آمنة وقدرات الأتمتة. يتخذ هذا البحث نهجاً جديداً من خلال تصميم إطار تكامل blockchain لسلاسل التوريد، وتعديل إطار MOHBSCChain لإنشاء إطار Supply-Blockchain. يتم التحقق من صحة هذا الإطار من خلال تطوير نموذج أولي وظيفي باستخدام Hyperledger Fabric، من خلال النظر في سيناريو حالة استخدام إزالة الازدحام في الموانئ. اعتمد هذا البحث نهجاً استقرائياً، بدءاً من الملاحظات غير الرسمية لعمليات الموانئ في العالم ومراجعة الأدبيات المستهدفة لتحديد الأنماط والتحديات. تم توجيه تطوير الإطار بمبادئ اقتصاديات تكلفة المعاملات، والنظرة القائمة على الموارد، ونشر نظريات الابتكار. تم استخدام طريقة MoSCoW لإعطاء الأولوية للميزات، في حين تم اعتماد إدارة المشروع الرشيق لضمان الإنجاز في الوقت المناسب. تم استخدام Hyperledger Firefly وإطار عمل الموصل الخاص به كبرنامج وسيط لتسهيل تكامل blockchain، في حين تم استخدام chaincode الذي تم تطويره باستخدام لغة Go ونشره لتنفيذ العقود الذكية. تم اختيار آلية إجماع Raft orderer لضمان المرونة والتسامح مع الأخطاء. من وجهة نظر الوظائف الأساسية، يسمح النموذج الأولي ببدء العقود الذكية المقابلة لوظائف مثل إنشاء وتحرير المستندات المتعلقة بعملية سلسلة التوريد، وتقليل التدخلات اليدوية وتعزيز الكفاءة للحد من ازدحام الموانئ. كما يوفر تتبعاً مباشراً لمعاملات blockchain، مما يسهل الشفافية والإشراف، وتضمن الطبيعة المسموح بها لـ Hyperledger Fabric الأمان وضوابط الوصول القوية. كانت نتائج الاختبارات الوظيفية والأداء التي أجريت باستخدام Hyperledger Caliper و Prometheus و Grafana مرضية، وهذا يشير إلى إمكانات النموذج الأولي في تخفيف الاختناقات في سلاسل التوريد وتقديم الفوائد بسرعة لأصحاب المصلحة الرئيسيين مثل سلطات الموانئ وموظفي الجمارك وممثلي خطوط الشحن ومقدمي الخدمات اللوجستية. من حيث القيود، يقتصر النموذج الأولي على الوظائف الأساسية ويفتقر إلى الميزات المتقدمة المطلوبة لتلبية المعايير التشغيلية والتنظيمية. يمكن أن تركز التحسينات المستقبلية على دمج الذكاء الاصطناعي لمهام مثل التحليلات التنبؤية والتحقق الآلي من المستندات، في حين يمكن للتقنيات مثل المخططات القائمة على NFT تعزيز التحقق من الملكية وتحسين تتبع الأصول.

جامعة البحرين

كلية تقنية المعلومات



إطار عمل لدمج تقنية البلوكشين في الخدمات اللوجستية وسلسلة التوريد

أطروحة مقدمة كجزء من متطلبات الحصول على درجة الدكتوراه في علوم الحوسبة والمعلومات

إعداد

بداح علي الخالدي

٢٠٢٠٠٠٠٢٨

إشراف

أ. علاء الدين العمري

(أستاذ)

جامعة البحرين

مملكة البحرين

نوفمبر ٢٠٢٤