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Use of Blockchain Technology in Business Operations

Master's Thesis by the 2nd year student — Anton S. Petukhov

Research advisor: Senior Lecturer, Vitaly L. Okulov

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ЗАЯВЛЕНИЕ О САМОСТОЯТЕЛЬНОМ ХАРАКТЕРЕ ВЫПОЛНЕНИЯ ВЫПУСКНОЙ КВАЛИФИКАЦИОННОЙ РАБОТЫ

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ABSTRACT

Master Student's Name	Petukhov Anton
Academic Advisor's Name	Senior Lecturer Vitaly L. Okulov
Master Thesis Title	Use of Blockchain Technology in Business Operations
Description of the goal, tasks and main results the research	The goal is to develop a standardized approach implementing decentralized public blockchain technology in companies operating in the food industry, particularly those with complex supply chains. This includes evaluating an alternative to potentially bug-prone private blockchains, which are recognized as obstacles for many businesses considering the adoption of blockchain systems. The focus will be on implementing systems on public blockchains, which not only provide comparable features, but also ensure heilighted levels of security and transparency. The objectives of the thesis are summarized as follows: Evaluate implementation of a decentralized, public blockchain technology in companies requiring streamlined business processes. The case study of CP Foods company is utilized as an example to assess the effectiveness of the approach. Offer a more available solution for companies with sophisticated supply chain processes looking to adopt blockchain technology. Develop a roadmap to promote the integration of public blockchain platforms into supply chain management, aiming to encourage the adoption of secure and transparent decentralized blockchain systems by addressing the obstacles associated with private blockchains. The implementation of open-source public blockchain system on a case study serves as a comprehensive roadmap for other companies in the industry aiming to streamline their business operations. The proposed system leverages the potential of the Polygon blockchain by thoroughly defining all elements and factors involved in supply chain management and establishing connections between relevant entities and their corresponding tokens and addresses.
Keywords	Blockchain, Smart Contract, Consensus, Private Blockchain, Public Blockchain, Charoen Pokphand Foods

АННОТАЦИЯ

Автор	Петухов Антон Сергеевич
Научный руководитель	Старший преподаватель Окулов Виталий Леонидович
Название ВКР	Использование технологии блокчейн в бизнес-операциях
Описание цели, задач и основных результатов исследования	Целью исследования является разработка стандартизированнного подхода к внедрению децентрализованной публичной технологии блокчейн в компаниях, работающих в пищевой промышленности, особенно в компаниях с комплексными цепочками поставок. Основное внимание уделено внедрению систем на публичных блокчейнах, которые предлагают более высокую безопасность и в то же время более экономически эффективные решения. Задачи работы сводятся к следующему: Оценить внедрение децентрализованной публичной технологии блокчейн в компаниях, нуждающихся в упорядочении бизнес-процессов. В качестве примера для оценки эффективности подхода будет использован пример компании CP Foods. Предложить более доступное решение для компаний со сложными процессами цепочки поставок, желающих внедрить технологию блокчейн. Разработать дорожную карту по интеграции публичных блокчейн-платформ в процессы цепочки поставок, чтобы стимулировать внедрение безопасных и проверенных децентрализованных блокчейн-систем. Рассмотренный вариант реализации публичной блокчейн-системы с открытым исходным кодом на примере CP Foods может служить комплексным планом для других компаний отрасли, стремящихся упорядочить свои бизнес-операции. Предлагаемая система базируется на платформе Polygon и учитывает элементы, звенья и процессы цепочки поставок, а также устанавливает связь между соответствующими токенами и адресами.
Ключевые слова	Блокчейн, смарт-контракт, консенсус, приватный блокчейн, публичный блокчейн, Charoen Pokphand Foods

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List of Abbreviations

CP Foods – Charoen Pokphand Foods

DApp – Decentralized application

dBFT – Delegated Byzantine Fault Tolerance (Consensus mechanism)

dPOS – Delegated Proof of Stake (Consensus mechanism)

DLT – Distributed ledger technology

ERC – Standards for tokens created using the Ethereum blockchain

ERP – Enterprise resource planning

EVM – Ethereum Virtual Machine

IBFT – Istanbul Byzantine fault tolerance (Consensus mechanism)

IoT – Internet of things

NFT – Non-fungible tokens

PBFT - Practical Byzantine fault tolerance (Consensus mechanism)

PoET – Proof of Elapsed Time (Consensus mechanism)

PoS – Proof of Stake (Consensus mechanism)

PoW – Proof of Work (Consensus mechanism)

RFID – Radio frequency identification

SCM – Supply chain management

SFT – Semi-fungible tokens

Introduction

The principle of blockchain is easiest to explain with a community aspect. It is based on what is known as distributed ledger technology (DLT). Each member of the peer-to-peer network that makes up these registries can view the same information in separate blocks.

Blockchain is a type of distributed ledger technology (DLT), a digital system for recording transactions and related data in multiple places at the same time. Blockchain technology allows a group of selected participants to exchange data and makes it possible to easily collect, integrate and exchange transaction data from multiple sources. Data is broken down into common blocks that are linked together through unique identifiers that take the form of cryptographic hash functions. Blockchain ensures data integrity with a single source of reliable information, eliminating data duplication and increasing data security. As a result, blockchain technology can be used by organizations from multiple industries to create an immutable or indefinite registry for tracking orders, payments, invoices, and other transactions.

The objective of this thesis is to develop practical recommendations for incorporating blockchain technology into business processes. To achieve this, a case study will be conducted on Charoen Pokphand Foods (CP Foods), a leading multinational agro-industrial and food conglomerate. CP Foods operates in diverse sectors such as animal feed, livestock farming, aquaculture, and food processing, all of which have intricate supply chain management procedures. These sectors are particularly sensitive to the need for transparency, as it becomes crucial to trace the origins of food within the supply chain, facilitating the detection of potential contaminations. Furthermore, given the company's size, wide range of activities, and expansive global supply chains, the adoption of blockchain networks becomes essential. Implementing blockchain technology can bring significant benefits, including streamlined processes, improved security, reduced expenses, and enhanced transparency. These benefits are especially vital for companies operating in these sectors.

The focus of this study will be on how CP Foods can leverage blockchain technology to streamline its supply chain management processes, enhance transparency, and improve traceability. One potential application of blockchain technology is to create a tamper-proof record of the origin, quality, and safety of the products. This record can be accessed and verified by multiple parties, including consumers, regulators, and trading partners. By improving transparency and traceability, blockchain technology can enhance consumer trust and confidence in the products.

Overall, this thesis will contribute to the growing body of knowledge on the potential use of blockchain technology in business processes. It focuses on companies that would greatly benefit from adopting blockchain systems, leading to improved efficiency and transparency, thereby gaining customers' trust. The research provides insights into the practical implementation of blockchain in a real-world setting, offering recommendations and necessary steps to ensure successful adoption for businesses of all scales, not just those willing to invest in costly customized private systems. The standardized approach employed in the study for implementing blockchain technology in Charoen Pokphand Foods' business processes can serve as a model for other companies in the food and agro-industrial sectors. These companies, seeking to enhance transparency and streamline their processes, can consider incorporating blockchain technology without incurring exorbitant costs.

The importance of the topic is highlighted by the fact that the increasing competition in the market demands the development of new technologies, such as corporate blockchain. Like how businesses closely observed technological advancements such as the personal computer revolution in the 1970s and 1980s and the Internet explosion in the mid-1990s, knowing that their rivals were leveraging the benefits of these innovations. Blockchain technology is already being used by several logistics organizations to track products as they move through the supply chain. Blockchain technology is being tested as a foundation for digital currency exchange by government central banks and the global financial sector. Various industries, including the legal and entertainment, are using blockchain developing and implementing smart contracts and other mechanisms for transferring and protecting intellectual property rights (David Essex, 2021).

Research Goal

Blockchain is a type of distributed ledger technology that brings together several attributes that, on their own, are not unique, but together produce a technological breakthrough in the way digital information is stored, verified, and exchanged. Blockchain technology is often cited as having high disruptive potential due to its ability to operate without the need for intermediaries. Due to its decentralized data storage system, blockchain technology has the potential to significantly reduce the risk of counterfeiting, ensuring the authenticity of the data. Any modifications to the blockchain require consensus from a substantial number of votes, making such systems favorable to the majority of participating members and nodes. The advanced capabilities of blockchain have not only established it as a trustworthy platform for cryptocurrencies but have also captured the attention of many businesses. Blockchain provides transparency, facilitates secure contract fulfillment, and offers a highly secure network that is resistant to manipulation. Therefore, in addition to many businesses utilizing blockchain for different purposes, businesses with complex supply chains, particularly those in the food industry, have recognized its value as the ability to track the entire path of food products is crucial for these companies as the blockchain enables them to identify potential contaminations and, therefore build trust with their customers worldwide. While several large-scale companies have implemented their own customized private blockchain networks, the implementation costs have proven to be significant. Furthermore, there is a risk of unsolvable bugs when attempting to create proprietary private blockchains.

The goal of the master thesis is to develop a standardized approach implementing decentralized public blockchain technology in companies operating in the food industry, particularly those with complex supply chains. This includes evaluating an alternative to potentially bug-prone private blockchains, which are recognized as obstacles for many businesses considering the adoption of blockchain systems. The adoption of private blockchains requires the engagement of dedicated developers solely for the project, thereby amplifying the potential risks associated with system bugs, given the lack of prior testing. Instead, the study is focused on implementing systems on public blockchains, which offer higher security while having the same features. The study employs CP Foods as a case study to implement public blockchain technology in their supply chain management. The objective is to create a roadmap that outlines the integration of a public blockchain platform into supply chain management for companies in the food industry, emphasizing the critical need for traceability to identify and address potential contaminations. The resulting roadmap can serve as a valuable resource for other agro-industrial companies looking to update their own supply chains. The objectives of the thesis can be summarized as follows:

1. Evaluate implementation of decentralized public blockchain technology in companies requiring streamlined business processes. The case study of CP Foods company will be utilized as an example to assess the effectiveness of the approach.
2. Offer a more available solution for companies with sophisticated supply chain processes looking to adopt blockchain technology.
3. Develop a roadmap to promote the integration of public blockchain platforms into supply chain management, aiming to encourage the adoption of secure and proved decentralized blockchain systems by addressing the obstacles associated with private blockchains.

Research questions

- What are the best practices and strategies for successful implementation and integration of public blockchain platforms in agri-food businesses to encourage industry-wide disruptive innovations?

- What are the recommended strategies for the successful implementation and adoption of public blockchain systems in the supply chain management of companies within the food industry, particularly those with complex supply chain operations?
- How can these strategies serve as a roadmap for other companies in the industry seeking to streamline their business operations?

Chapter 1. Blockchain Principles: Understanding Blockchain Technology in the Context of Business processes

1.1. Tracing Blockchain's development

Blockchain technology is an advanced database mechanism that allows the open exchange of information within a business network. The word "blockchain" refers to how transaction data is stored in blocks that are linked together to form a chain. The blockchain grows in size as the number of transactions increases. Blocks record and confirm the timing and sequence of transactions, which are subsequently registered onto the blockchain inside a distinct network regulated by network participants' agreed-upon regulations (Manav Gupta, 2018).

In 1991, Stuart Haber and W. Scott Stornetta released an article "How to time-stamp a digital document" on timestamping digital documents. The article suggested a method to prevent users from backdating or forward-dating electronic documents. The objective was to make the document completely private without requiring record-keeping by a timestamping service. The system used a cryptographically fixed blockchain to store time-stamped documents and in 1992 Haber and Stornetta revised the architecture of the system to include Merkle trees, which made it more efficient by allowing numerous document certifications to exist on a single block (Haber, S., Stornetta, W.S., 1991). However, the innovation did not attract much attention until 2008, when an unknown programmer or group of programmers, working under the name Satoshi Nakamoto, gave the impetus for its use. Bitcoin emerged in 2008 as the first application of blockchain technology. Satoshi Nakamoto described it in the white paper as an electronic peer-to-peer system. Nakamoto formed a genesis block, from which other blocks were mined and linked together, resulting in one of the largest chains of blocks carrying various information and transactions. Bitcoin allows to actually own the currency, control it, and send it anywhere in the world. It does this by enabling a large number of people who don't trust each other to reconcile the ledger without the need for a trusted intermediary. Bitcoin is open to all, and no one has the power to change its rules such as its scarcity and openness, which are spelled out in the technology.

In 2013, Vitalik Buterin, a programmer and co-founder of Bitcoin Magazine, suggested that Bitcoin required a programming language for developing decentralized apps. However, his proposal did not gain enough community support. In response, Buterin decided to develop a new blockchain-based distributed computing platform, called Ethereum, which included scripting capability known as smart contracts (Binance Academy, 2023). The Ethereum platform, which first appeared in 2015, is based on the developments of Bitcoin, but it has several notable distinctions. Both technologies enable the use of digital currency without intermediaries like payment service providers or banks. However, unlike Bitcoin, the Ethereum platform is programmable, and it allows for the creation and deployment of decentralized applications that can utilize blockchain to store data. As a result, a blockchain with broad applicability that can be programmed to perform a wide range of tasks has been developed. The nearly boundless potential of Ethereum allows for significant innovation on its network. While Bitcoin only serves as a payment network, Ethereum functions more like a marketplace for a variety of financial services, games, social networks, and other applications that prioritize privacy and resist censorship.

In 2015, the Linux Foundation introduced an umbrella open-source blockchain project. The team went on to call it Hyperledger, which until now has operated as a collaborative distributed ledger allowing developers to contribute and maintain open-source platform. Hyperledger was founded to bring the transparency and efficiency of distributed ledger technologies to the enterprise market, using the proven open-source software model. The overarching goal is to enable solutions that directly connect industries, organizations, and individuals, transforming how information is shared and business is conducted. The Hyperledger Foundation hosts several open-source software projects that serve as building blocks for enterprise blockchain deployments. These projects are created and developed by the Hyperledger developer community and are available as enterprise-grade software for vendors, end user organizations, service providers, startups, academics, and others to build and deploy blockchain networks and even commercial solutions. As open-source technologies, all Hyperledger projects are community-led. This means that the code is written collaboratively and is available for anyone to review and use (Anthony Lusard, Arnaud Le Hors, 2021). With this approach, multiparty systems, also known as networks, are designed to be modular and flexible. This allows them to support various industries and use cases. The diverse and constantly expanding Hyperledger ecosystem enables businesses to mix and match technologies in order to achieve the right balance between privacy and performance. Organizations and enterprises can create permissioned, permissionless, or hybrid networks, and integrate with legacy systems as needed.

The IBM Blockchain Platform, which was introduced in 2017, is based on Hyperledger Fabric 2.0, provides a range of features that augment and improve the value of Fabric. Although Hyperledger is considered a foundation that has quickly gained widespread popularity as the blockchain technology of choice for creating decentralized business networks, IBM recognized that creating the tools alone would not be enough to overcome skepticism about blockchain technology. To address this, its main strategy has been to organize blockchain projects that can be applied to various industries. The IBM Blockchain Platform, built around Hyperledger Fabric, provides capabilities that enable members to model, create, and operate networks with the necessary performance and security for a variety of use cases in regulated industries (IBM

Corporation). The developer tools for the IBM Blockchain Platform are comprehensive and include a simplified Software Development Kits (SDKs) for Hyperledger Fabric 2.0, samples of smart contracts and applications, and tutorials to simplify every step of building application.

1.2. How does Blockchain work

The essence of blockchain technology can be disclosed through the prism of such a concept as "registry. A registry is a form of systematization and recording of any type of information. Thus, the register in its original form was the basis of commercial activity in ancient times and was used to record and store various information, mainly about money or property. At first, clay tablets were used for recording, then papyrus, parchment, and paper. The turning point, however, was the introduction of computer technology, which was first used to convert information from paper into a digital code. Currently, algorithms have made it possible to create digital distributed registries, which have properties and capabilities far beyond the traditional paper and electronic registries. A distributed registry or distributed ledger is a database that is distributed across multiple network nodes, each of which receives data from other nodes and stores a complete copy of the registry. Such nodes are updated independently of each other. The key feature of a distributed registry is decentralization, i.e., there is no single data storage and registration center. At the same time, the information in all nodes of the distributed registry must be valid and up-to-date, which is possible only by reaching agreement between all the nodes of such a registry. Each node compiles and writes updates to the registry independently of the other nodes. The nodes then vote on the updates to make sure that a majority of the nodes agree with the final version. Reaching agreement on one copy of the registry is called consensus, a process that is done automatically by a consensus algorithm. Once consensus is reached, the distributed ledger is updated, and the last agreed version of the registry is stored in each node. The data block and transaction-verification mechanisms make it nearly impossible to hack a blockchain to change data or disrupt transactions. No central authority exists for malicious actors to target, and no single player can take data private or change the rules without agreement, or whose failure can bring the whole network down. Data redundancy and transparency are provided by multiple copies. This is how blockchain achieves immutability, by being permanent and tamper-proof, and therefore reliable (David Essex, 2021). When participants reach consensus, transactions in the blockchain are written into blocks equivalent to registry pages. Along with the transactions, a cryptographic hash is added to the new block. The hash acts as a chain linking the blocks together. If the contents of a block are changed intentionally or accidentally, the hash value changes, which leads to detect data tampering. In this way, blocks and chains are securely linked and can neither be edited nor manipulated. Each additional block strengthens the validation of the previous block and, therefore, the entire blockchain. This principle is similar to building a tower of wooden blocks. Blocks can only be stacked on top, and if one block is removed from the middle, the whole tower collapses.

1.2.1. Blockchain components

At the first, basic, level of the model, there are infrastructure components that ensure the functioning of the system. These include the node – a single computer that performs actions in the network, the client – the software that implements the virtual machine, a software system that emulates the operation of a distributed, decentralized blockchain platform and executes decentralized applications and smart contracts.

Nodes are divided into the following categories:

Full Nodes: Full nodes store a complete copy of a blockchain, including all blocks. Once a full node joins a blockchain, it synchronizes with all other nodes in the network and can add new blocks to the blockchain. Full nodes are typically equipped with more memory than light nodes and can accept, reject, and validate transactions.

Light Nodes: Also known as partial nodes, light nodes do not copy all blocks in the blockchain. Instead, they store only recent blocks and access older ones only when users request them. Light nodes maintain the hash code of transactions, which must be solved to access data. Unlike full nodes, they have lower computing power and memory (Kalla Saikuma, 2023).

The second layer hosts the components that make the blockchain network work. Depending on how this layer is constructed, different implementation features are established. The network architecture is the combination of network nodes, as well as the set of rules according to which messages are transmitted over the network. Blockchain networks can be single-layer or double-layer, public or private, and may have nodes separated by roles.

The consensus mechanism is a protocol that allows equal members of a decentralized network to reach an agreement. There are many implementations, but the most popular consensuses are PoW, PoS, dPos, dBFT, and Kraft.

The transaction model is a set of algorithms and blockchain design features that determine how transactions are conducted and the state of the distributed system is fixed. Currently, there are two models – the UXTO or the accounts model records.

The third level contains objects and processes whose structure depends on the implementation of the previous level.

A block is a data structure used to store data in a blockchain. A block stores transactions, network state, smart contracts, permissions to access data and other information. Each block contains a hash (a digital fingerprint or unique identifier), timestamped batches of recent valid transactions, and the hash of the previous block. The previous block hash links the blocks together and prevents any block from being altered or any block being inserted between two existing blocks. This method strengthens the verification of the previous block and the entire blockchain, rendering the blockchain tamper-evident and immutable (Manav Gupta, 2018).

A hash code is a crucial security feature used in blockchain technology. In its most basic form, a hash code has a fixed length, helping ensure that no one can crack blockchains or alter block data. Hash codes are used to verify the integrity of transactions and for authentication. New blocks can only be added after solving hash codes. It is important to note that the hash function must generate the same output every time it's applied to the data in a block. Otherwise, it means that the data in the block has been modified (Kalla Saikuma, 2023).

A transaction is a data structure that describes an asset transfer or exchange. It must be performed in its entirety and is considered a minimum logically meaningful transaction. Transactions can carry out message transfers, actions, create contracts, and more.

An address (account) is used to identify a valid object in the network. Addresses uniquely identify the sender and receiver of value in the blockchain network. All user actions in the network are associated with an address. Depending on the blockchain, an address can be either a string or a structure of data and can be associated with a user or a smart contract.

A smart contract is a set of formalized rules implemented as software code. Execution of the code triggers certain events in the real world or digital systems. Smart contracts are not required in a blockchain network, but they are a major functional element.

1.2.2. Types of Blockchain

In essence, blockchain is a distributed database in which all changes are recorded as a chain of blocks. At the same time, the very structure of a blockchain implies different levels of access to information. This parameter is used as a criterion for blockchain classification, which is conditional because the principle of blockchain technology is the same.

The first type of blockchain technology is permissionless blockchain. It is the technology behind cryptocurrencies like Bitcoin and has helped spread the use of distributed ledger technology (DLT). By distributing information across a peer-to-peer network, DLT avoids the problems that come with centralization, such as lower security and transparency.

Because public blockchain is decentralized, it requires a consensus algorithm to verify the authenticity of data. Two common consensus methods are proof of work (PoW) and proof of stake

(PoS). Under these methods, participants in the blockchain reach agreement on the current state of the ledger (Christine Campbell Parizo, 2021).

Permissionless blockchain is non-restrictive and permissionless, meaning that anyone with internet access can sign up for a blockchain platform and become an authorized node and can read the blockchain, send transactions, participate in the consensus process, access current and past records and conduct mining activities, which are complex computations used to verify transactions and add them to the ledger. All transactions are public, and users can remain anonymous. Once a record or transaction is verified and added to the network, it cannot be changed. Additionally, anyone can verify transactions, find bugs, or propose changes because the source code is usually open source.

Private blockchain is commonly referred to as permissioned or enterprise blockchain and controlled by selected users. Ripple (XRP) private blockchain network called RippleNet is one of the more well-known examples of private blockchain networks, and it is specifically designed for financial transactions and cross-border payments. Private blockchains are only partially decentralized because they include access restrictions. It operates on a restricted or closed network, where typically a single entity has control over the network and private blockchains. This entity is responsible for setting permission levels, accessibility, and authorizations (Kalla Saikuma, 2023). Private blockchains are hierarchical structures consisting of two or more layers. The key pairs granting access to the system are issued and managed by special administrative nodes and can be revoked if necessary. Thus, private blockchains do not implement the basic principles of the technology - decentralization and equality of participants - because there are significant risks to corporate systems. Private networks, by virtue of their settings, are best suited to businesses when a legal entity wants to take advantage of blockchain technology without making its network accessible to others. Usually, companies utilize enterprise blockchains for internal business purposes, limiting access to company members and employees. In the event that non-members need to be included in the blockchain, access is granted on a need-to-know basis (Faith Obafemi, 2022). On a permissioned blockchain, events and activities are only accessible to a set of identified and often vetted participants, such as partners or competitors. This type of membership service, similar to a know-your-customer approach, ensures confidentiality among participants, including the firm itself and its collaborative partners or competitors, using a channel-based architecture. Participants are organized into subsets based on their assigned roles, granting them rights to view authorized events and transactions. Only those participating in a channel have access to the permitted data, preserving the confidentiality of all participants within the blockchain network. A permissioned blockchain functions effectively as a traditional enterprise system, combining business traits such as membership service and channel-based privacy with blockchain-specific traits such as immutability and smart contract enabling, as well as performance traits such as higher transaction throughput (Chou Chi-Chun, 2023). Therefore, a permissioned blockchain possesses attributes that can be implemented practically to fulfill any enterprise's needs. Some well-known examples of private blockchains are Quorum, Hyperledger Fabric, and R3 Corda.

Consortium or federated blockchain lies somewhere between public and private circuits, incorporating features of both. The most significant difference from either of these systems is at the consensus level. Rather than an open system where anyone can validate blocks, or a closed system where only one person can appoint a validator, a consortium chain designates multiple peers as validators simultaneously. However, forming consortiums can be a challenging process as it requires cooperation between multiple organizations, which presents logistical obstacles as well as potential antitrust risks (which we will address in an upcoming article). Additionally, some members of supply chains may lack the necessary technology or infrastructure to implement blockchain tools, and those who do may decide that the upfront costs are too high a price to pay to digitize their data and connect with other members of the supply chain.

A popular suite of consortium blockchain solutions for the financial services industry and beyond has been developed by the enterprise software firm R3 Corda. In the supply chain sector, CargoSmart has established the Global Shipping Business Network Consortium, a not-for-profit blockchain consortium aimed at digitalizing the shipping industry and enabling maritime industry operators to work more collaboratively (Kathleen E. Wegrzyn, Eugenia Wang, 2021).

1.3. Defining smart contracts

The concept behind *Bitcoin* was to create means of private digital currency that could overcome the issue of double-spending, enabling individuals to transfer funds without requiring financial intermediaries (Satoshi Nakamoto, 2008). Bitcoin aimed to bypass intermediaries in the financial industry, but the underlying blockchain technology can enable disintermediation in almost any sector. With blockchain, any asset or data can be transferred directly between peers without requiring a trusted intermediary. Moreover, predefined processes can be anchored decentrally on the blockchain through computer code that prescribes a certain reaction to new information, such as an incoming transaction. These scripts are known as smart contracts, and they take decentralized systems to the next level by allowing predefined processes or even real contracts to be executed transparently and without external influence. Smart contracts can be of any degree of complexity, from simply forwarding a transaction to another entity or address to anchoring values on the blockchain through token (smart) contracts that issue and transfer digital tokens, such as cryptocurrencies.

According to Buterin (2013), a "smart contract" is code that is deployed and run in a blockchain environment, as adopted by the blockchain community. Miners of a blockchain-based network execute smart contracts, which are software programs that take input parameters via incoming blockchain transactions, process these parameters according to some deterministic algorithm, and generate either a state change in the smart contract memory or a new blockchain transaction as output. Smart contracts can be programmed in any language that can be compiled into a particular blockchain environment or virtual machine. Currently, the most prominent platform for their deployment is Ethereum. Ethereum implements a Turing-complete programming language called Solidity, combined with a shared virtual machine (the Ethereum Virtual Machine or EVM), which has become the de facto standard for developing and deploying smart contracts. Solidity is an object-oriented programming language with a strong procedural flavor. Its core components consist of imperative instructions defining "positive" actions, such as storing the result of a numeric expression in a variable or logging certain events on the EVM (Primavera De Filippi, 2022).

Smart contracts are like containers of code that encapsulate and replicate the terms of real-world contracts in the digital domain. Contracts are legally binding agreements between two or more parties, with each party committed to fulfilling their obligations (Hamed Taherdoost, 2023). Smart contracts are software scripts that are triggered by blockchain transactions and validated across the network, and once the predefined conditions are met, the blockchain transparently executes the code without any external interference. Since the conditions of a smart contract are transparently stored on the blockchain, it will always operate as all parties intend, which can reduce trust issues between involved parties. Anyone with access to the blockchain can see the underlying code, which removes the need for counterparty trust. The use of a single shared contract eliminates the need to interpret terms and conditions, and processing can happen in real time. Additionally, digital signatures ensure transparency regarding the sender of the transactions that triggered the smart contract.

The secure transfer of value peer-to-peer over the internet between non-confiding parties is made possible by blockchain technology. This technology provides a distributed infrastructure suitable for the application of smart contracts, which enable the transparent execution of predefined terms without external interference. Smart contracts are a significant innovation that is taking decentralized systems to the next level (Lennart Ante, 2021).

Smart contracts are a digital substitute for the usual documents that seal the deal. Smart contracts have become 'smart' precisely because of their features, which include:

1. Precision: Smart contracts only perform the actions for which they were created, and it is important that all requirements are precisely adhered to. It is noteworthy that a smart contract can only be in writing, as all terms are recorded in the blockchain.
2. Security: Smart contracts are signed by the parties using an electronic signature.
3. Digital Footprint: The subject matter of the contract has a digital footprint.
4. Automation: Smart contracts can automate all kinds of tasks and work as a fine-tuned program that requires no supervision.
5. Immutability: Smart contracts are not subject to change once the algorithm has been developed and activated, which helps protect contracts from malicious developers who might try to hack the document. Changes to a digital document can only be made by developers if they have previously implemented a particular function. The immutability (or sophisticated modifiability) of a smart contract ensures its authenticity and security.
6. Global Access: Smart contracts allow even strangers from different parts of the world to transact. The blockchain in which the contracts are stored accounts for all data and ensures its accuracy.
7. Transparency: Smart contracts are completely transparent: blockchain technology is public and therefore the source code is available to everyone.

1.3.1. Life cycle of smart contract

Creation. The creation phase consists of an implementation phase and iterative contract negotiation. The parties must first agree upon the general purpose and objectives of the contract. This can be done online or offline, similar to conventional contract negotiations. Each user must have a wallet to use the underlying ledger platform. Its identification, which is typically pseudonymous and used to identify the parties and transfer funds, is used. Most smart contract systems offer the infrastructure needed to create, update, and test smart contracts to verify their content and execution behavior. After the goals and the content have been decided, the agreement must be translated into code. Software engineers take the agreement, which is written in natural language, and convert it into a smart contract using computer languages such as declarative languages and logic-based rule languages (Diana Ambolis, 2022).

Deployment. Smart contracts can be deployed on top of blockchains once they have been validated. Smart contracts that have been verified will be deployed on blockchain technology platforms. Due to the immutability of the blockchain, contracts stored in it cannot be altered, and any changes require a new contract. Once the smart contracts are deployed on the blockchains, all parties can access them via the blockchains (Christian Sillaber and Bernhard Waltl, 2017).

Additionally, digital assets belonging to the parties are locked by freezing their corresponding digital wallets. For example, any coin transfers (incoming or outgoing) related to the contract will be blocked. The parties can be identified by their digital wallets.

Execution. After deploying smart contracts, the contractual clauses are monitored and evaluated. Once the contractual conditions are met, the contractual procedures (or functions) are automatically executed. It's important to note that a smart contract consists of a series of declarative statements with logical connections. When a condition is triggered, the corresponding statement is executed automatically, and as a result, a transaction is executed and validated by miners in the blockchains. The committed transactions and the updated states are then stored in the blockchains.

Completion. Once a smart contract has been executed, updated status information and resulting transactions are placed in a distributed registry and validated using a consensus process. This includes recording the transactions that took place during the execution of the smart contract, as well as the updated states, in blockchains (Zheng Zibin, 2020).

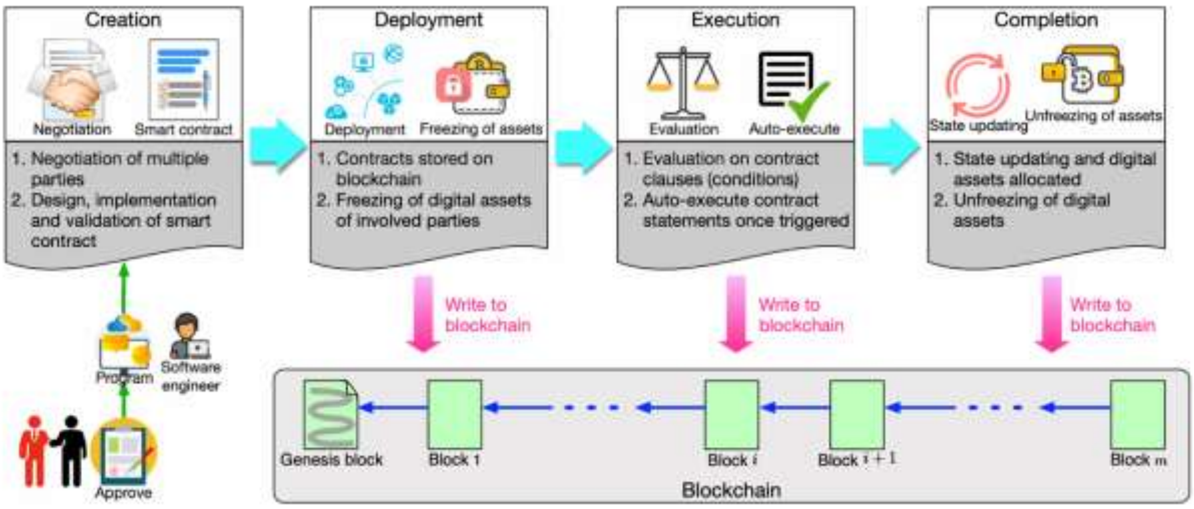

Figure 1. A life cycle of a smart contract (Zheng Zibin, 2020)

1.3.2. Oracles: Connecting blockchain to the off-chain world

Blockchain-based smart contracts, traditional databases and APIs have the potential to merge into hybrid smart contracts, creating a new architecture for database automation. However, blockchains and smart contracts cannot access off-chain data. For many contracts, it is crucial to extract relevant information from the outside world to comply with the agreement's terms. That's where oracles come in. They provide a link between external and internal sources, making them a much-needed element of the blockchain ecosystem as they empower smart contracts. Without oracles, smart contracts would have limited access to data exclusively within their network.

Blockchain oracles are third-party services that provide smart contracts with external information. It's important to understand that a blockchain oracle is not the data source itself, but rather a layer that queries, verifies, and authenticates external data sources before relaying that information. There are various oracles with different functions and characteristics. The way a blockchain oracle operates depends on its intended purpose. One important distinction among blockchain oracles is their ability to process data. Therefore, a variety of data sources are necessary for the blockchain, not just a continuously updated digital market or similar sources.

Hardware Oracles. Certain oracles are tailored to handle non-digital offline data, such as readings from motion sensors. These oracles are known as hardware oracles because they connect to external hardware or computer peripherals to receive data and transmit it to the blockchain. This is achieved by using Internet of Things (IoT) sensors and radio frequency identification (RFID) tags, and GPS locators. Once the data is collected, the hardware oracle sends it to the smart contract, which can then use it to initiate certain actions or make decisions. Hardware oracles are becoming more important as various industries explore the potential applications of blockchain technology. For example, supply chain management and logistics companies use oracles to track shipments and verify the authenticity of products.

Software oracles. Software oracles, also known as deterministic oracles, interact with online sources of information and transmit it to the blockchain. This information can be sourced from online databases, servers, websites, or essentially any data source on the Web. The fact that software oracles are connected to the Internet not only enables them to supply information to smart contracts but also to transmit that information in real-time. This makes them one of the most common types of blockchain oracles. Information typically provided by software oracles can include exchange rates, digital asset prices, real-time flight information (Abdeljalil Beniiche, 2020).

When creating simple oracle patterns, it is common to categorize the direction (inbound/outbound) and initiation of data flow (pull/push) between on-chain and off-chain components. This categorization helps distinguish between inbound and outbound oracles, which can then be further refined based on data pull and push strategies. This approach enables a clear understanding of the different types of oracles, which is essential for selecting the appropriate oracle for a particular use case.

An inbound oracle is responsible for transmitting information from the outside world to the blockchain. Since a blockchain cannot directly obtain information from external sources, it depends on the outside world to push information into the network. The most straightforward approach to obtaining external information on the blockchain is to notify the outside world of the need to push the required information into the network. This approach is known as the pull-based inbound oracle pattern and is characterized by the initiation of the exchange of information on-chain.

An outbound oracle is responsible for transmitting information from the blockchain to the outside world. While a blockchain can store state information in the form of transactions, it cannot actively communicate that state to the off-chain world. Therefore, the most straightforward way to obtain data from the blockchain is to fetch it. This approach is known as the pull-based outbound oracle pattern, where the exchange of information is initiated off-chain (Roman Mühlberger, 2020).

1.4. Enterprise Blockchain platforms

Blockchain technology offers many advantages, including increased speed of exchange, reduced time costs, reliability, accessibility, and transparency. As a result, blockchain is applicable in a wide range of industries, such as banking, finance, logistics, healthcare, energy, and more.

While blockchain is often associated with the crypto industry, it has far-reaching potential beyond that realm. By removing middlemen and automating processes, blockchain has the potential to reduce IT and labor costs, speed up e-commerce and finance, and enable new lines of business. Additionally, blockchain can expand businesses' customer bases and improve efficiency in reaching them.

The trust that blockchain fosters, along with its built-in privacy, security, and data integrity, contribute to its many benefits. Trust enables businesses to do business with unknown parties, which can expand markets and potentially boost profits. Additionally, the accuracy and impermeability of blockchain systems can reduce fraud, eliminate data leaks, and bring in more customers and partners. By boosting data accuracy and facilitating auditing, blockchain can also cut data management costs.

The transparency of blockchains is particularly useful in supply chain management, providing visibility and traceability. Blockchain is already making it easier and more affordable to extend supply chain transparency to the smallest suppliers, such as coffee growers, tuna fishing operations, and miners. This transparency helps to shore up trust in information about product provenance as goods move through the supply chain to consumers (David Essex, 2021).

A blockchain platform is a computational environment that companies can use to solve problems and meet their business needs. It is distributed and integrated, and allows network participants to search, interact, create, and share value in the form of products and services. A key feature of a blockchain platform is the shift away from traditional governance towards consensus and code execution. Blockchain technology is highly scalable and can be used across a wide range of industries. Digital assets can be anything with explicit or implicit value, such as digital currencies, securities, precious metals, commodities, materials, identities, and credentials. Since the first full-featured cryptocurrency trading systems, like Bitcoin, Ethereum, BNB, Litecoin, and XRP, blockchain platforms have formed an entire ecosystem, including both industry-specific, cross-industry permissioned blockchain platforms like Hyperledger Fabric, Hyperledger Sawtooth, R3 Corda, Quorum, IBM Blockchain, and IBM Food Trust, BiTA.

Blockchain platforms specialize in different roles and value streams based on compartments and activities. Participants in these platforms can form consortia to address industry-wide problems. Such platform solutions are characterized by the following features:

- Establishment of partnerships for shared value creation based on a mutual vision of a common goal of cooperation.
- Formation of a blockchain community dialogue through the representation of various networks, including research and development networks, the Internet, engineering infrastructure, transnational cooperation in cybersecurity, artificial intelligence, immunity, multiple networks of organizations.

Ultimately, blockchain platforms facilitate the creation of new business models and the revision of existing ones by changing one or more components, which may include:

- Using their own blockchain technology or co-developed technology with others and changing only a portion of the management and business processes associated with it.
- Using blockchain technology without altering the structure of business processes, either by using off-the-shelf blockchain technology from outside the company or by hiring contractors through blockchain platforms.

Intermediation is the most prevalent asset ownership verification and transaction processing solution today (Michael Nofer, 2017). Intermediaries typically provide relevant information on supply and demand, prices and trade requirements, and match market supply with demand. They also offer value-added services such as the transportation and distribution of goods, trustee services, payment arrangements, and consultancy (Efraim Turban, 2018). In e-commerce markets, intermediaries also provide technology for the exchange of services and act as a platform provider. By doing so, they earn the trust of businesses, enabling them to form relationships with unknown parties with confidence and reducing risk.

Logistics chains today consist of third-party and fourth-party logistics providers who act as neutral business partners in the supply chain and offer various services to the companies involved. Intermediaries also serve a regulatory function by covering legal uncertainties and the high cost of bilateral contracts between trading partners. The challenge of international cooperation is often hindered by logistics service providers who lack communication and information exchange. This is due to the use of fragmented data repositories, differing standards, communication channels, and data formats. These issues can lead to inefficiencies, delays, and mistakes in the logistics process.

Blockchain technology with its peer-to-peer network and distributed data management can lead to an elimination of intermediaries, also known as disintermediation (Stefan Tönnissen, 2020). Blockchain offers a decentralized, secure, and transparent ledger that can record transactions without intermediaries. This technology can reduce transaction costs, increase efficiency, and eliminate the need for trust in intermediaries. As blockchain continues to evolve, it is likely that it will disrupt many industries that rely on intermediaries, including logistics and finance.

Cross-industry logistics and supply chain automation solutions are available in various fields. These solutions can help improve efficiency and productivity, reduce costs, and streamline processes:

1. Verification of product origin and authenticity (G2B level). An example is IBM Food Trust, VeChain which cover procurement, sales, and logistics of food products.
2. Origin authentication and protection against counterfeiting (B2B). These platforms include Everledger, which focuses on counterfeit, diversion, stolen goods, and fraudulent transactions in the pharmaceuticals, luxury goods, diamonds, and electronics sectors minerals and metals, wine, and fine art (Everledger, 2023). There are concerns in the diamond industry regarding the origin and authenticity of stones. Today, a decision has been presented to record more than 40 identifying characteristics of a diamond, including color and clarity, and register them on blockchain.
3. Optimization in transport and logistic processes. The Hyperledger platform offers numerous opportunities for streamlining logistics processes. Through its use, an infrastructure can be created that incorporates data from any device, such as IoT, GPS locators, and RFID tags, which provides real-time information on the movement and condition of shipping containers as they pass through the supply chain. This enables advance information on the time of arrival of production or retail consignments to the consumer.

Therefore, an organization' presence on a blockchain platform can offer several key business benefits, including:

- Time savings: Transactions for complex, multilateral interactions are reduced from days to minutes. Transaction settlement is faster because it does not require verification by a central authority.

- Cost savings: Less control is required because the network is self-monitoring by network participants, all of whom are known to the network. There are no intermediaries, and there is no duplication of work due to interoperability in a single cloud space.
- Increased security of transactions from hacking, fraud, and cybercrime.
- Authorized access that allows users to set different viewing and access rights to work with transaction information.
- Objective monitoring and auditing of transactions.
- Streamlined business processes: Digitization of assets simplifies the transfer of ownership, and transactions are carried out at a speed more consistent with the pace of business.
- Increased trust between network participants: Cryptographic confirmation of a set of transactions creates trust, and because transactions cannot be tampered with and are signed by the counterparties involved, any disruption becomes obvious.
- Knowledge and technology advantage by participating in the development of the decentralized platform as a new standard, thereby gaining a competitive advantage.

1.4.1. Hyperledger Fabric

Fabric is a blockchain system that supports modular consensus protocols, allowing it to be customized for particular use cases and trust models. It is unique in that it allows distributed applications to be written in standard, general-purpose programming languages, without the need for a native cryptocurrency, which differs from existing blockchain platforms that rely on “smart-contracts” written in domain-specific languages or tied to a cryptocurrency. Fabric employs a permissioned model that incorporates a portable notion of membership, which can be integrated with industry-standard identity management. To achieve this level of flexibility, Fabric introduces a novel blockchain design and improves the way blockchains handle non-determinism, resource exhaustion, and performance attacks (Elli Androulaki, 2018).

Hyperledger Fabric is a blockchain project that is part of the Hyperledger family. Like other blockchain technologies, it uses a registry, smart contracts, and a system in which participants manage their transactions. What sets Hyperledger Fabric apart is its private permissioned network. Unlike public permissionless systems, which allow unknown entities to participate in the network (requiring "proof of work" protocols to validate transactions and secure the network), Hyperledger Fabric requires its members to join the network through a trusted Membership Service Provider (MSP). Hyperledger Fabric also offers a range of interchangeable options. For example, registry data can be stored in multiple formats, consensus mechanisms can be swapped out, and multiple MSPs are supported.

Hyperledger Fabric smart contracts are created using a chaining pattern and are triggered by an external application to interact with the registry. Usually, the chaining code only interacts with the registry database, which includes the world state component, such as making search queries.

Transactions should be recorded in the registry in the order they occur. Even if the transactions involve different sets of participants within the network, it is important to maintain a clear ordering of transactions, as well as a method for rejecting bad transactions that have been entered in error or maliciously. There are several methods available to achieve this goal, each with its own drawbacks. For example, PBFT (Practical Byzantine Fault Tolerance) can provide a reconciliation mechanism through communication between multiple replicas of the same file, even if one of them is corrupted. Alternatively, Bitcoin ordering occurs through a mining mechanism, in which computers compete to solve a cryptographic puzzle that determines the order in which all other processes are built. Consensus can be achieved in many ways, but there is a common approach that is generally followed, even though different Hyperledger frameworks may implement these steps differently. Hyperledger enterprise blockchain frameworks reach consensus through two distinct activities: Endorsement, Ordering of transactions, Validation of transactions (Hyperledger Foundation, 2017).

The transaction steps in Hyperledger Fabric include:

2. Initiation of transaction: The client is the initiator of the transaction. Initially, a request proposal is created to invoke a chaincode function. Next, this proposal is signed by the client and submitted to the channel on which the chaincode is deployed. As per the policy of endorsement regarding chaincode, the client expects a number of endorsements to receive.
3. Execution of transaction: The endorsing peer (EP) verifies the signature. To do this, the endorsing peers do all the validity checks for the well-formedness, authenticity, replay protection, and authorization of the client. If all the checks are correctly passed, the transaction is executed by the peers against their own key-value stores, and then the peers generate an acknowledgment containing read-write sets produced as an output of the chaincode function execution. Next, all these values are signed by the peers and sent back to the client as an acknowledgment of the proposal or endorsement. No modifications to the ledger are made at this moment.
4. Collection of endorsements and ordering requests: A client receives all the endorsements and then examines, compares, and verifies whether it has fulfilled all the requirements according to the endorsement and policy of the chaincode. For a read operation, the client does not send an ordering request. If the request is for a chaincode invocation, i.e., write, the endorsements

are consolidated into a transaction and submitted to the orderer by the peer. The transaction and order are then verified by the orderer according to the channel.

5. Transaction validation and commit: The orderer delivers all ordered transactions within blocks to all peers on the channel. According to the endorsement policy, the transaction is verified by the peers, and if all the checks are correct, then the peers add the corresponding block to the ledger. It is mandatory for all the peers to commit (commit peer) the transaction. The endorsement can be done by only a particular subset of peers in the channel, and these peers are known as endorsing peers (Ravi Deebthik, 2022).

1.4.2. Hyperledger Sawtooth

Hyperledger Sawtooth is a modular platform that can be used to build, deploy, and run distributed ledgers. These ledgers provide a digital record of asset ownership, among other things, that is maintained without the need for a central authority or implementation. Sawtooth is designed to ensure that distributed ledgers remain distributed and that smart contracts are safe for enterprise use. To support this enterprise focus, Sawtooth is highly modular, allowing enterprises and consortiums to make decisions about their blockchain applications for themselves (Hyperledger Foundation, 2021).

Sawtooth provides selective permissions, allowing specific clusters of Sawtooth nodes with different permissions to be easily deployed in the same blockchain. The registry stores the necessary permit, node, and identity data. The Sawtooth network's performance is enhanced by the parallel transaction execution mechanism, which has an advantage over the sequential execution mechanism. The latter is often a bottleneck when dealing with large transaction volumes in many popular cryptocurrency networks.

Sawtooth supports the Proof of Elapsed Time (POET) consensus mechanism, which offers the advantages of low resource usage and low power consumption. It is typically used in permissioned blockchain networks to determine mining rights or winners of blocks in the network. PoET is based on the idea that proof-of-work is essentially a way to create and enforce random wait times. Proof-of-work selects the first participant to solve a cryptographic puzzle as the leader, introducing a random delay drawn from an exponential distribution. Like proof-of-work algorithms, at the beginning of each PoET consensus round, a validator constructs a block that extends the chain it believes is correct. This selection of a chain to extend is an implicit "vote" for the chain. Next, the validator performs a computation to determine the duration of time it must wait before it can claim leadership and extend the chain with the block it built. If no other validator claims leadership before the computed time expires, the validator broadcasts its proposed block and proof that it computed the time correctly. The chain is then extended with the new block and the process repeats. The computed future time represents a type of "lottery" where each validator is given a ticket, and the validator with the smallest ticket wins the lottery.

One of the main benefits of Nakamoto consensus over traditional Byzantine Fault Tolerance is its ability to adapt to changing populations of validators. Proof-of-work algorithms handle adaptation through a variable difficulty level. If blocks are published more frequently than the target interval, indicating an increase in the population of validators, then the difficulty level increases enough to slow down block publication. Similarly, PoET samples the random wait times generated for winning blocks and determines if the intervals are appropriate. If blocks are published too quickly, the distribution from which each validator chooses its wait time is increased. This is done deterministically, and the result of the computation is captured in the leadership claim and signed by the enclave (Mic Bowman, 2021).

When transitioning to new business cases, it is crucial to retain key features of the distributed ledger. Deploying a distributed ledger in an enterprise should not be reduced to a mere replicated database. Enterprise participants need autonomy and the ability to manage their own nodes. This interaction, where each participant manages nodes in their own interest, ensures the integrity of the blockchain. To achieve this integrity, the blockchain must meet the following complex requirements: ensure security against intruders within the network, manage a large number of people, manage a dynamic population.

Many of the consensus algorithms used in typical replicated databases are not designed to meet the requirements of blockchain. However, Sawtooth and PoET were designed specifically for decentralized blockchain applications, which involve many participants in the consensus process who are distributed both administratively and physically. PoET provides security against malicious participants and is designed to manage the arrival and departure of nodes in a large network. Additionally, Sawtooth provides on-chain management for updating consensus and other business rules that are agreed upon by the consortium over the life of the network. This means that the consortium can change consensus on the fly, using only transactions.
Users can start with a limited consensus and then move to PoET-type consensus, which provides the secure, dynamic, and scalable features needed for a production network.

1.4.3. Ethereum

Ethereum is a blockchain ecosystem that allows users to create and operate decentralized applications (DApps). The ecosystem's currency, ETH (ether), serves as the unit of exchange. Ethereum operates as a blockchain network with several modifications to provide a toolkit for DApp creation and operation. DApps are governed by smart contracts, and unlike traditional applications, they are not controlled by centralized development teams. Instead, developers only maintain them. The Ethereum Virtual Machine (EVM) is a vital component of the Ethereum ecosystem. It is a virtual computing environment that enables developers to create smart contracts, and network nodes can interact with them. The EVM emulates the processes that occur on the network before they are executed. Each Ethereum node has its own copy of the EVM. When a user sends a transaction to a smart contract on Ethereum, the nodes execute the contract and its incoming transactions through their EVMs.

The Ethereum network has four main layers:

1. The physical network consists of a distributed set of computers, or nodes, running Ethereum software.
2. The Ethereum Virtual Machine allows developers to upload smart contracts to the blockchain and enables external accounts (users) to interact with those contracts. External accounts are controlled by a private key (password). Smart contracts are just computer programs that are stored on every node in the Ethereum network, making it highly redundant and resilient.
3. The smart contract layer receives instructions and can send messages or instructions to other accounts or smart contracts. Smart contracts can perform tasks such as changing a variable or sending transactions to another address.
4. The decentralized application (Dapp) layer can be accessed through websites that allow users to connect their "Web 3" wallets to the Ethereum network. Web 3 wallets hold passwords associated with cryptocurrency addresses and can broadcast instructions (lines of code) to the Ethereum blockchain. These wallets approve transactions by electronically signing them with passwords and sending the approval to the Ethereum network (Denny Galindo, 2022).

Ethereum is based on the The Proof-of-Stake (PoS) consensus algorithm. The Proof-of-Stake algorithm assumes that a validator's vote carries more weight based on the number of coins they have deposited in the stack. The amount of blocked funds determines the reward for the node. Unlike the Proof-of-Work (PoW) algorithm, which consumes a lot of energy during the searching process, PoS selects a leader based on their stakes to perform the mining process and add a new block to the chain. To simulate the stake-based leader selection process, many PoS-based blockchain networks have adopted the Follow-the-Satoshi (FTS) algorithm. This algorithm uses a hash function that takes a seed such as the previous block's header or a random string created by some other selected nodes as input and then outputs a token index (Cong Nguyen, 2019). Using the index, the algorithm searches the transaction history to find and select the current owner of that token to be the leader.

Proof-of-Stake (PoS) working principle:

1. The node locks coins, and once it is done, the blockchain considers the node ready to work. The minimum entry threshold varies for each blockchain. In Ethereum, for instance, to become a validator, you need to lock 32 ETH.

2. All validators compete for the right to add a new block to the distributed ledger chain.

3. The network randomly selects a node to add a block based on certain criteria. There are several options for choosing a device for block forging:

By the "age" of the coin, taking into account the time during which the validator staked their coins, as well as the total number of all coins locked as a stake. After a node is chosen by a validator, the "age" of its coins is reset.

By the staking metrics, i.e., the amount of coins sent to staking and the hash value. The higher the staking metric and the lower the hash value, the greater the chances for the node to create a new block.

4. The validator checks the legitimacy of transactions in the block, signs it, other nodes confirm the legitimacy of the block, and if the majority of them consider it valid, it is added to the blockchain chain. If a block is marked as invalid by other validators, the node that was selected to validate it will lose its stake (all coins being staked), and the validation process will start again from the beginning. The validator who submitted the invalid block will be prevented from creating blocks in the future

5. The node receives a reward in the form of a commission for transactions. The reward and the stake of the node are frozen for some time so that the network can recheck the legitimacy of the transactions.

On the blockchain, fungible tokens are usually ERC-20 tokens (which stands for "Ethereum Request for Comments 20"). However, some fungible tokens exist in other variants, like BEP-20, SLP, and TRC-20. ERC-20 is the most widely used token standard on the Ethereum network and can be used for a variety of purposes, including stock shares, loyalty points, and almost all cryptocurrencies. Currently, ERC-20 tokens are valued at over US$100 billion. Fungibility refers to whether a token has identical or equivalent properties to other tokens in the same category. This means that fungible tokens can be exchanged or replaced with other assets of the same kind. An ERC-20 token is a type of token that follows the ERC-20 guidelines. These guidelines provide certain features that make each token of the same type and value as another token. For instance, an ERC-20 token functions in the same way as ETH on the Ethereum blockchain, meaning that each token always has equal value to any other token. Additionally, the ERC-20 standard specifies a common interface for fungible tokens that can be divided and are indistinguishable from one another, ensuring interoperability within the Ethereum blockchain community (Gang Wang, 2021).

Non-fungible tokens (NFTs), on the other hand, are the opposite of ERC-20 tokens. While ERC-20s are interchangeable, NFTs have their own identification and metadata, which makes them unique. The identification consists of a serial number and the address of a parent smart contract, while the metadata describes various attributes of the NFT. The uniqueness of NFTs makes them ideal for storing digital goods, such as art, domain names, sound clips, in-game items, and more (Yan Meng, 2022). While fungible tokens can be divided into smaller units, NFTs are indivisible and contain unique information and attributes that set them apart from one another. As a result, NFTs cannot be exchanged with each other as each token is unique and distinct.

The ERC-20 standard provides a technological framework and best practices for creating fungible tokens under Ethereum blockchains. Similarly, the ERC-721 standard provides the same for non-fungible tokens, enabling developers to create a digital asset representation that can be exchanged and tracked on the blockchain (Gang Wang, 2021).

The Ethereum ERC-1155 standard also known as the Multi-Token Standard is another noteworthy variant of Ethereum that provides a SFT (Semi-fungible token). SFT is a type of digital asset based on blockchain technology that blends fungible and non-fungible characteristics. More specifically, SFTs combine the quantitative attributes of a fungible token and the descriptive features of a non-fungible token. SFT can be used to represent any digital asset that has quantitative attributes and is required to be fractionalized or combined in certain circumstances. This kind of token can include personalized information, such as metadata, timestamp data, supply, and other characteristics. Overall, ERC-1155 tokens introduce a new token proposal standard that enables the creation of both fungible and non-fungible tokens within a single contract. In a financial application, using an SFT is probably most straightforward when combining a $20 bond and a $30 bond into a $50 bond (Yan Meng, 2022).

Enterprise Ethereum refers to tailor-made software and networks built on top of Ethereum, designed specifically for private corporations and businesses. These networks are permissioned, which means that enterprise clients retain full control over the architecture, the validators, and the users. Consortium networks built on Ethereum can achieve heightened scalability and performance with the help of Proof of Authority consensus and custom block time and gas limit. This allows them to outperform the public mainnet and scale up to hundreds of transactions per second, or even more depending on the network configuration. Enterprise Ethereum uses the IBFT (Istanbul Byzantine Fault Tolerant) consensus mechanism instead of the public Ethereum network's POS mechanism. IBFT guarantees a single, agreed-upon ordering for blockchain transactions and provides settlement finality, which makes it particularly beneficial for enterprises.

To determine if a proposed block is suitable for inclusion in the blockchain, IBFT uses a pool of validating nodes known as Validators. One Validator is randomly selected as the Proposer and is

responsible for creating a block at the block interval and sharing it with the group. If a super-majority of Validators agree that the block is valid, it is added to the blockchain.
After the consensus round is complete, the Validators may choose a new Proposer who will provide the candidate Block at the next block interval.
The consensus mechanism is a synchronized state machine that ensures all Validators append the same block to the chain at the same height.
If a block fails to insert, the Proposer is changed, and the process starts over.
To prevent the proposed block from being changed once a super-majority of validators have agreed to its insertion, IBFT uses a process called "Block Locking." This ensures that only one block can be appended to the state machine. The IBFT consensus mechanism offers system stability as long as less than one-third of the validating nodes are behaving incorrectly (either due to being compromised or due to faulty code). To tolerate F faulty nodes, the validation group must contain at least 3F + 1 nodes; more than this does not increase system integrity (ConsenSys, 2022).

1.4.4. Polygon

Polygon is a layer 2 solution with support for sharding aimed at facilitating the mass adoption of blockchain projects through sidechains that offer two-second block confirmation times. Polygon blockchains have a high level of functional compatibility and can interact with each other and with the Ethereum network. The technical stack of the solution consists of two main types of blockchain networks: secured chains and autonomous chains. At its core is Polygon EDGE (formerly DSK - Software Development Kit) - a modular structure that supports the connection of two main types of Ethereum-compatible networks:

1. Autonomous blockchains also known as sidechains with their own pool of validators responsible for their security. The main example of such architecture is the Polygon Proof of Stake network;

2. Blockchain networks that use the Security as a Service model instead of creating their own pool of validators. These include Plasma chains, Optimistic Rollups, zkRollups, and other similar solutions.

Sidechain is an alternative blockchain to the parent chain. Plasma is a framework for child blockchains and a solution for scaling Ethereum (or any blockchain, for that matter). The concept of a sidechain is to launch another blockchain alongside some other "main" blockchain. These two chains of blocks can then communicate with each other in a way that allows assets to move between the two chains. Like sidechains, Plasma chains have a consensus mechanism that creates blocks. However, unlike sidechains, the "root" of each Plasma chain block is published on

Ethereum. The roots of the blocks are essentially small pieces of information that users can use to verify the contents of these blocks. The Polygon Network employs a dual strategy of Proof of Stake at the checkpoint level and Block Producers at the block producer level. This approach allows for faster block times while maintaining a high level of decentralization by utilizing checkpoints and anti-fraud mechanisms to achieve finality in the main chains. Through this mechanism, the Polygon Network achieves high transaction speeds with a high degree of decentralization and finality in the main chain. In the first version, which only utilizes Ethereum as the underlying chain, the Ethereum root contract effectively enforces solvency and finality through the header block checkpoints. The Matic Network POS mechanism selects a proposer among interested parties every few blocks at the Matic Network block level to propose a checkpoint on the main chain. The proposer verifies all blocks at the Matic Network block level and creates a Merkle tree of block hashes since the last checkpoint. Then, they create these checkpoints and broadcast the Merkle root to the Staker network for their signatures. Other interested parties also verify the proof and approve the proposed block if it's valid, providing their signatures. To propose a "header block" for the root contract, the system requires 2/3 stakeholder approval. Once a checkpoint is proposed on the main chain, any user on the Ethereum main chain can contest the proposed checkpoint within a specified period. If no one contests it and the contest period ends, the checkpoint is formally included as a valid checkpoint in the main chain.

Checkpoints play an important role in withdrawals, as they contain the proof of burning (withdrawal) of tokens in the event of a user withdrawal. This allows users to validate their remaining tokens in the root contract using Patricia Merkle's proof and header block proof. Please note that to validate remaining tokens, the header block must be committed to the root chain via POS stakeholders. The withdrawal process incurs Ethereum gas fees as usual. Through this mechanism, the Matic Network achieves high transaction speed, high decentralization, and finality on the Mainchain. In its first version, which uses Ethereum as the underlying chain, the Ethereum root contract efficiently enforces solvency and finality with header blocks (Jaynti Kanani, 2021).

1.5. Key stages of blockchain technology implementation in food supply chain management

Currently, there is no standardized methodology for implementing blockchain technology due to its novel approach to working with data. However, there has been a surge of empirical research in the scientific literature on how to implement blockchain technology in business, particularly in supply chain management, which has been heavily impacted by the COVID-19 pandemic. There are already several reviews in the scientific literature devoted to this direction, including studies by Patidar, Shukla & Sukhwani (2022), Talwar et al. (2021), Karakas, Acar &

Kucukaltan (2021), Singh et al. (2022), Risso et al. (2023), and many others. The use of blockchain technology in the food supply chain is particularly important as it increases operational efficiency through mapping and visualization (Patidar, Shukla & Sukhwani, 2022), improves food safety (Chaudhuri et al., 2018), and facilitates verification of sources, production time, and production location of raw materials as part of quality management (Chen et al., 2021).

A recent study proposed a conceptual model for the implementation of blockchain technology in food supply chain management, which includes three main stages: initiation, adoption decision, and implementation (Fig. 2).

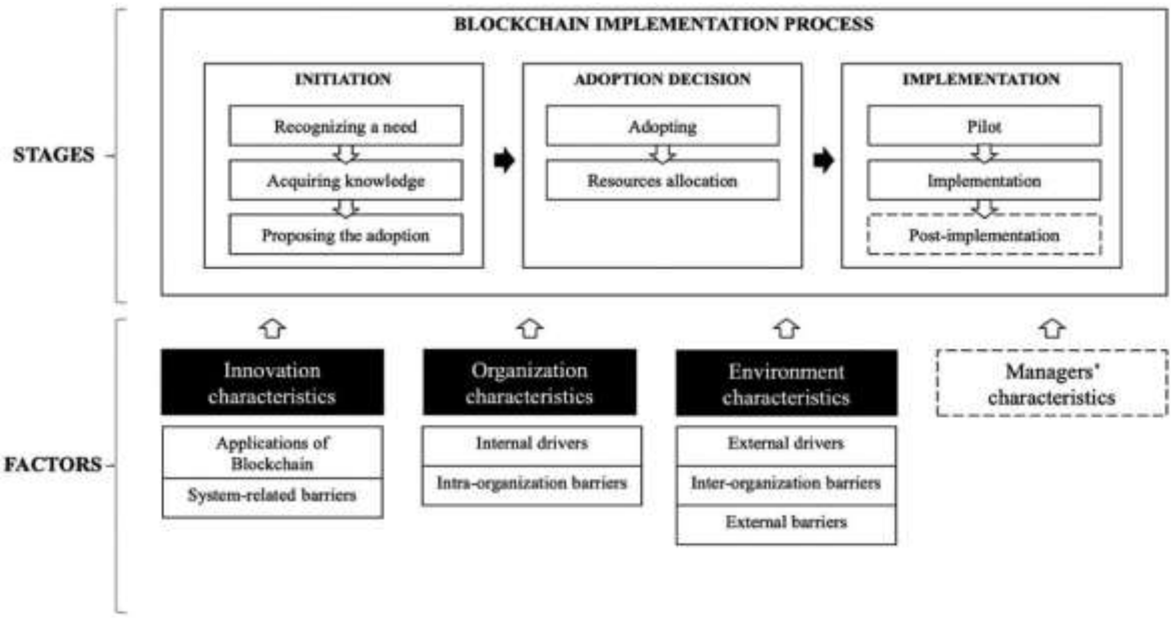

Fig. 2. Conceptual model of blockchain technology implementation in food supply management (Vu, Ghadge & Bourlakis, 2021).

In addition, a group of Indian scientists has developed an integrated structure for analyzing the management decision-making system through blockchain technology as part of supply chain management. The structure consists of 5 stages of blockchain technology implementation: gathering the data, reducing the data, generating the decisions, validating the decisions, and communicating the decisions (Karamchandani, Srivastava & Srivastava, 2023).

Fig. 3. Example of using blockchain technology in food supply chain management at Walmart (Vu, Ghadge & Bourlakis, 2021).

At this point, there will be considered an example of the stages of implementing blockchain technology in food supply chain management in Walmart, which uses blockchain technology to track the lifecycle of food products (Fig. 3).

At Walmart, the implementation of blockchain technology in food supply chain management can be summarized as follows:

1. Define the goals of using blockchain technology in food supply chain management (e.g., creation of a global blockchain platform, monitoring the authenticity of food products, optimization of calculations and/or document flow, storage of cargo delivery records, optimization of monetary settlements in logistics and supply chains, etc.).
2. Involve partners in the implementation of the project, creating relationships with partners in which all counterparties in the supply chain will use the blockchain.
3. Build consensus, identifying and selecting a method of correlating data in the blockchain within a single model (data architecture).
4. Select a suitable platform.
5. Develop smart contracts, which are computer algorithms for the automation of formalized business processes and/or exchange of values.
6. Develop a software application, as well as additional applications such as a mobile application (independently or by hiring a team of specialists).
7. Test the blockchain and verify its effectiveness in real business processes.

8. Correct errors and make adjustments to the operation of the system based on the problems identified during testing.
9. Integrate blockchain into logistics processes.

1.5.1. Factors to consider when choosing a blockchain technology platform in food supply chain management

Nowadays, many platforms have the potential to modernize supply chain processes if used effectively. For example, Polygon, IBM Food Trust, Ethereum, Hyperledger Fabric, Hyperledger Sawtooth, VeChain, Provenance, and ChainLink are just a few. Thus, it's crucial to analyze existing solutions when deciding on a specific platform for implementing blockchain technology for food supply chain management.

There are several primary considerations when selecting a blockchain technology platform for food supply chain management. These can include the type of information that should be collected in the blockchain (either automatically or manually), business processes that will be transferred to the blockchain, transaction processing rate, the number of participants in the blockchain system and their roles, validation of data subjects, and availability of information.

It's worth noting that not all food enterprises have the necessary resources (such as money or influential connections) to immediately transfer all supply chain management processes to the blockchain. Instead, they may proceed in stages by improving only some elements, such as payment processing, document management, and quality monitoring.

Furthermore, it's important to consider the level of transparency and privacy required for the specific use case. For instance, some organizations may require complete transparency in supply chain management, while others may require limited visibility. It's also important to consider the level of security required for the blockchain platform, as well as the scalability of the system. Ultimately, selecting the right blockchain technology platform for food supply chain management will require careful analysis and consideration of the specific needs and requirements of the organization.

1.6. Blockchain use cases in business operations

Blockchain technology has been gaining popularity in many industries as a distributed ledger system that enables secure and transparent record-keeping. Its potential to revolutionize how businesses operate has been recognized in sectors such as supply chain management, finance and healthcare. With its decentralized nature, blockchain can provide greater transparency and accountability, while also reducing the costs associated with traditional intermediaries. As more and more companies begin to explore the possibilities of blockchain, it becomes increasingly evident that this technology is here to stay and is likely to have an even more significant impact on the way people do business in the future.

In 2016, Walmart collaborated with JD, IBM, and Tsinghua University in Beijing to establish a Blockchain ledger system to track the movement of pork in its Chinese supply chain (Hyperledger Foundation, 2021). The goal of this partnership was to enhance food safety through the development of necessary standards, solutions, and partnerships. IBM provided its private Blockchain Platform, which is based on Hyperledger Fabric and runs on the IBM cloud, while Tsinghua University acted as the technical advisor for the key technologies required for the process. The collaboration involved working with food supply chain providers and regulators to create a safe food ecosystem in the country. The new system connected and verified various pork suppliers, shippers, buyers, and others involved in the movement of the product around China. These efforts were the industry's most significant proof of concept and paved the way for better food traceability.

In 2017, Walmart partnered with IBM to further develop and implement its blockchain food traceability system after successful completion of the pilot projects. This partnership demonstrated Walmart's commitment to using advanced technology to address food safety concerns and enhance supply chain transparency. The collaboration also highlighted the potential of blockchain technology to improve the efficiency, reliability, and security of global supply chains, extending beyond the food industry to other sectors. Using the IBM Food Trust network, which is a leading global initiative that aims to improve the efficiency, safety, transparency, and sustainability of the entire food supply chain, Walmart began tracing over 25 different types of products in 2018. A year later, Walmart announced that all their suppliers of leafy green vegetables must upload their data to the blockchain within a year, demonstrating their commitment to supply chain transparency and safety (Zifa Mae, 2023).

According to Walmart’s senior director of software engineering, ensuring accountability and transparency in the food supply chain is crucial, particularly with the prevalence of food contamination worldwide. Blockchain technology can efficiently track a contaminated product, including its ingredients, to its source, thereby preventing the further spread of foodborne diseases. In addition to the swift containment of illnesses and reduced response times, Blockchain also minimizes food waste by enabling selective recalls, leading to better recall management. Moreover, using Blockchain supply chain solutions to obtain detailed information about food items eliminates uncertainty and assists vendors in making decisions about how they handle their products, such as obtaining precise data on the shelf life of fruits to prevent the disposal of fresh food (Archana Sristy, 2021).

In 2019, Carrefour and Nestlé, two international food companies, have announced their collaboration to add Mousline Purée, a popular instant mashed potato mix available in France, to the Food Trust blockchain network. Mashed potatoes have been a beloved food in France since their invention in the 1800s. French consumers consider it imperative that the potatoes used are of the highest quality and grown in France. Therefore, Mousline Purée is an ideal food to offer traceability. Each 520g package has a barcode that can be scanned with a smartphone. This provides consumers with valuable information about the mix they are about to prepare, including the region where the potatoes were grown and the varieties used. In addition to providing consumers with more information about their food, the collaboration between Carrefour and Nestlé also aims to improve food safety and reduce food waste. By using blockchain technology, the companies can identify places and dates of storage and eliminate potential risks in the supply chain, ensuring that the quality control in the Nestlé factory is maintained from farm to table (IBM, 2019).

As stated by the General Manager of IBM Food Trust, the lack of transparency is the root of many problems in food systems. This includes how visible the information is, how well people understand what is happening, and how they react in a timely and appropriate manner. Blockchain technology creates a decentralized ledger that records transactions in a global food network, providing a neutral playing field for all participants in the supply chain to share important information. This will benefit the entire food ecosystem by untangling the complex web of growers, suppliers, manufacturers, retailers, regulators, consumers, and restaurants. The secure data-sharing platform lets participants share information about food origin, processing, and shipping information in a permissioned way, ensuring that the data and insights gained remain the property and under the control of the respective companies (Raj Rao, 2019).

Besides private blockchain solution implementation Nestlé has partnered with OpenSC blockchain platform, to promote supply chain transparency. This move marks Nestlé as the first major food and beverage company to announce its pilot of open blockchain technology. OpenSC, founded by WWF-Australia and The Boston Consulting Group Digital Ventures, provides a platform that grants anyone, anywhere access to independently verifiable sustainability and supply chain data (Nestlé, 2019).

The initial pilot program tracks milk from farms and producers in New Zealand to Nestlé factories and warehouses in the Middle East. OpenSC is a public blockchain platform based on the Ethereum network, and it provides transparency in the chain between customers and sellers. This enables consumers to trace a product's origin and journey from source to supermarket. According to Magdi Batato, Executive Vice President, Head of Operations at Nestlé S.A., the company aims to empower their consumers with the information needed to make informed decisions about their choice of products, specifically those produced responsibly (Mark Jones.

2020). Open blockchain technology has the potential to share reliable information with consumers in an easily accessible way.

In 2022, Unilever, the multinational consumer goods company, is committed to enhancing transparency and traceability in its global supply chain of palm oil. To achieve this, the company has launched a new blockchain pilot initiative that focuses particularly on the initial stage of production, where raw materials are often blended with identical materials from verified sustainable and non-verified sources after the first mile of the supply chain. This blending process means that the origin information is frequently concealed or lost, making it difficult to track the journey of the commodity from the field to the shelf. Unilever's blockchain pilot is a proof of concept that was successfully implemented in Indonesia using GreenToken, based on a private blockchain platform by SAP. The solution enabled Golden Agri-Resources and other Unilever suppliers to create tokens that mirror the material flow of palm oil throughout the supply chain and capture the unique attributes of the oil's origin. By doing so, Unilever can identify the percentage of palm oil products purchased from a sustainable source and track it to the end consumer product. This increased traceability and transparency help the company to ensure that its palm oil supply chain meets its sustainability objectives (Unilever, 2022).

According to Andrew Wilcox, Senior Manager of Unilever's Sustainable Sourcing and Digital Programs, the blockchain technology has the potential to capture and transfer data about the commodity, including first-mile data about the crops, such as location and conditions under which they were grown or harvested. This provides additional transparency to the movement of the commodity and visibility of its unique attributes, which is not currently available in the status quo. As a result, Unilever can make informed decisions about its supply chain and ensure that it is sourcing palm oil sustainably (Lisa Johnston, 2022).

Unilever's blockchain pilot is an innovative solution to enhance transparency and traceability in its palm oil supply chain. By using blockchain technology, the company can ensure that its consumers are getting the products they want while maintaining its sustainability objectives. The ability to capture and transfer data about the commodity is a significant breakthrough, and it has the potential to revolutionize the way companies track and monitor their supply chains. Unilever's blockchain pilot is an excellent example of how technology can be used to promote sustainability and ethical practices in business.

1.7. Research Gap

Many individuals associate blockchain with the emergence of bitcoin as the primary cryptocurrency. Nevertheless, blockchain is not solely limited to bitcoin; it is a technology for monitoring transactions that has the potential to be groundbreaking. The increasing interest in blockchain technology in recent years has been driven by its potential to enhance the security, transparency, and data integrity without any third-party organization in control of transactions.

In particular, in the agro-food sector, it is essential to ensure food safety and identify the source of the food to locate possible contaminations. Therefore, supply chain accountability and traceability are crucial and the implementation of blockchain technology in this very sphere can provide enhanced food safety as well as increased operational efficiency. However, companies using blockchain technology in this sector mostly have opted to develop their own private blockchains and ERP softwares. While this approach can still increase the operational efficiency and supply chain transparency, it comes with the high costs of designing and implementing a state-of-the-art system. It requires hiring professional developers and yet, companies would face the risk of system bugs, as these new platforms have not been thoroughly tested.

The objective of this master's thesis is to address the research gap by proposing a practical method for adopting public blockchain platforms in the agro-food industry to enhance supply chain efficiency at a lower cost. The proposed method offers improved efficiency and streamlined business processes that result in reduced operational costs. Additionally, the platform used is easier to access, has fewer bugs, and requires less investment to implement.

Moreover, Public blockchain platforms offer greater transparency, security, and a higher degree of decentralization, making them ideal for use in the agro-industrial sector. To address the research gap, the system was explained on the case study of Charoen Pokphand Foods to be an example of practical implementation of public blockchains on agro-industrial sector to trace the origin of the food, increase the transparency of the supply chain and, most importantly, to streamline the business process. By addressing this research gap, the study will contribute to the existing knowledge on blockchain technology and provide insights on how public blockchain platforms can be adopted and integrated into the agro-industrial sector to enhance security and transparency in data sharing and management.

1.8. Summary of Chapter 1

Blockchain technology is a decentralized database that records all changes as a chain of blocks, encompassing its components, types, and smart contracts. It acts as a distributed registry or ledger upheld across multiple network nodes, each with a complete copy of the registry. Updates are compiled and written to the registry independently of other nodes and are later voted on by the nodes to guarantee a majority consensus. This consensus algorithm ensures that the distributed ledger is updated, with the final agreed version stored in each node. This technology enables disintermediation in almost any sector, allowing any asset or data to be transferred directly between peers without requiring a trusted intermediary. Smart contracts are software scripts triggered by blockchain transactions and validated across the network. Upon meeting the predefined conditions, the blockchain transparently executes the code without any external interference. Smart contracts operate transparently, reducing trust issues between parties, and are a digital substitute for the usual documents that seal the deal. Their features include precision, security, digital footprint, automation, immutability, global access, and transparency. They encapsulate and replicate the terms of real-world contracts in the digital domain. Blockchain oracles are third-party services that provide smart contracts with external information, making them an essential element of the blockchain ecosystem. These oracles provide a link between external and internal sources, and their ability to process data varies. Hardware oracles connect to external hardware or computer peripherals, while software oracles interact with online sources of information. When creating simple oracle patterns, it is common to categorize the direction (inbound/outbound) and initiation of data flow (pull/push) between on-chain and off-chain components.

Several blockchain platforms, including Hyperledger Fabric, Hyperledger Sawtooth, Ethereum, and Polygon, are discussed. These platforms offer benefits such as streamlined business processes, increased trust between network participants, and a competitive edge. They also use different consensus algorithms, such as Proof-of-Work, Proof-of-Stake, Proof-of-Authority, and Byzantine Fault Tolerance to validate transactions. Businesses can use these technologies to create decentralized applications, manage digital assets, and enhance security. Fungible and non-fungible tokens can be created for various purposes, such as loyalty points, stock shares, and digital goods. These technologies help businesses achieve greater efficiency, security, and innovation. In the business context, blockchain technologies can help organizations optimize their operations by improving transparency and trust between network participants. Decentralized applications can streamline business processes, reducing operational costs and increasing efficiency. Digital tokens like FT, NFT, and SFT can open up new revenue streams and enhance security and customer engagement. Hyperledger Fabric and Hyperledger Sawtooth are two options for businesses seeking to deploy enterprise-grade blockchain solutions. Fabric provides a modular architecture that can be customized to meet specific business needs, while Sawtooth is highly modular and allows for easy deployment of specific blockchain applications. Both use endorsement and ordering of transactions to achieve consensus. Ethereum is a popular platform for creating decentralized applications, and its use of smart contracts allows for automated and transparent execution of business logic. Its Proof-of-Stake consensus algorithm provides a more energy-efficient alternative to Proof-of-Work, which can be beneficial for businesses seeking to reduce their energy consumption. Additionally, Ethereum supports the creation of fungible and non-fungible tokens, providing businesses with new opportunities to monetize their assets and engage with customers. Polygon is a layer 2 solution that offers fast block confirmation times and sharding, which can help businesses achieve scalability and high transaction speeds. Its use of sidechains and Plasma chains allows for greater flexibility in deploying blockchain solutions tailored to specific business needs.

Over time, it has become evident to both companies and individuals that the revolutionary capabilities of blockchain extend beyond Bitcoin. Research has concluded that the operating principles and technologies behind blockchain have the necessary properties and potential for businesses looking to optimize their operations. By leveraging blockchain technology, businesses can enhance operational efficiency, reduce costs, and improve transparency and trust between network participants. However, instead of leveraging existing public blockchains that offer the same advantages, studies have predominantly researched adopting private blockchains and companies have opted developing these kind of blockchains. This overlooks the accessibility and implementation ease of public blockchains, which can provide enhanced security, traceability, and reduced investment costs. Consequently, there is a research gap in assessing the implementation of such systems that combine the benefits of private blockchains while offering higher security and lower costs. Addressing this gap would encourage other companies to adopt these systems for their own supply chain management needs.

Chapter 2. Public Blockchain Adoption: A Disruptive Innovation Perspective

2.1. Disruptive innovation theory

The concept of disruptive innovation theory was first introduced by Clayton Christensen in his book "The Innovator's Dilemma." It proposes that innovative technologies or business models, which initially target niche markets, can eventually grow and displace the dominant players in a given industry, thereby disrupting established companies. According to the theory, established companies often prioritize serving their existing customers and improving their existing products, which can make them vulnerable to disruptive innovations from outside their industry. Over time, these disruptive innovations can become mainstream and fundamentally alter the competitive landscape of the industry.

In his theory, Christensen describes two types of innovations: "sustaining" and "disruptive". Sustaining innovations enhance the qualities of an already existing product. Established companies introduce them in an existing market to gain a competitive advantage over their rivals. These improvements are valued and deemed significant by the "mainstream customers" (Clayton Christensen, 1997). Sustaining innovations aim to improve the performance of existing products or services, increase their efficiency, or add new features to keep up with changing customer needs. Sustaining innovations are incremental in nature and do not disrupt the market or the existing business model. Instead, they help companies maintain their competitive advantage, increase their market share, and retain their customers.

Disruptive innovations, on the other hand, either create a new market by catering to customers that were previously underserved or target less sophisticated customer groups that contribute only a small fraction of the market leaders' sales (Clayton Christensen, 2015). At the time of launch, disruptive innovations have lower quality than established products, at least in terms of the performance metrics that are essential to mainstream customers (Anton Ron Adner, 2002). However, they are sought after by a smaller group of customers with lower expectations for traditional product features.

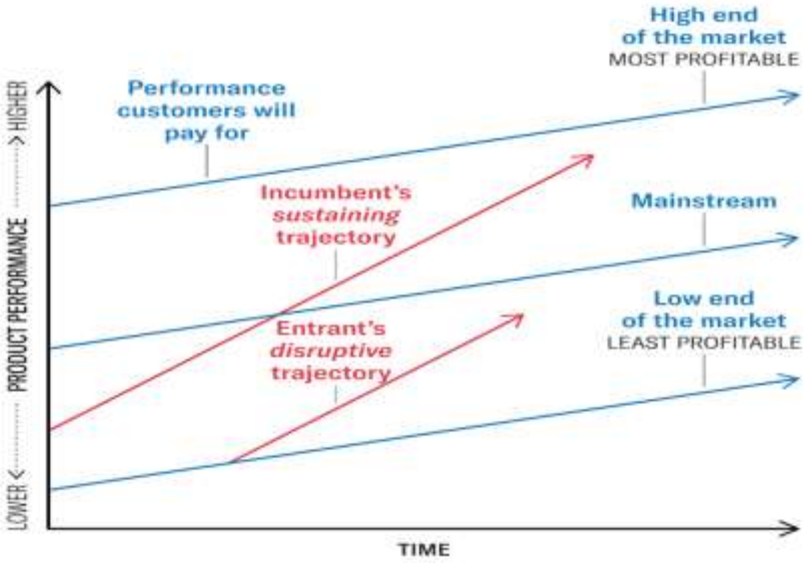

Figure 4. "What is disruptive innovation?" (Clayton Christensen, 2015)

In the illustration shown in Figure 4, the red lines depict the progress in the performance of products or services, while the blue lines represent the willingness of customers to pay for such performance. Established companies tend to introduce better products or services that cater to the needs of the upper end of the market, as it is more profitable for them. However, this often results in neglecting the low-end and mainstream customers. This provides an opportunity for new players to capture the neglected less-profit segments. Participants in the disruptive trajectory, represented by the bottom red line, enhance the performance of their offerings to challenge the dominance of established players and move up the market to where profitability is also high for them.

Disruptive innovations are a crucial aspect of the business world. They have the potential to fundamentally alter the dynamics of the market, opening up new opportunities for businesses to thrive. These types of innovations typically result from in-depth research and development efforts, and they can lead to substantial improvements in products and services.

However, along with these opportunities come challenges that companies must be prepared to face. One of the primary challenges is the need to adapt to new market conditions. Disruptive innovations can completely transform the competitive landscape, leaving companies that fail to adapt behind. Another challenge is the need to invest in new technologies and processes. Disruptive innovations often require significant investments in research and development, as well as new manufacturing techniques and supply chain strategies. Companies that are unwilling or unable to make these investments may struggle to compete in the new market.

Low-end disruption and new-market disruption are two types of business disruptions described in Clayton Christensen's book "The Innovator's Dilemma".

Low-end disruption occurs when a company offers a product or service that is cheaper and simpler than the existing market leaders. This kind of disruption often targets customers who are overserved by the current market offerings and are looking for a more affordable alternative. Low-end disruption can be a threat to established companies that focus on high-end products or services and do not want to compromise their quality or profit margins.

New-market disruption, on the other hand, occurs when a company creates a market where none existed before. This type of disruption often targets non-consumers, people who were not previously using a particular product or service because it was expensive, complicated or inconvenient. By offering a simpler, cheaper and more accessible solution, the company can create a new market and disrupt the existing players.

Low-end and new-market disruptions present opportunities for innovative new companies to enter a market and compete with established players. However, established companies can also benefit from these disruptions by developing their own low-end or new-market offerings. Recognizing the different types of disruptions can help businesses anticipate and respond to changes in their markets, and position themselves for long-term success.

2.2. Disruptive Potential of Blockchain Technology

Blockchain technology alone may not disrupt business models. However, the various applications that utilize this technology have the potential to bring about efficiency innovations, such as lowering transaction costs and improving process speed. It is important to note that not all blockchain-based applications are inherently disruptive, and blockchain technology itself cannot be classified as a disruptive innovation.

It is crucial to understand that blockchain technology is not a one-size-fits-all solution that will automatically lead to disruption. Instead, it is the specific applications of the technology that have the potential to disrupt existing business models. For example, blockchain-based applications can help to reduce the need for intermediaries in certain industries, which can significantly reduce costs and increase efficiency. Public blockchain platforms and Layer-2 scaling solutions, including Polygon, provide unique features, such as decentralization, immutability, and transparency, and have the potential to revolutionize the supply chain industry. For instance, as an open-source platform, Polygon provides accessibility and customization that supports disruptive advancements in using blockchain in supply chain management as by leveraging the open-source nature of Polygon, businesses can push boundaries, explore new possibilities and create their own transformative customized solutions that have the potential to disrupt traditional supply chain managements and business models. With blockchain applications, supply chain stakeholders can securely and transparently exchange information and assets without the need for intermediaries, significantly reducing costs and improving efficiency. One of the main benefits of blockchain in supply chain management is the ability to provide end-to-end traceability. By utilizing specified blockchain applications, companies can track products from the point of origin to the end consumer, ensuring that products are authentic and ethically sourced. This is especially important in industries such as food and pharmaceuticals, where quality and safety are paramount. Moreover, blockchain solutions can help to prevent fraud and counterfeiting in the supply chain. The technology can provide a tamper-proof record of transactions, making it difficult for bad actors to manipulate the system. This can help to reduce the risk of product recalls and reputational damage.

Bottom line, not all blockchain-based applications have the potential to be disruptive. Some applications may simply improve existing processes of the very business that they have designed for, without fundamentally changing the industry or inspire other competitors to adopt similar systems. Therefore, it is important to broaden the body of knowledge in a manner that encompasses the entire industry, encouraging progress and development that can be customized on open-source platforms rather than relying on private systems tailored to specific businesses. The technology itself is not inherently disruptive, it can be customized to optimize processes within individual businesses. However, the true potential for disruptive innovations arises when the technology is adopted industry-wide, allowing the whole industry to benefit and implement it for their own operations.

2.3. Summary of chapter 2

According to Clayton Christensen's theory of disruptive innovation, innovative technologies or business models can eventually grow and displace dominant players in a given industry, which can disrupt established companies. Christensen identifies two types of innovation: sustaining and disruptive. Sustaining innovations enhance the qualities of an already existing product, while disruptive innovations create a new market by catering to customers that were previously underserved or targeting less sophisticated customer groups.

Low-end and new-market disruptions provide opportunities for innovative new companies to enter a market and compete with established players.

Although not all blockchain-based applications are disruptive, Blockchain technology can be considered a disruptive innovation, as it has the potential to transform various industries and markets, including supply chain management. With its distinctive features of transparency and security, Blockchain has significant potential to bring about a revolutionary improvement in efficiency across various industries.

The blockchain technology itself is not disruptive, it provides enhanced transparency and lowered operational costs for the businesses that have designed it individually to streamline their own business operations. Certain private blockchain-based applications can significantly reduce costs and increase efficiency by reducing the need for intermediaries in certain industries. Hence, blockchain's disruptive potential emerges when it is embraced by the entire industry. Public Blockchain platforms such as Polygon, offer disruptive attributes like decentralization, immutability, and transparency that have the potential to benefit not only individual businesses but the entire industry as a whole. They have the potential to revolutionize the supply chain industry, helping prevent fraud and counterfeiting, reducing the risk of product recalls and reputational damage, and providing end-to-end traceability.

Chapter 3. Methodology of research

3.1. Research strategy

The case-study method is typically considered within the qualitative research paradigm. As a qualitative research approach, case-study assumes that individuals' interpretations of the world around us are shaped by the context in which they exist. The basic idea behind this approach is that subjective opinions and assessments play a significant role in shaping our actions. When conducting a case-study, the objects that surround the individual or group being studied are imbued with a specific meaning for that particular group or individual. Case-studies are used to answer questions such as "how" and "why", which differ from the quantitative questions that are typically asked in other research methods. Qualitative research examines a situation from a natural perspective, with the goal of providing meaning or interpreting phenomena in terms that are closely associated with how people naturally view them (Norman Denzin, 1994). The researcher has freedom to choose the method of data analysis, but the goal is to obtain new knowledge about a particular object. The data collected is usually non-numerical and requires interpretation, making it subjective in nature. However, this subjectivity allows for a deeper understanding of the context and the experiences of the participants, making it a valuable tool for exploring complex phenomena.

The most important characteristic of a "case" is its inherent limitations. This means that a case, case study, or phenomenon has well-defined, though not always obvious, boundaries (Robert Yin, 1994). It is important to note that qualitative research, in general, and the case-study method, in particular, seek to develop an understanding of the intricacies of a phenomenon, rather than to explain it statistically. Consequently, case-studies are often used in situations where the researcher is interested in exploring a unique or complex situation, such as a particular event, group, or organization. The case-study method is a valuable tool for researchers seeking to gain an in-depth understanding of a complex or unique phenomenon. By providing a detailed and nuanced analysis of a particular situation, the case-study method offers insights that would not be possible with other research methods. However, it is important to recognize the limitations of the case-study method and to use it appropriately, given the specific research question and context.

The integration of public blockchain technology into business processes in supply chain management, is a rapidly developing field where new practices are constantly arising within a complex environment. As a result, conducting research in this subject can be complex, and the findings may not be easily transferable to other contexts or the complexity of the processes may not be adequately reflected in the model. All this has made the use of a study method such as a case study essential. Although survey methods can be useful for comparing results and attitudes within the same context, they may not be as suitable for comparisons across multiple organizations with different contexts. Because complexity is inherent in the blockchain environment, a case study method that allows researchers to observe and accurately assess the impacts of those contexts is likely to be necessary. Case studies continue to be one of the best ways to ensure that researchers make valid observations and contributions to the body of knowledge regarding operations management including blockchain technology implementation.

In order to identify the most suitable case study for examining the implementation of public blockchains in a simplified manner for an entire industry, specific criteria need to be considered. Industries characterized by intricate and complex supply chain management are highly suitable for this purpose, with the food industry being a prominent example. The food industry is distinguished by its elaborate supply chains and the indispensable requirement for traceability to guarantee the safety of food products and, subsequently establish trust among consumers. Additionally, adopting blockchain systems in the food industry can lead to reduced intermediaries, enhanced information security, and decreased operational costs. Selecting an appropriate case study requires choosing a company that is large enough to justify the implementation of a new system. Furthermore, the chosen company should have a well-established reputation and a loyal customer base to facilitate the acceptance of blockchain-based tokens as a means of payment.

The case study selected for this research is Charoen Pokphand Foods Public Company Limited (CP Foods). CP Foods is a prominent agro-industrial and food conglomerate operating in the Asia Pacific region. With involvement in livestock (including swine, broilers, layers, and ducks) and aquaculture (shrimp and fish) businesses, the company holds a leading position in the industry. CP Foods was chosen as a case study due to its global recognition, its significance within the agri-food sector, and the existing requirement to improve its supply chain management in order to enhance its competitive edge.

Implementing blockchain systems in CP Food company can result in increased supply chain transparency, financial benefits such as establishing a new transaction network with company-specific tokens, and the potential to utilize funds for further investments. Additionally, the adoption of blockchain systems within CP Food company will not only contribute to its business processes but also serve as a roadmap for other companies in the industry to implement their own more simplified systems. This approach supports the disruptive potential of blockchain technology in revolutionizing supply chain management.

The research design for this case study analysis is qualitative in nature, using semi-structured interviews to collect data from key stakeholders involved in the supply chain management of Charoen Pokphand Foods. The interviews were conducted in person or via video conferencing, using open-ended questions to allow for a detailed exploration of supply chain processes of the company as well as identifying the feasibility of introducing blockchain technology into processes. The data collected from the semi-structured interviews was used to analyze and find the best solution for introducing blockchain technology into the company's supply chain. The information gathered from the interviews identify the most pressing supply chain issues that can be addressed with blockchain technology as well as potential blockchain implementation possibilities. Following data analysis, a roadmap for implementing the technology was developed.

3.2. Literature selection

The data was collected from a variety of literature on Blockchain technology, including reports, manuals, articles, academic research, whitepapers from the scientific databases Scopus, Emerald, JSTOR. In addition, blockchain-recognized publications as TechTarget, Consensys and Everledger, Deloitte and other publicly available information on blockchain technology were used to form a more comprehensive understanding of the topic. The data sources provide insights into the research area and the current state-of-the-art methods, while also identifying research gaps that need to be addressed by the researcher.

Analyzing the state of the art is an important part of the research process that enables the researcher to comprehend the most recent developments in their field of study. By examining the existing research, the author can identify gaps in the literature that require further exploration. In this instance, the data sources were chosen meticulously to provide a comprehensive evaluation of blockchain technology and its current state-of-the-art methodologies. The analysis aimed to identify the fundamental concepts and themes associated with blockchain technology, including its history, architecture, consensus mechanisms, applications and serves as a starting point for future investigations.

3.3. Data collection

Qualitative designs are adaptable and can be modified to gather significant and relevant data. Regardless of the methodology, qualitative designs usually involve a small sample size to obtain a profound comprehension of the studied phenomenon or process. Data collection is carried out through interviews, questionnaires, documentation, archival records or field observations, often occurring simultaneously with data analysis to inform subsequent sampling and data collection (David Silverman, 2013).

The collection of primary data can be accomplished through various methods, but it is typical for this sort of research to adhere to the principles of the scientific method (Dana Driscoll, 2010). This entails creating research questions or hypotheses, gathering, and analyzing empirical data, and drawing conclusions that are supported by evidence. Primary data sources for the master thesis were internal and external company’s documentation, official websites, and the data from semi-structured interviews with Charoen Pokphand Foods Company representatives. Semi-structured interviews conducted in person or via video conferencing with key stakeholders involved in supply chain management at Charoen Pokphand Foods. The interview questions were based on the objectives and covered different processes and procedures in the supply chain of Charoen Pokphand Foods Company, including an overview of logistics processes, types of product batches, conditions for transportation of products, and documentation. Participants were selected based on their roles in supply chain management in Russian and Thai divisions including chief legal officer, deputy vice president for sales (Russia), export managers, and supply chain managers.

3.4. Data analysis

The data collected from the interviews was analyzed using qualitative data analysis techniques. In order to identify key themes and patterns in the data, which were used to develop a comprehensive understanding of the supply processes that can be integrated with blockchain technology the thematic analysis was utilized.

Thematic analysis is a qualitative data analysis method that involves identifying patterns or themes in the data and interpreting them in relation to the research question or objective. Thematic analysis can be used to analyze different types of data, such as interviews, focus groups, surveys, and observational data, among others.

One of the main advantages of thematic analysis is its flexibility, as it allows researchers to identify and analyze themes in a way that is relevant to their research question or objective. This approach can be applied to both deductive and inductive research, as themes can be identified either based on pre-existing theoretical frameworks or emerging from the data itself (Lorelli S. Nowell, 2017). Thematic analysis involves several stages: first, the researcher familiarizes themselves with the data by reading or listening to it several times. Next, identifies patterns and themes within the data. These patterns may be identified through codes, which are labels or tags that capture a particular concept or idea. The researcher may create a coding dictionary to guide this process.

Once patterns and themes have been identified, the researcher organizes the data into categories. These categories may be based on the research questions or may emerge from the data itself. Finally, the researcher interprets the data by drawing connections between the categories and themes, and the research questions.

Thematic analysis is a valuable method of qualitative data analysis that allows researchers to identify and analyze patterns or themes in the data. Its flexibility and adaptable nature make it a popular choice for researchers across different disciplines and research questions.

The findings from this analysis revealed that the company's current supply chain processes could be modernized through the use of blockchain technology.

3.5. Expected findings

Based on the data collected during the research, the initial steps for establishing a roadmap framework for the implementation of blockchain technology in supply chain management at Charoen Pokphand Foods were outlined:

1. **Abstract Representation of CPF as a Supplier of Various Products**: The first step is to create an abstract representation of Charoen Pokphand Foods as a supplier of a spectrum of various products, including feed, pork, broiler, and shrimp. This will include multiple points of product dispatch, different types of product batches, an overview of logistics processes, conditions for transportation of products, and tracking software systems.
2. **Analyze the Current Supply Chain**: The current supply chain processes and stages of Charoen Pokphand Foods will be analyzed to identify the existing inefficiencies, bottlenecks, and pain points. This analysis will help in identifying the specific areas where blockchain technology can be implemented to improve supply chain transparency and efficiency. Such areas may include manufacturing, inventory management, supply chain control, instant cargo tracking, and product quality control.
3. **Define the Blockchain Solution**: A blockchain solution will be defined based on the identified pain points and inefficiencies in the supply chain. This solution will include the type of blockchain, consensus mechanism, smart contracts, and other relevant features. A list of processes and smart contracts involved in these processes will be created, taking into consideration transportation processes of products including various modes of transportation, transportation conditions, integration with cargo sensors, and metadata from third-party logistics (3PL) operators. The purchase process using stablecoins (USDT, etc.) and CPF tokens will also be considered, along with the storage process, order formation, and consolidation in supplier warehouses. A list of entities will be created and linked to different token standards, addresses, and metadata, along with an explanation of why they are suitable for the exact format. For example, factories will be represented as unique combinations of wallet addresses and smart contracts, documents as NFT tokens

ERC-721, product units as SFT tokens ERC-1155, and CPF token as FT tokens ERC-20 as a means of procurement and reducing exchange rate differences and financial risks.

4. **Breakdown of Stages and Resources**: A breakdown of the stages that need to be completed over time and how long each one takes will be provided. Each stage will be described separately, and an estimate of how many developers are needed, what type of developers, and the cost of their work in US dollars will be provided.

The establishment of a roadmap framework for implementing blockchain technology in supply chain management at Charoen Pokphand Foods is a significant step towards improving transparency and efficiency in the supply chain processes. With a well-defined blockchain solution and a thorough breakdown of the stages and resources needed, Charoen Pokphand Foods can implement this technology successfully and reap its benefits.

Chapter 4: Implementing Public Blockchain for CP Foods' Supply Chain Management

4.1. CP Foods Abstract Representation

After carefully analyzing the information gathered from interviews, a set of initial codes was created to represent the various meanings and patterns that emerged during the interviews. These meanings and patterns were examined carefully, and new interpretations were made to fully capture the essence of the data. Interesting excerpts were highlighted, and appropriate codes were applied to them. This allowed for a thorough understanding of the data.

Figure 5. Thematic analysis

In order to comprehensively define processes and develop a roadmap for implementing blockchain technology in supply chain operations, interviews were conducted with Charoen Pokphand Foods representatives from Thailand and Russia. During the interviews analysis, various themes emerged and were identified after thorough analysis and structuring of the data. These themes were categorized and represented by different codes that were related to different aspects of supply chain operations. The created themes provided valuable insights regarding challenges and opportunities that exist in the current supply chain industry, as well as processes that could be modernized by blockchain implementation.

The theme of "Production certification" relates to the types of certifications required for food production operations. As a producer, it is essential to establish an updated food safety management system that covers practically all stages of production. This includes identifying the potential hazards and critical control points in the supply chain, implementing control measures to prevent or reduce the risk of contamination, and monitoring the effectiveness of these measures.

“HACCP is a preventive system aimed at preventing problems before they become a threat to the safety of food products. Hence, the need to plan measures to correct potential deviations from established critical limits. And the actions that will be taken in case of problems at critical control points”. “ISO includes the concept underlying HACCP, which is the identification and control of critical production points. As a producer, the company must establish an updated food safety management system that covers practically all stages of production”.

"Preparation for distribution" contains information about product packaging and labeling. It is a necessary step for the subsequent sale of products through sales to wholesalers, the sale of products directly, or through 3PL providers. “Product labeling takes place at the production stage after the product is packed into individual and/or group packaging. After packing, the product is labeled by applying labels to the tray, pad, or box manually or automatically. In the first case, the label is hand-applied to each product, while in the second case, an automatic applicator is used on the line”.

Storage conditions for products require a lot of attention, as they vary depending on the production methods, the type of product, and the route to the end consumer. The company's storage facilities are equipped with the state-of-the-art technology that ensures the safety and quality of products. In addition, the company and 3PL provider conduct regular inspections to ensure that the products meet the company's high standards for safety and quality. During these inspections, checks are performed to detect any signs of damage, contamination, or other issues that could compromise the product's quality. “Our storage facilities are equipped with state-of-the-art technology that ensures the safety and quality of our products. The products are also inspected regularly to ensure that they meet our high standards for quality and safety. Regarding storage conditions for product delivery, there are four different types of conditions to consider: ambient, air, cold chain, and freezer”.

The "Distribution Channels" theme contains information on distribution channels in both the Thai and Russian markets. In Thailand, the company relies on third-party logistics (3PL) providers for the transportation of products to retailers. This is a crucial aspect of their supply chain management as it ensures that the products are delivered to the retailers safely and efficiently. By working with 3PL providers, the company can take advantage of their expertise in managing logistics and transportation, allowing them to focus on their core business activities. “This service ensures that products are transported in dedicated trucks that are not shared with other companies, thus ensuring maximum safety and security for goods during the transportation process”. In contrast, in Russia, the company's main distribution channel is through wholesalers who purchase the products and either sell them independently or through retailers. “The main volume is taken by wholesalers, who either independently sell the product or through retailers”. This approach has its own advantages, such as allowing the company to reach a wider customer base and expanding their market share. However, it also presents some challenges, such as the need to carefully manage the relationships with the wholesalers to ensure that they are representing the company's products effectively and accurately.

When it comes to exporting products, there is a lot to consider. It was crucial to pay attention to “Export transaction" theme as it encompasses the Incoterms rules that CPF relies on for its exports. These rules are essential to understand because exporting involves a multitude of steps, and it's crucial to allocate obligations and financial costs properly between the parties to the sales transaction. For instance, the Incoterms rules dictate which party is responsible for each step in the exporting process, such as loading the goods onto a vessel, obtaining insurance, and paying for transportation. These rules ensure that both parties understand their respective responsibilities and rights, which is essential for a successful transaction. “CIF is often used because sea transportation is the most optimal. In this case, the contractual price includes the final cost of the product, taking into account export registration with payment of export duties, loading of goods onto the vessel, cost of freight to the destination port and marine insurance”.

The interview also touched on processes in the supply chain that the company would like to optimize. The interviewee made a statement regarding the export process. The statement highlighted the common occurrence of document exchange taking longer than expected, which can lead to delays and errors in other processes. These delays are often associated with paper-based systems, which are prone to errors and can cause further slowdowns in the process.

One of the most common problems in the supply chain was mentioned, which is related to packing and maintaining the required temperature during transportation of frozen products. Furthermore, the interviewee noted that after selling the product to the first buyer, only the Federal Service for Veterinary and Phytosanitary Surveillance (Rosselkhoznadzor) can track this batch of products further. “Regarding export, when it comes to document exchange, it's not uncommon for the process to take longer than expected. Unfortunately, this can have a domino effect on other processes that are dependent on the timely exchange of information. This is especially true for paper-based systems, which can be prone to delays and errors that can further slowdown the process”. “One of the most common problems in the supply chain is related to packing for frozen products as well as tracking and maintaining the required temperature during transportation. After selling the product to the first buyer, only the Federal Service for Veterinary and Phytosanitary Surveillance (Rosselkhoznadzor) can track this batch of products further”.

4.2. Identifying Challenges Through Analysis of the Existing Supply Chain

Charoen Pokphand Foods Company is a well-known supplier in the food industry. Established in 1978, the company has grown to become one of the largest producers of animal feed, livestock, and food products in Asia. It operates in more than 20 countries, including China, Russia, Vietnam, and Thailand, and has a reputation for providing high-quality products and services.

Based on interviews with representatives of Charoen Pokphand Foods in Russia and Thailand, it was discovered that some operations and work principles in the supply chain differ between the two countries. However, there are common processes that can be optimized through the implementation of blockchain technology. In Russia, CPF lacks organized data sets about the company's states and processes, which hinders their understanding of the movements and states of goods on the free market after the first sale. Even when using the Mercury system, only the Rosselkhoznadzor can trace the batch of products after they have been sold to the first purchaser. On the other hand, CPF Thailand relies on SAP software for supply chain management and optimization and works with a permanent third-party logistics provider (3PL). The 3PL company provides CPF with data about the product up to its arrival on the store shelf. In Thailand, operations and distributed channels are structured in such a way that they do not rely on wholesalers to sell their products, unlike operations in the Russian Federation where wholesalers take the main volume and either sell the product independently or through grocery retailers.

It has been observed that there is currently no uniform system in place for tracking goods from their origin to the end consumer. This has led to fragmented and disjointed processes, with multiple parties in the supply chain using different methods to track the products they handle. The lack of a standardized system means that there is no single, continuous system in place for tracking goods to the end consumer. Furthermore, there is presently no system that enables consumers to track the entire path of a product. This poses difficulties for consumers who wish to make informed choices about the products they purchase, as they are unable to easily access information about the origin of the product, the methods used to transport it, or the conditions under which it was produced.

4.3. Defining concepts

To enhance the efficiency of entity and process structuring, and to develop a successful roadmap for implementing blockchain technology in Charoen Pokphand Foods' operations, the following concepts and groups of concepts were introduced:

Entities

Production Entities are the locations where CPF goods are produced. They are situated in different countries around the world.

Goods are the units of production that are either packaged for consumers or without packaging. They are produced by production entities and are ready for storage, packaging, transport, and sale. Goods can be divided into those that are packaged for the end consumer and those that are intended for the professional market, such as restaurants, farms, and markets, and are sold without packaging or in professional packaging. Wholesale and retail batches of bulk goods, such as shrimp or pork, are considered professional goods, which are supplied for processing and sale to the population at retail.

Customer is a buyer of CPF goods under specific conditions, whether located in the country of production or abroad. It is important to note that the customer is not the end consumer of the product. Customers of CPF include a range of market points, such as supermarkets, restaurants, and public catering points. These customers purchase CPF goods wholesale and then sell them at retail to the end consumer. Additionally, some customers may operate as logistics or wholesale intermediaries, purchasing CPF goods and then reselling them to their own clients.

Consumer is the final retail buyer of CPF goods who will directly consume the product.

Order is a certain amount of different goods that the customer ordered at a certain point in time.

Product Batch is a certain amount of different goods combined to achieve certain goals such as storage, consolidation, maintenance of the product matrix, etc.

Freight is a product batch that has undergone packaging, labeling procedures, and has been accepted for transportation by the relevant carrier.

Carrier is transportation company or logistics operator that acts on behalf of clients or the CPF itself, or the corresponding division of the CPF that is responsible for logistics and transportation of goods.

Warehouse is a place for storing goods in compliance with their storage conditions. It can be a customs warehouse for temporary storage, temporary storage warehouse in the customs control zone of the terminal or airport.

Processes

Packaging is the complete cycle of professional standardized packaging and preparation of goods for transportation. For example, packaging goods in boxes and subsequent palletizing.

Labeling includes the processes of labeling individual goods, labeling of cargo places, and cargo itself.

Transportation modes

Road transport refers to the transportation of goods by road from warehouse A to warehouse B, in accordance with all requirements and norms. The CMR (Convention relative au contrat de transport international de Merchandise par Route) transport document is used for this type of transport.

Sea transport refers to the transportation of goods in containers by water from warehouse A to warehouse B, in accordance with all requirements and norms. The Bill of Lading transport document is used for this type of transport. As CPF goods are food products, LCL transportation is not considered, in which various goods from different shippers can be transported in one container.

Railway transport refers to the transportation of goods in containers by railway from warehouse A to warehouse B, in accordance with all requirements and norms. The railway transport document or the Bill of Lading (in some countries) is used for this type of transport. As CPF goods are food products, LCL transportation is not considered, in which various goods from different shippers can be transported in one container.

Conditions / Parameters / Information

Responsibility is a defined and legally understood concept that determines which participant in the supply chain (whether it be the client, carrier, warehouse, or CPF) is responsible for preserving goods and ensuring proper conditions during transportation and storage.

Storage Conditions refers to the minimum and maximum temperature, humidity, and sanitation parameters within which goods can be stored without a loss of quality.

Shelf Life is the period during which goods are fit for consumption or use, provided that the conditions for proper storage and transportation are met.

Typical Documents

Contract assumes agreement between CPF and its partners.

Invoice refers commercial invoice for goods or services.

Packing List is document containing information about the weight, volume, and cargo of the shipment.

Bill of Lading includes CMR, Bill of Lading, and any other forms of bills of lading accepted in any country of the world.

Veterinary Control Documents is package of documents for veterinary control during customs procedures.

Permitting Documents is package of other permitting documents, including various certificates, for control during customs and other procedures.

Commercial Act refers to the main document confirming the circumstances of loss, shortage, damage, or destruction of the transported cargo. It is drawn up by the carrier and used to determine the responsibility of the carrier, shipper, and consignee for the damage caused.

4.4. Defining blockchain solution

Based on reliable research on blockchain technology, three distinct approaches to implementing blockchain technology in agricultural enterprises were identified. These approaches can bring numerous benefits to the industry, including increased efficiency, transparency, and security.

The first approach is Public Blockchain Solutions. These networks are open to anyone who meets specific requirements and are generally transparent and decentralized, with users able to participate in consensus mechanisms. Examples of such networks include Ethereum Mainnet, and Polygon. These blockchains can communicate with each other, allowing for the exchange of data and assets between different networks. This opens up new possibilities for cross-border transactions and collaborations, which can be a significant advantage for agricultural enterprises. However, there are some downsides to Public Blockchain Solutions. Gas fees for transactions can be significant on some networks, and some networks can be relatively slow. Moreover, all transaction information is publicly available through Scan services, which can be a disadvantage for businesses that require confidentiality.

The second approach is Private Blockchain Solutions. Controlled blockchains are available only through invitations, franchises, or other paid mechanisms. They are used in private businesses and designed for specific tasks. These blockchains are managed by a small group of validators who make most decisions on the network. While these solutions can provide a high level of security and confidentiality, there are centralization risks, risks of copying and selling information to the public, dependence on validators supporting the network, significant investments in the technology stack, complexity of development, high cost and/or difficulty in hiring developers, and some networks can be relatively slow.

The third approach is Test Blockchain Solutions. Testnets are blockchains based on the same underlying technology stack but designed for testing and experimentation purposes. They are designed to simulate the behaviour and functionality of a real-world blockchain network without the risks and costs associated with deploying a production-ready blockchain network. They can be a great way to start working right away and create a Minimum Viable Project (MVP) to launch the initial version of the system and develop it with the minimum set of features required to gather feedback for further development. They are easy to transfer to a public network. Many developers are available in the job market, and there is the possibility to switch to one's own blockchain fork later. Moreover, gas and any tokens are free. However, there are also some downsides to Test Blockchain Solutions, such as a low level of security, relatively slow networks, and all transaction information being publicly available. Additionally, the network may be closed (centralized), which can limit its use for agricultural enterprises.

After considering various approaches and analyzing blockchain networks, technologies, services, and programming languages, it is evident that CPF's development will benefit from the following technology stack.

Polygon is a Layer 2 network built on top of the Ethereum Mainnet that offers several advantages to users. In addition to its high security, low gas cost for transactions, high decentralization, and optimal transaction speed, Polygon also provides a variety of other benefits that make it a compelling option for agro-industrial enterprises.

For example, Polygon offers a wide range of developer tools and resources that can be used to build scalable and secure decentralized applications. This can be particularly useful for agro-industrial enterprises that need to process large amounts of data in real-time or that require high levels of security and transparency in their operations.

Moreover, the Polygon network is highly interoperable, which means that it can easily connect with other networks and blockchains. This can be especially advantageous for agro-industrial enterprises that need to interact with different stakeholders, such as suppliers, customers, and regulatory bodies.

However, one downside of using Polygon is that all transaction information is visible through Polygonscan. While this may be seen as a disadvantage, it is important to note that in the world of Web3 and modern methodologies, companies are expected to be transparent and open to the public, especially in the food industry. Therefore, CPF can benefit from being publicly open and transparent with their information, which can also help to build trust with their clients and partners. In contrast, using a closed blockchain network could pose a risk of closed information being stolen and published on the darknet, potentially causing reputational damage to CPF and its clients and partners. Thus, using an open blockchain network like Polygon can help to mitigate this risk. It is worth noting that public information in the blockchain may not include certain metadata, which will only be stored on the company's own servers. This metadata can be used to place the closed part of information that contains personal data of CPF's clients and/or partners.

Polygon is a blockchain network that was built with the goal of increasing scalability and interoperability among different blockchain networks. It is based on the open-source Ethereum network and uses the object-oriented programming language Solidity for self-executing contracts.

One of the key features of Polygon is its ability to support multiple layer 2 solutions, which allows for faster and more efficient transactions using smart contracts.

Smart contracts are becoming increasingly complex as they are designed to handle larger volumes of assets. This means that smart contract developers need to have a deep understanding of the tools and technologies available to them to analyze and test their contracts for vulnerabilities. Fortunately, there are tools that can make this process easier and more effective.

Two such tools are Consensys Fuzzing and Echidna. These Fuzzing as a Service (FaaS) tools are easy to use and powerful, providing developers with the ability to find bugs in their smart contracts immediately after writing their first specification. This ensures that any issues are identified and resolved quickly, reducing the risk of exploitation, and increasing the overall security of the smart contract. By using these tools, developers can be confident that their smart contracts are as secure as possible, protecting both themselves and their users from potential threats.

4.5. Linking entities to tokens and blockchain addresses

In order to maximize the potential of the Polygon blockchain implementation, it is essential to identify and link the relevant entities to their corresponding tokens and addresses. This process can be carried out by conducting a thorough analysis of the network and its various components. By doing so, not only can the efficiency and transparency of the system be improved, but also the security of the transactions can be ensured. Additionally, it is important to keep abreast of the latest developments and updates in the network in order to stay ahead of the curve and fully leverage its capabilities.

Products: Each released item corresponds to an SFT token of the ERC-1155 standard. These tokens relate to semi-fungible type of token, which is highly useful for releasing an unlimited number of batches of products. For instance, Production N has produced 10,000 consumer packs of chicken wings. As such, SFT tokens with the appropriate name and metadata should be issued on the blockchain in a batch of 10,000 pieces.

Producers: A unique blockchain address is created for each producer, which is controlled by CPF employees with appropriate access to the functionality.

Customers: Each customer who is familiar with Web3 technology sets up a blockchain wallet address on the Polygon network and authenticates with it on the CPF information systems via the Connect Wallet authorization feature. For customers who do not want to use Web3 technology, CPF may assign wallet addresses to ensure uniformity in CPF's internal accounting or restrict these customers by including the appropriate legal clauses in the company agreements.

Operators: All parties involved in the logistic and documentary processes required for the passage of each consignment from production to the end customer. These parties comprise of freight forwarders, carriers, logistics operators, warehouses, temporary storage warehouses, customs representatives, certification and authorization documentation companies, and other non-governmental companies that are either CPF or CPF Clients' partners. Each Operator independently sets up a blockchain wallet address on the Polygon network and authenticates with it in CPF information systems via the Connect wallet authorization function. Operators who choose not to create wallets and authorize in CPF applications will not be permitted to enter into contracts with CPF and CPF customers. However, this requirement is an added benefit, as large and modern companies are increasingly embracing the integration of modern IT solutions, making it more advantageous and secure to work with.

Unfortunately, it will not be immediately possible to connect to this blockchain-based CPF system state authorities such as customs and veterinary services, certification bodies, and integrate accounting systems such as Mercury in the Russian Federation. But decisions to integrate CPFs can be promoted in each country of the world through official events, as well as through public and media channels of communication between businesses and the government.

Documents: Each document sent with a shipment to CPF clients' needs to be linked to an ERC-721 standard NFT token. These tokens are unique and non-interchangeable, which is great for ensuring the uniqueness of each document and their accurate accounting. Additionally, the scanned and/or formalized copy of the document should be stored in the metadata of the respective NFT token. The CPF can easily and reliably control access to such metadata. The documents that usually accompany an order can differ depending on the country or region, but the main ones include commercial invoices, packing lists, bills of lading, certificates, and customs declarations. Blockchain-based document flow is incredibly convenient and secure for several reasons:

- Access to metadata, and therefore content, can be easily controlled, especially for documents that contain trade secrets.
- Documents cannot be tampered with, deleted, or altered by anyone involved.
- The origin and path of each document can be easily traced.
- The occurrence, alteration, and transmission of documents between participants is simple to track.

4.6. Description of processes and smart contracts

The next step is to create a matrix of processes and the necessary smart contracts for each of them. This will involve identifying the various stages of the supply chain, such as production, selling and buying, transportation, and determining the smart contracts that will be needed to facilitate each stage. Additionally, it will be important to ensure that the smart contracts are properly integrated with each other to ensure smooth and efficient operation of the supply chain. This will require careful planning and coordination between all parties involved in the supply chain process.

Production Process

In the production process, when goods are produced and accepted in the CPF warehouse, the corresponding SFT tokens should be issued in the same amount on the Polygon network and sent to the wallet address of the corresponding production. To enhance the process, it has been proposed to mark the consumer packaging of the produced batches of goods and introduce the mandatory marking of each item with a QR code that links to the respective SFT token on Polygonscan. This will be useful many more times in the future.

To minimize the cost of blockchain gas, tokens should be generated for goods issued in production batches rather than issuing each token separately. For example, if a production has shipped 10,000 packs of chicken breasts to the warehouse, the warehouse employees should manually or automatically label all goods in this batch and place them in the warehouse for further sale to customers and shipment to operators.

Before labeling a product, the responsible CPF employee should initiate a smart contract in which they: enter the number of products in the batch produced, select the required goods from the CPF goods database, sign the transaction with a wallet, such as the Meta Mask or a CPF company wallet. Once the Smart contract has received the necessary information and an employee signature, it generates 10,000 SFT tokens under a single ID token number and name, corresponding to the product name from the CPF database. These tokens are then sent to the wallet address of the corresponding Production.

Using the CPF application, it is easy to obtain links to the received tokens, convert them into QR codes, and apply them to the products within the batch before they are placed in the warehouse. According to the CPF, goods are labelled at the factory after they have been packed in individual and/or group packaging. Labels are then applied to the tray, substrate, or box either manually or automatically. In the first case, each item is manually labeled. In the second case, an automatic applicator or an oracle could be used on the line to securely label and subsequently transmit data regarding the product to the blockchain. Besides, based on the priority and the type of the products other information could also be tracked, such as, temperature, humidity, location, and general conditions of packaging.

Using hardware oracles would mitigate human errors and manipulations and enhance the correctness of data in the network by providing a secure and tamper-proof way to input data into the blockchain. Based on this information, it can be concluded that adding a corresponding QR code with a link to the SFT token of the product to the labels is a technically feasible task.

Purchasing process

There are two options for organizing the process of purchasing goods from CPF Manufacturing.

Option 1 - Fiat Payment (Current)

This is the traditional payment option under the contract with CPF in the currency agreed upon in the contract through traditional systems such as SWIFT and others.

The client makes the payment, CPF accounting sees the receipt of funds in the account and makes the appropriate entries in the CPF database, such as reserving goods in the warehouse for a particular client or allowing shipment to the first operator.

Option 2 - Native CPF Token Payment (Proposed)

Depending on the legislation of a particular country, an effective and convenient payment option can be considered in native CPF tokens. CPF can issue its own native token and subsequently receive payment in this token for goods.

Proposed Properties of CPF Token

Ticker: CPF

Token contract address: TBA

Decimals (number of decimal places of the token): 6

Network: Polygon

Standard: ERC20

Token type: stablecoin with a fixed exchange rate

In order to maintain the desired stability of the tokens, they are backed by a reserve of fiat currencies equal to the amount of tokens in circulation. For example, when conducting transactions in Russia, the number of tokens in circulation is matched with the amount of Russian rubles held in the company's bank account.

Benefits of Using CPF token By selling CPF tokens to suppliers:

The company can immediately reinvest the funds for its own needs, essentially receiving an upfront payment for goods that have yet to be produced. The company may offer incentives such as discounts upon fulfilling payments through CPF tokens rather than fiat currencies to encourage and regulate the purchase of CPF tokens by customers. CPF can also implement an appropriate pricing policy to further incentivize CPF token use. The company can also establish customer trust by ensuring that CPF tokens can be immediately and inexpensively converted to fiat currency, providing customers with instant liquidity. This not only allows customers to benefit from the company's incentives, but also provides them with a sense of security when using CPF tokens for payment. As for other benefits associated with using CPF tokens for Clients, clients who have free floating capital and are certain that it will be used for the planned purchase of CPF tokens find it more advantageous to keep the funds in CPF tokens for the planned purchase of goods at a discount. Customers paying with CPF tokens have an advantage in shipment queues and/or production times over those customers who purchase with fiat money. Win-Win Model CPF sells 100,000 CPF tokens on its website at an exchange rate of 1 CPF = 1 USDT. The client buys 100,000 CPF tokens for 100,000 USDT, knowing that they will purchase goods for that amount during the next month and that they have some funds available. CPF reinvests the 100,000 USDT it receives for its current production needs. The client then buys goods from CPF in CPF tokens, with prices 3-7% lower than the price list in dollars. In addition, both the seller and the buyer benefit from the absence of commissions from banks, payment systems, exchange control authorities, and other fees. Transaction fees at Polygon are extremely low, under $0.7, and the transaction speed is much faster than a bank transaction, ranging from a few seconds to maximum half an hour. While banking transfers from one country to the other, depending on the countries involved and type of transaction might take up to 5 business days.

Transportation and Storage processes

This section outlines the steps involved in moving goods between participants. Operators are responsible for the logistical and documentary processes required for each shipment to move from production to the final consumer. The process of moving NFT and SFT tokens between participants' wallets works as follows:

Production creates the goods and mints SFT tokens for each product on its wallet.

Customer pays for the goods with CPF tokens, transferring them to the CPF wallet or using fiat currency in accordance with the payment terms in the contract with CPF.

Production assembles batches of goods ordered by the **customer** from SFT tokens and generates the corresponding NFT Document tokens for each batch of goods, sending all the tokens for the corresponding batch to the first **operator** when shipping the batch of goods: SFT tokens for goods and NFT tokens for documents.

Operator sends all the tokens for the order to the customer’s wallet when transferring the batch of goods to the **customer**: SFT tokens for goods and NFT tokens for documents.

Each subsequent **customer** and **operator** send the corresponding tokens to the next participant in the process from their wallet.

If it is necessary to divide the batch of goods into smaller ones, the **customer** can do so through the CPF application by launching the corresponding smart contract.

If any product damage is detected at any stage, the SFT tokens for the damaged goods are burned by sending them to the address 0x0000000000000000000000000000000000000000. Null addresses are generated specifically for proof-of-burn. Token burns occur when tokens are intentionally sent to unusable wallets to remove them from circulation. This address is called the burn address or diner address. It cannot be accessed or assigned to anyone.

After the sale to the final consumer, the retail **seller** must initiate a smart contract that will send the tokens for the sold SFT goods to the technical CPF address, which is not accessible to anyone. The retail **seller** should transfer all sold tokens to this address once a day. This will allow tracking sales with accuracy down to the date without spending extra funds on transaction gas.

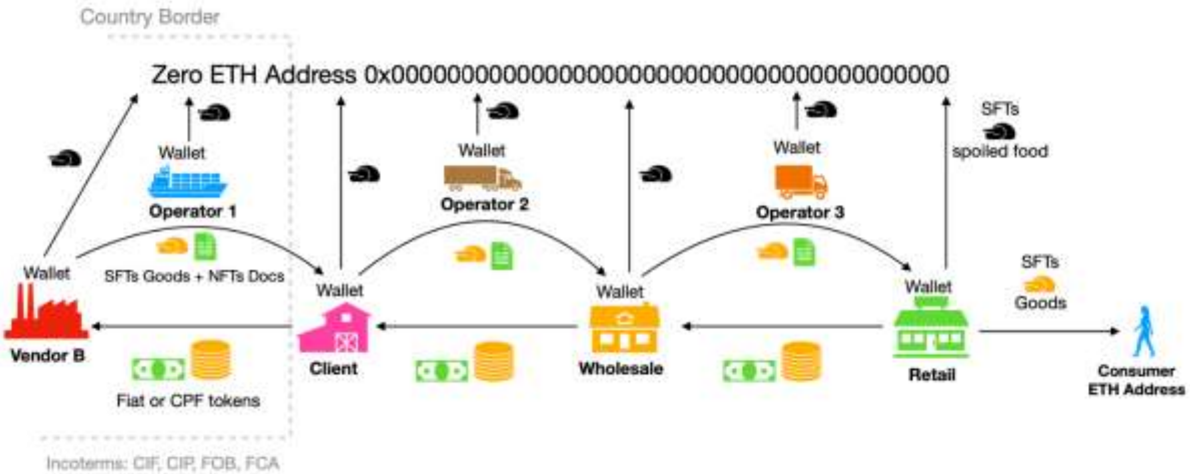

Figure 6. CPF supply chain on blockchain

Custom Clearance processes

Three options are available for integrating CPF software for customs formalities:

Option 1:

The responsible declarant of the CPF or the CPF client interacts directly with Customs and Phytosanitary authorities.

Option 2:

Access is given to the customs representative (broker) with a contract with the CPF or the CPF client who liaises with the customs and phytosanitary authorities on behalf and for the account of CPF or the client.

Option 3:

Customs inspectors and phytosanitary officers and other designated border and foreign exchange control officers are granted access.

In all options, access for the above-mentioned persons is limited to metadata and their additions, as well as the smart contract of issue of additional NFT documents for the consignment. Editing metadata and deleting or moving SFTs and NFTs is not permitted.

An example of the customs clearance process:

A consignment of goods accompanied on the blockchain by the appropriate SFT and NFT tokens enters the bonded warehouse in the Customs control zone. The respective operator or the client controls the goods and the SFT and NFT of the consignment are in the wallet of the relevant client or operator. No provision is made to move the tokens to a special "custom" wallet.

When a consignment arrives at a bonded warehouse, information about its arrival is transmitted to persons responsible for customs clearance (declarer, customs representative, inspector, etc.) as a notification via the CPF software. After authorization in the CPF software system using the wallet, the persons responsible for customs clearance receive limited access to the NFT-documents metadata, as well as to the contents of the consignment of SFT goods and their total quantity, net and gross weight and volume.

For example:

NFT Commercial Invoice - metadata: quantity and value of goods, total value, buyer and seller, Incoterms and city of shipment, etc.

NFT Packing List - metadata: gross and net weight, number of boxes, number of pallets, temperature, etc.

NFT Contract - metadata: seller and buyer, their details, delivery terms, currency control information, etc.

NFT Annex 1 - metadata: any additions to the contract

NFT Certificate: metadata: information for phytosanitary inspection

NFT EX1 - metadata: export consignment information, export customs declaration

NFT ( ) - metadata: any information required for customs clearance, phytosanitary inspection, and other border state control.

The aggregation of SFT tokens is also useful for identifying errors and inaccuracies in documents, such as the sum of net and gross weights in the packing list and the amount of goods indicated in the invoice and the specification. This facilitates reliable declaration of goods.

After the release of goods into free circulation, the customs authority issues a customs declaration and customs value declaration, which the person responsible for customs clearance shall issue as new NFT to the consignment and upload scans of these documents and formalized information from them as metadata to the tokens.

CPF software is useful for customs control purposes and has the following advantages:

It allows the reconciliation of information from documents with calculated information based on the SFT and the actual.

Allows the customs officials to trace the entire supply chain and provides adequate evidence and documents to prove the actual cost and price of the shipment to customs authorities, so that the cargo value will be determined fairly, enabling customs officials to levy customs charges more accurately.

Allows a foreign trade participant to prove the customs value.

Provides all documents required for customs clearance without delay.

Can be easily integrated with information systems of Customs and other agencies such as banks and tax inspectors.

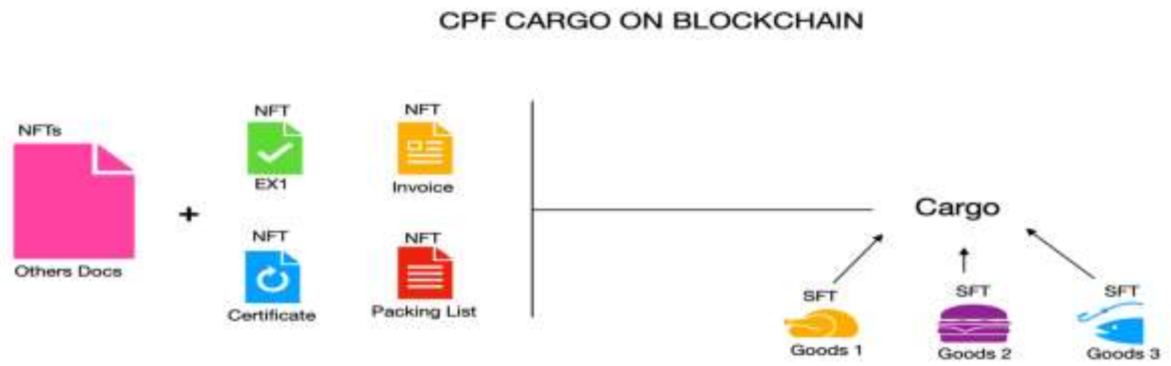

Figure 7. Linking documents and cargo to tokens

4.7. A Roadmap for Agri-Industrial Businesses to Implement Streamlined Blockchain Systems

By examining the implementation stages of blockchain technology in supply chain management, as demonstrated through the case study of CP Food, other businesses in the food industry can adopt a similar system to streamline their operations using blockchain technology. The process outlined in figure 6 can be replicated in any food industry business, and the specific details provided in figure 7 can also be utilized by such companies.

For software development and smart contract implementations, companies may consider the following formation represented in Table 1:

Profession	Number of employees needed
Product owner	1
Senior Solidity Developer	1
Medium Solidity Developer	2
Senior UX/UI Designer	2
Senior Full-stack TeamLead Developer	1
Front-end (React JS) Middle Developer	2
Back-end Middle Developer	2
Senior Full-stack TeamLead mobile developer	1
Intermediate iOS / Android mobile developer	2
Senior Systems Administrator	1
Senior Software Tester	1
Average Software Tester	1

Table 1. Development team

The project can be completed according to the following schedule with the following development team and given compensations per individual all represented in Table 2:

Period	Stages to be completed	Required developers	Monthly compensation per individual
1st month	• Product name and the platform architecture • Development of SFT-Goods Smart Contract • Development of NFT-Documents Smart Contract Development of company tokens • Website sandboxing	Product Owner	350,000 Russian ruble
		Senior Solidity Developer	350,000 rub
		Middle Solidity developer	200,000 rub * 2
		Senior Full-stack TeamLead developer	300,000 rub
		Senior System Administrator	150,000 rub

<table>
<tr><td colspan="3" align="right">First month total</td><td>1,550,000 rub</td></tr>
<tr><td rowspan="10">2nd month</td><td rowspan="10">Web UX/UI design
Front-end and back-end development
Metamask integration
SFT- Goods smart contract
Testnet deployNFT-documents
Testnet deploy company token
Testing</td><td>Product Owner</td><td>350,000 Russian ruble</td></tr>
<tr><td>Senior Solidity Developer</td><td>350,000 rub</td></tr>
<tr><td>Middle Solidity developer</td><td>200,000 rub * 2</td></tr>
<tr><td>Senior UX/UI designer</td><td>150,000 rub * 2</td></tr>
<tr><td>Senior Full-stack TeamLead developer</td><td>300,000 rub</td></tr>
<tr><td>Middle front-end developer (React JS)</td><td>200,000 rub * 2</td></tr>
<tr><td>Middle back-end developer</td><td>200,000 rub * 2</td></tr>
<tr><td>Senior Software tester</td><td>200,000 rub</td></tr>
<tr><td>Middle software tester</td><td>150,000 rub</td></tr>
<tr><td>Senior System Administrator</td><td>150,000 rub</td></tr>
<tr><td colspan="3" align="right">Second month total</td><td>3,000,000 rub</td></tr>
<tr><td rowspan="11">3rd month</td><td rowspan="11">Audit of smart contracts
Integration of more wallets
MVP release
MVP testing</td><td>Product Owner</td><td>350,000 Russian ruble</td></tr>
<tr><td>Senior Solidity Developer</td><td>350,000 rub</td></tr>
<tr><td>Middle Solidity developer</td><td>200,000 rub</td></tr>
<tr><td>Senior UX/UI designer</td><td>150,000 rub * 2</td></tr>
<tr><td>Senior Full-stack TeamLead developer</td><td>300,000 rub</td></tr>
<tr><td>Middle front-end developer (React JS)</td><td>200,000 rub * 2</td></tr>
<tr><td>Middle back-end developer</td><td>200,000 rub * 2</td></tr>
<tr><td>Senior Software tester</td><td>200,000 rub</td></tr>
<tr><td>Middle software tester</td><td>150,000 rub</td></tr>
<tr><td>Senior System Administrator</td><td>150,000 rub</td></tr>
<tr><td>CertiK Audit for each smart contract</td><td>800,000 * 7</td></tr>
<tr><td colspan="3" align="right">Third month total</td><td>8,400,000 rub</td></tr>
<tr><td rowspan="5">4th and 5th month</td><td rowspan="5">Mobile UX/UI design
iOS / Android app development
app testing</td><td>Product Owner</td><td>350,000 Russian ruble * 2 (months)</td></tr>
<tr><td>Senior Solidity Developer</td><td>350,000 rub * 2 (m)</td></tr>
<tr><td>Senior UX/UI designer</td><td>150,000 rub * 2 (m)</td></tr>
<tr><td>Senior Full-stack TeamLead developer</td><td>300,000 rub * 2 (m)</td></tr>
<tr><td>Senior Full-stack TeamLead Mobile developer</td><td>250,000 rub * 2 (m)</td></tr>
</table>

		Middle iOS/Android Mobile developer	200,000 rub * 2 * 2 (m)
		Senior System Administrator	150,000 rub * 2 (m)
		Forth and fifth month total	**3,900,000 rub**
6th month	• Control testing and debugging • Product launch	Product Owner	350,000 Russian ruble
		Senior Solidity Developer	350,000 rub
		Middle solidity developer	200,000 rub * 2
		Senior UX/UI designer	150,000 rub
		Senior Full-stack TeamLead developer	300,000 rub
		Senior Full-stack TeamLead Mobile developer	250,000 rub
		Senior System Administrator	150,000 rub
		sixth month total	**1,950,000 rub**
7th month and afterwards	• Monitor and fix minor bugs	Product Owner	350,000 Russian ruble
		Senior Solidity Developer	350,000 rub
		Senior UX/UI designer	150,000 rub
		Senior Full-stack TeamLead developer	300,000 rub
		Senior Full-stack TeamLead Mobile developer	250,000 rub
		Senior System Administrator	150,000 rub
		seventh month total	**1,550,000 rub**
		Total costs by the end of the seventh month	**20,350,000 rub**

Table 2. Development schedule and prices[1]

4.8. Summary of chapter 4

The fourth chapter starts with the process of analyzing and interpreting data gathered from interviews conducted with representatives of Charoen Pokphand Foods in Thailand and Russia. The initial set of codes was created to represent the various meanings and patterns that emerged during the interviews. After analyzing and structuring the data, various themes emerged, which were identified and categorized by different codes related to different aspects of supply chain operations. These themes provided valuable insights regarding challenges and opportunities that exist in the current supply chain industry, as well as processes that could be modernized by blockchain implementation.

Based on the analysis of blockchain solutions and data from interviews conducted with representatives of Charoen Pokphand Foods, Polygon was identified as a suitable technology stack for CP Food's blockchain system, offering high security, low transaction gas costs, decentralization, and optimal transaction speed. The adoption of public blockchains, as opposed to private ones,

[1] Source: Adapted from data obtained https://www.hh.ru (29.05.23)

offers the advantage of utilizing a system that has already demonstrated its reliability without any known bugs. The proposed system leverages the potential of the Polygon blockchain by defining all elements and factors involved in supply chain management and establishing connections between relevant entities and their corresponding tokens and addresses.

A matrix of processes and the necessary smart contracts was created based on CP Foods' supply chain management structure, considering the specifics of the Polygon blockchain platform. This involved identifying the various stages of the supply chain, such as production, selling, buying, and transportation, and determining the smart contracts needed to facilitate each stage. This was done to ensure that the smart contracts are properly integrated with each other, securing the smooth and efficient operation of the supply chain.

Chapter 5. Discussion, Contributions, and Limitations

5.1 Discussion

The research aimed to explore the optimal strategies for the successful implementation and integration of public blockchain platforms in agri-food businesses, with the goal of encouraging disruptive innovations throughout the industry. Given the complex supply chains in the agri-food sector, transparency in supply chain management is of utmost importance to enable traceability and identify potential contaminations. Additionally, enhancing supply chain efficiency by reducing costs through the elimination of unnecessary intermediaries is crucial to remain competitive in the industry.

To promote disruptive innovations, the research emphasized the development of comprehensive roadmaps and strategies that can be adopted by other businesses in the industry. Subsequently, the study delved into recommended strategies for the effective and cost-efficient implementation of public blockchain systems within the food industry, particularly for companies with intricate supply chain operations. Extensive analysis of blockchain networks, consensus mechanisms, services, and programming languages led to the identification of Polygon as a suitable technology stack for CP Food's blockchain system.

Polygon, functioning as a Layer 2 network built on top of the Ethereum Mainnet, offers a range of advantages to its users. Notably, it ensures high security, low transaction gas costs, decentralization, and optimal transaction speed. In addition, Polygon provides a wide range of developer tools and resources that empower agro-industrial enterprises to build scalable and secure decentralized applications. This feature is especially valuable for businesses in the sector that handle large volumes of real-time data and require reliable security and transparency in their operations. Furthermore, the interoperability of the Polygon network enables seamless connections with other networks and blockchains. This capability proves advantageous for agro-industrial enterprises that need to interact with diverse stakeholders such as suppliers, customers, and regulatory bodies. By leveraging the strengths of the Polygon network, companies in the food industry can enhance their supply chain management processes, facilitate transparent transactions, and unlock new avenues for innovation and collaboration within the broader ecosystem.

The adoption of public blockchains, as opposed to private ones, offers the advantage of utilizing a system that has already demonstrated its reliability without any known bugs. The integration of blockchain technology enables businesses to monitor the entire supply chain process comprehensively. By employing oracles in storage facilities and trucks transporting goods, it becomes possible to track the condition of food products at any given moment, facilitating the prompt detection and containment of potential contaminations. Additionally, issuing tokens as a form of payment enables companies to use the generated funds as capital for investments. This payment method also simplifies international transactions for clients. Furthermore, blockchain streamlines the process of managing paper documents. Through the use of smart contracts, concerns related to payment security and document release can be addressed and resolved, providing reassurance to all parties involved in the contract.

The implementation of public blockchain systems on a case study and an open-source, development-friendly platform serves as a comprehensive roadmap for other companies in the industry aiming to streamline their business operations. Unlike other studies and practices that focus on developing private blockchain applications for complex supply chain management, this research focuses on providing guidance applicable to the entire sector. The proposed system leverages the potential of the Polygon blockchain by thoroughly defining all elements and factors involved in supply chain management and establishing connections between relevant entities and their corresponding tokens and addresses. This meticulous analysis of the network and its components not only enhances system efficiency and transparency but also ensures transaction security. Consequently, each business can customize the suggested system based on its specific needs and requirements.

5.2 Contribution

The research focused on CP Foods as a case study, representing a large company with complex business processes. Specifically, the study aimed to explore how blockchain technology can be utilized to streamline supply chain management in the food industry. The chosen public blockchain platform, Polygon, operates as a Layer 2 network built on the Ethereum Mainnet. This platform was selected due to its scalability and low transaction fees, making it an ideal choice for large-scale businesses like CP Foods.

To ensure the relevance of the study to other businesses in the food industry, the proposed system was designed to be applicable to companies facing similar challenges with their supply chain management. By conducting a detailed case study and exploring the intricacies and difficulties associated with managing supply chains in large-scale agri-food businesses, the research was able to provide valuable insights into the specific problems and challenges faced by companies like CP Foods.

These insights can be utilized and customized by other businesses looking to adopt their own blockchain networks in a simplified manner. In fact, the findings and methodologies presented in the research serve as a resource for businesses seeking to streamline their supply chain management processes through the adoption and utilization of blockchain technology. As such, the research contributes to the existing knowledge regarding the development of public blockchains on open-source, developer-friendly platforms, and offers a valuable starting point for businesses looking to implement blockchain technology in their operations.

5.3 Study Limitations and Future Research Directions

While the research makes significant contributions to the field, it is important to acknowledge its limitations and identify potential directions for future studies.

Although it was emphasized on the significance of a case study approach in addressing real-world supply chain challenges, one potential limitation of this study is its singular focus on a specific case study. This narrow scope may restrict the applicability of the findings and strategies to a broader context. To overcome this limitation, future research endeavors could incorporate multiple case studies from diverse industries characterized by complex supply chains. By doing so, the validity and generalizability of the findings can be enhanced, providing a more comprehensive understanding of the adoption and implementation of public blockchain systems in various business settings.

Another limitation is the reliance on the Polygon blockchain technology as the chosen platform for implementation. While Polygon offers several advantages, exploring and comparing other blockchain platforms could provide a more comprehensive understanding of the best-suited technologies for different businesses and supply chain complexities.

Additionally, this study primarily focuses on the adoption and implementation of public blockchain systems in the context of supply chain management. Further research could explore other functional areas within agri-food businesses where blockchain technology could be beneficial, such as quality control, inventory management, or customer engagement.

Furthermore, this study primarily considers the perspectives of the agri-food businesses adopting blockchain systems. Future research could also incorporate the perspectives of other stakeholders, including suppliers, customers, regulatory bodies, and industry associations, to gain a more holistic view of the potential benefits and challenges associated with blockchain adoption in the food industry.

Lastly, this study focuses on simplifying operations by adopting blockchain systems. Future research could explore the broader implications of blockchain technology on sustainability, food safety, and social responsibility within the food industry.

Overall, addressing these limitations and pursuing further research in these directions would enhance the understanding and applicability of blockchain technology in optimizing supply chain management processes and driving industry-wide transformative innovations in the food sector.

5.4 Summary of chapter 5

This study focuses on CP Foods, a large company in the food industry with complex business processes. The proposed system provides a comprehensive roadmap for other industry companies seeking to streamline their business operations. The research findings and methodologies contribute to the existing knowledge on developing public blockchains on open-source, developer-friendly platforms. These findings are significant as they serve as a resource for businesses looking to streamline their supply chain management processes through blockchain technology adoption and utilization.

While the research is valuable, it is essential to acknowledge its limitations and identify potential directions for future studies. One possible limitation is its singular focus on a specific case study. Future research could incorporate multiple case studies from diverse industries with complex supply chains, providing a more comprehensive understanding of the best-suited technologies for different businesses and supply chain complexities.

Exploring and comparing other blockchain platforms could also prove insightful. This could lead to a more profound understanding of the most optimal platforms for different industries and supply chain complexities. Further research could also explore other functional areas within agri-food businesses where blockchain technology could be beneficial. Additionally, incorporating the perspectives of other stakeholders could provide a more holistic view of blockchain adoption in the food industry.

Lastly, future research could explore the broader implications of blockchain technology on sustainability, food safety, and social responsibility within the food industry. By understanding these implications, industries could leverage blockchain technology to promote sustainability, ensure food safety, and promote social responsibility within their supply chains.

Conclusion

The research has explored the adoption and implementation of blockchain technology in industries characterized by complex supply chain operations, particularly emphasizing the food industry.

The study began by conducting a through literature review to establish a foundation understanding of blockchain technology. The review highlighted recent developments and real-world applications across various sectors, with a specific emphasis on successful implementations within the food industry. Notably, it was observed that many businesses in the industry have predominantly adopted private blockchain systems. However, the study revealed the potential for greater accessibility by implementing blockchain technology on public blockchains. Such an approach has the potential to disrupt the entire industry by streamlining processes and enhancing transparency.

The primary objective of the research was to evaluate the practicality of implementing blockchain systems as a roadmap for the food industry. The chosen methodology involved conducting interviews and utilizing thematic analysis to analyze the collected data. Through this approach, the study identified the challenges faced by businesses in the industry and proposed solutions to address them.

One of the key findings was the effectiveness of smart contracts in simplifying processes and improving operational efficiency. The integration of tokens as a means of payment provided additional benefits, facilitating transactions and capital management within the company. Moreover, the study demonstrated the advantage of implementing the system on established public blockchain platforms. This approach eliminates the requirement for private blockchains and provides additional security within a bug-free environment.

By demonstrating a practical and feasible implementation approach, this thesis supports the disruptive potential of blockchain technology in the food industry. It provides a blueprint that other businesses can customize and adopt, enabling them to streamline their operations and leverage the benefits of blockchain. The research contributes to the existing body of knowledge by offering insights into the adoption of public blockchain systems and their impact on supply chain management.

Bottom line, the study demonstrates that the adoption of blockchain technology in industries with complex supply chains, specifically the food industry, can revolutionize operations and pave the way for industry-wide disruption. The findings suggest a customizable approach that businesses can leverage to optimize their processes and enhance competitiveness. By embracing blockchain technology, the industry can achieve greater transparency, efficiency, and security, ultimately benefiting consumers and stakeholders alike.

Bibliography

1. Adner, R. (2002). When are technologies disruptive? A demand-based view of the emergence of competition. *Strategic Management Journal, 23*(8), 667–688.
2. Ambolis, D. (2022). All about the lifecycle of smart contracts. *Blockchain Magazine*. https://blockchainmagazine.net/all-about-the-lifecycle-of-smart-contracts/
3. Androulaki, E., Barger, A., Bortnikov, V., Cachin, C., & Christidis, K. (2018). Hyperledger fabric: A distributed operating system for permissioned blockchains. In Proceedings of the Thirteenth EuroSys Conference (EuroSys '18) (pp. 1-15). Association for Computing Machinery.
4. Ante, L. (2021). Smart contracts on the blockchain – A bibliometric analysis and review. *Telematics and Informatics, 57*.
5. Bager, S. L., Singh, C., & Persson, U. M. (2022). Blockchain is not a silver bullet for agro-food supply chain sustainability: Insights from a coffee case study. Current Research in Environmental Sustainability, 4, 100163.
6. Beniiche, A. (2020). A study of blockchain oracles. *Computer Science, Mathematics*.
7. Blockchain Academy. (2023). History of blockchain.
8. Bowman, M., Das, D., Mandal, A., & Montgomery, H. (2021). On elapsed time consensus protocols. In A. Adhikari, R. Küsters, & B. Preneel (Eds.), *Progress in Cryptology – INDOCRYPT 2021* (Vol. 13143). Lecture Notes in Computer Science.
9. Burgess, P., Sunmola, F., & Wertheim-Heck, S. (2022). Blockchain enabled quality management in short food supply chains. Procedia Computer Science, 200, 904-913.
10. Buterin, V. (2013). Ethereum whitepaper.
11. Casino, F., Dasaklis, T. K., & Patsakis, C. (2019). A systematic literature review of blockchain-based applications: Current status, classification and open issues. *Telematics and Informatics, 36*, 55-81.
12. Chaudhuri, A., Dukovska-Popovska, I., Subramanian, N., Chan, H. K., & Bai, R. (2018). Decision-making in cold chain logistics using data analytics: a literature review. The International Journal of Logistics Management.
13. Chou, C. C., Hwang, N. C. R., Li, C. W., Wang, T., & Wang, Y. Y. (2023). Implementing a multichain framework using hyperledger for supply chain transparency in a dynamic partnership: A feasibility study. *Computers & Industrial Engineering, 175*.
14. Christensen, C. M. (1997). The innovator's dilemma: When new technologies cause great firms to fail. Harvard Business School Press.

15. Christensen, C. M., Raynor, M., & McDonald, R. (2015). What is disruptive innovation? *Harvard Business Review*, *93*(12), 44-53.
16. ConsenSys. (2022). Enterprise Ethereum: Accelerating blockchain adoption for business. https://consensys.net/enterprise-ethereum/
17. Creydt, M., & Fischer, M. (2019). Blockchain and more-Algorithm driven food traceability. Food Control, 105, 45-51.
18. Dave, D., Parikh, S., Patel, R., & Doshi, N. (2019). A survey on blockchain technology and its proposed solutions. Procedia Computer Science, 160, 740-745.
19. Dedeoglu, V., Malik, S., Ramachandran, G., Pal, S., & Jurdak, R. (2023). Blockchain meets edge-AI for food supply chain traceability and provenance. Comprehensive Analytical Chemistry.
20. De Filippi, P., Wray, C., & Sileno, G. (2021). Smart contracts. *Internet Policy Review, 10*(2).
21. Denzin, N. K., & Lincoln, Y. S. (1994). Handbook of qualitative research. Sage Publications, Inc.
22. Driscoll, D. (2010). Introduction to primary research: Observations, surveys, and interviews. In C. Lowe & P. Zemliansky (Eds.), *Writing spaces: Readings on writing, vol. 2* (pp. 153-174).
23. Essex, D. (2021). Blockchain for businesses: The ultimate enterprise guide. TechTarget.
24. Everledger. (2023). Industry solutions. https://everledger.io/industry-solutions/
25. Galindo, D., & Ferraioli, J. (2022). Cryptocurrency 201: What is Ethereum? Morgan Stanley, Wealth Management Global Investment Office.
26. Gartner Reveals Seven Mistakes to Avoid in Blockchain Projects. Gartner. https://www.gartner.com/en/newsroom/press-releases/2019-06-12-gartner-reveals-seven-mistakes-to-avoid-in-blockchain
27. Gaur V. (2020). Building a transparent supply chain. Business Harvard Review. https://hbr.org/2020/05/building-a-transparent-supply-chain
28. Gupta, M. (2018). Blockchain for dummies, 2nd IBM limited edition (pp. 13-26).
29. Haber, S., & Stornetta, W. S. (1991). How to time-stamp a digital document. *Journal of Cryptology*, *3*, 99-111.
30. Hyperledger Foundation. (2017). Introduction to Hyperledger Business Blockchain Design Philosophy and Consensus. Hyperledger Architecture, Volume 1.
31. IBM Corporation. (2022). IBM Blockchain Platform: Technical Overview.
32. IBM Think Blog (2019). Carrefour and Nestlé Partner with IBM to Extend Use of Blockchain to New Food Categories. IBM Corporation. https://www.ibm.com/blogs/think/2019/04/tracing-your-mashed-potatoes-on-ibm-blockchain/

33. Johnston L. (2022). How Unilever's Blockchain Pilot Will Scale Palm Oil Traceability. Consumer Goods Technology. https://consumergoods.com/how-unilevers-blockchain-pilot-will-scale-palm-oil-traceability
34. Kalla, S. (2023). Components of blockchain. MindMajix Technologies, An Appmajix Company. https://mindmajix.com/components-of-blockchain
35. Kanani, J., Nailwal, S., Arjun, A., & Matic. (2021). Matic whitepaper. Whitepaper Version 1.1 Polygon technology.
36. Karakas, S., Acar, A. Z., & Kucukaltan, B. (2021). Blockchain adoption in logistics and supply chain: a literature review and research agenda. International Journal of Production Research, 1-24.
37. Karamchandani, A., Srivastava, S. K., & Srivastava, A. (2023). A lower approximation based integrated decision analysis framework for a blockchain-based supply chain. Computers & Industrial Engineering, 177, 109092.
38. Khan, S., & VanWynsberghe, R. (2008). Cultivating the under-mined: Cross-case analysis as knowledge mobilization. *Forum Qualitative Sozialforschung / Forum: Qualitative Social Research*, *9*(1), Art. 34.
39. Liu, X., Yan, J., & Song, J. (2020). Blockchain-based food traceability: A dataflow perspective. In Advances in E-Business Engineering for Ubiquitous Computing: Proceedings of the 16th International Conference on e-Business Engineering (ICEBE 2019) (pp. 421-431). Springer International Publishing.
40. Longo, F., Nicoletti, L., & Padovano, A. (2019). Estimating the impact of blockchain adoption in the food processing industry and supply chain. International Journal of Food Engineering, 16(5-6), 20190109.
41. Lusard, A., & Le Hors, A. (2021). An overview of Hyperledger Foundation. Hyperledger Foundation.
42. Machado, T. B., Ricciardi, L., & Oliveira, M. B. P. (2020). Blockchain technology for the management of food sciences researches. Trends in Food Science & Technology, 102, 261-270.
43. Marshall, S., & Grewal-Carr, V. (2016). Blockchain enigma. Paradox. Opportunity. Deloitte.
44. Meng, Y., Wang, W., Chow, R., Hu, H., Chak, J., Li, Z., & Lin, S. (2022). Semi-fungible tokens: Theory, standard and practice. Solv Protocol.
45. Mirabelli, G., & Solina, V. (2020). Blockchain and agricultural supply chains traceability: Research trends and future challenges. Procedia Manufacturing, 42, 414-421.
46. Nestle (2019). Nestlé breaks new ground with open blockchain pilot. https://www.nestle.com/media/pressreleases/allpressreleases/nestle-open-blockchain-pilot

47. Mühlberger, R. (2020). Foundational oracle patterns: Connecting blockchain to the off-chain world. In *Business Process Management: Blockchain and Robotic Process Automation Forum*.
48. Nakamoto, S. (2008). Bitcoin: A peer-to-peer electronic cash system.
49. Nguyen, C. T., Hoang, D. T., Nguyen, D. N., Niyato, D., Nguyen, H. T., & Dutkiewicz, E. (2019). Proof-of-stake consensus mechanisms for future blockchain networks: Fundamentals, applications and opportunities. *IEEE Access, 7*.
50. Nofer, M., Gomber, P., Hinz, O., & Schiereck, D. (2017). Blockchain. *Business & Information Systems Engineering, 2*.
51. Nowell, L. S., Norris, J. M., White, D. E., & Moules, N. J. (2017). Thematic analysis: Striving to meet the trustworthiness criteria. *International Journal of Qualitative Methods, 16*(1).
52. Obafemi, F. (2022). Blockchain applications in business: Public vs private. *Flexiple network*. https://flexiple.com/blockchain/blockchain-applications-in-business-public-vs-private/
53. Pandey, V., Pant, M., & Snasel, V. (2022). Blockchain technology in food supply chains: Review and bibliometric analysis. Technology in Society, 101954.
54. Parizo, C. C. (2021). What are the 4 different types of blockchain technology? Blockchain for businesses: The ultimate enterprise guide. TechTarget.
55. Patel, D., Sinha, A., Bhansali, T., Usha, G., & Velliangiri, S. (2022). Blockchain in Food Supply Chain. Procedia Computer Science, 215, 321-330.
56. Polit, D. F., & Beck, C. T. (2004). Nursing research: Appraising evidence for nursing practice (7th Edition). Wolters Klower/Lippincott Williams & Wilkins.
57. PwC's Global Blockchain Survey 2018. PwC. https://theblockchaintest.com/uploads/resources/PwC - Global Blockchain Survey 2018 - 2018.pdf
58. Ravi, D., Ramachandran, S., Vignesh, R., Falmari, V. R., & Brindha, M. (2022). Privacy preserving transparent supply chain management through Hyperledger Fabric. *Blockchain: Research and Applications, 3*(2).
59. Risso L.A. et al. (2023) Present and future perspectives of blockchain in supply chain management: a review of reviews and research agenda. Computers & Industrial Engineering, 109195.
60. Sillaber, C., & Waltl, B. (2017). Life cycle of smart contracts in blockchain ecosystems. *Datenschutz und Datensicherheit - DuD, 41*(8), 497–500.
61. Silverman, D. (2013). Doing qualitative research. SAGE.
62. Sristy, A. (2021). Blockchain in the food supply chain - What does the future look like?

63. Walmart Global Tech India. https://one.walmart.com/content/globaltechindia/en_in/Tech-insights/blog/Blockchain-in-the-food-supply-chain.html
64. Tönnissen, S., & Teuteberg, F. (2020). Analysing the impact of blockchain-technology for operations and supply chain management: An explanatory model drawn from multiple case studies. *International Journal of Information Management*, *52*.
65. Turban, E., Outland, J., King, D., Lee, J. K., Liang, T. P., & Turban, D. C. (2018). Electronic commerce 2018: A managerial and social networks perspective. Springer International Publishing AG.
66. Unilever (2022). SAP, Unilever pilot blockchain technology supporting deforestation-free palm oil. https://www.unilever.com/news/press-and-media/press-releases/2022/sap-unilever-pilot-blockchain-technology-supporting-deforestationfree-palm-oil/
67. Wang, G., & Nixon, M. (2021). SoK: Tokenization on blockchain. In Proceedings of the 14th IEEE/ACM International Conference on Utility and Cloud Computing Companion.
68. Wegrzyn, E., & Wang, E. (2021). Types of blockchain: Public, private, or something in between. Manufacturing Industry Advisor. *https://www.foley.com/en/insights/publications/2021/08/types-of-blockchain-public-private-between*
69. Yin, R. K. (1994). Case study research: Design and methods.
70. Yin, R. K. (2018). Case study research and applications: Design and methods (6th ed.). Sage.
71. Zheng, Z., Xie, S., Dai, H.-N., Chen, W., Chen, X., & Weng, J. (2020). An overview on smart contracts: Challenges, advances and platforms. *Future Generation Computer Systems*, *105*, 475-491.
72. Mae Z. (2023). Walmart & Blockchain: New Era of Supply Chain Management. Changelly Blog. https://changelly.com/blog/walmart-blockchain/

Appendix

Interview 1. Head of Legal Department at LLC Poultry Farm "Severnaya"

Anton: Good afternoon, thank you for taking the time. As you are a representative of LLC Poultry Farm "Severny", which is a part of the Thai international agro-industrial holding Charoen Pokphand Foods, I would like to ask a couple of questions regarding supply chain processes.

Company representative: good afternoon, Anton, that's correct, LLC Poultry Farm "Severny" is a part of Charoen Pokphand Foods and is one of the conglomerate's most important assets in the Russian Federation, as well as a leading enterprise in the poultry meat production industry in the North-West region of Russia.

Anton: Let's start with the systems and standards you use to certify your products. Could you tell more about that?

Company representative: Let's start from the beginning; as food producers, we are required to implement the HACCP (Hazard Analysis and Critical Control Points) system, which involves risk analysis and includes so-called CCPs (Critical Control Points). This concept provides for the systematic identification and management of hazardous factors, i.e. critical points that can affect the safety of the produced goods. To ensure safety in production, we determine and establish these critical control points and develop corrective actions, which are taken in case of exceeding the established limits. HACCP is a preventive system aimed at preventing problems before they become a threat to the safety of food products. Hence, the need to plan measures to correct potential deviations from established critical limits. And the actions that will be taken in case of problems at critical control points.

Anton: Thank you for such detailed information. Could you please tell me at which stages you have the ability to track your products?

Company representative: each batch of goods is tracked in the "Mercury" system: on the date of production of each batch of products, the operator of the economic entity of the poultry farm enters information about each batch of products produced into the "Mercury" system, that is, every day. In the "Mercury" system, information about each batch of produced products is recorded and traced until it is transferred to the first recipient, or rather, the buyer of each batch. When transferring (selling) a batch of products to the buyer, the Poultry Farm warehouse informs the state veterinarian who works daily at the enterprise about the need to draw up veterinary accompanying documents (VAD) for the specific batch of products sold to this buyer. After selling the product to the first buyer, only the Federal Service for Veterinary and Phytosanitary Surveillance (Rosselkhoznadzor) can track this batch of products further.

Anton: Thank you for your answer. And perhaps the last question I would like to ask you about the processes that you as a company would like to optimize and speed up? This can apply to any processes from the production stage to the transportation to the end customer.

Company representative: I cannot give you an exact answer to this question, I think each process has its own nuances. But I can say that document exchange often drags on, which affects the speed of other processes. This is especially true for paper media. Also, regarding bank commissions, of course, I mean more about exporting products. According to our working principles, bank commissions for transferring currency (yuan and dollars) to our accounts are borne by the buyers, that is, in the contract we specify the amount we want to receive from the buyer, and the commission is already paid by the buyer. I'm not sure that this can be directly attributed to the processes that we strive to optimize and, in general, able to optimize, but nevertheless, this is present.

Anton: Thank you for the information provided. I want to thank you again for your time.

Interview 2. Supply Chain Representative from "Severnaia" Poultry Farm Ltd. (Russian division)

Anton: Good afternoon, I would like to ask you questions regarding the supply chain processes. Let's start with product labeling. At what stage does labeling begin?

Company Representative: Product labeling takes place at the production stage after the product is packed into individual and/or group packaging. After packing, the product is labeled by applying labels to the tray, pad, or box manually or automatically. In the first case, the label is hand-applied to each product, while the second case uses an automatic applicator on the line.

Anton: Could you also describe the methods used for product packaging?

Company Representative: Group packaging includes a corrugated cardboard box with a polyethylene bag. Individual packaging looks like this: the product is placed on a polystyrene tray with an absorbent napkin, wrapped in PVC film. We also use a disposable PP container for packaging the product with an absorbent napkin. It is covered with PET-PE film using simple or vacuum sealing methods.

Anton: Could you also clarify how the products are collected in batches at different stages?

Company Representative: In the slaughterhouse, the product in corrugated boxes is collected on a pallet of one assortment and quantity for transportation to the finished product warehouse. After transportation to the warehouse, batches of products are formed according to the customer's order.

Anton: Could you tell us about the methods used for transporting products?

Company Representative: From the manufacturer, the product is transported by refrigerated truck. In most cases, wholesalers pick up the product themselves from the finished product warehouse. At the warehouse, the refrigerated transport is checked for compliance with standards, and after loading, the right to own the product is transferred to the buyer.

Anton: Thank you for your answer. Could you also touch on the methods used for exporting products?

Company Representative: As for exports, in this case, the enterprise uses its own transport. It depends on the type of agreement with the buyer. Usually, we send the product from the enterprise to our own product warehouse, where it is stored for some time. If it is CIF, FOB, or CIP, we send the product by refrigerated transport from the warehouse, whether it is a port or a railway. If we talk about FCA, then the buyer's representatives pick up the product from our warehouse and send it to the destination.

Anton: Thank you. Can you tell us about the distribution path to the end consumer?

Company Representative: Regarding implementation, I can name several options. In the territory of the Russian Federation, the main volume is taken by wholesalers, who either independently sell the product or through grocery retailers. That is, on average, there are 1-2 intermediaries. There are a couple of retailers with whom we work directly, but I cannot say that they account for a significant share of the volume. As for export, we have already talked about it, so it should be clear. We are also actively developing our own online store with delivery to the end consumer.

Anton: And the last question; can you name the supply chain processes that you would like to optimize or speed up?

Company Representative: Processes related to production are almost all automated. As for what else can be added, even though it is not our direct responsibility and task, we do not have the opportunity to track the product and its condition on the free market after the first sale, that is, after the transfer of ownership rights to the first buyer. Also, regarding export, when it comes to document exchange, it's not uncommon for the process to take longer than expected. Unfortunately, this can have a domino effect on other processes that are dependent on the timely exchange of information. This is especially true for paper-based systems, which can be prone to delays and errors that can further slowdown the process.

Anton: Thank you for your time and the information provided.

Interview 3. Charoen Pokphand Foods supply chain management representative (Thai Division)

Anton: thanks for the opportunity to interview you. I would like to ask a couple of questions regarding the supply chain management of Charoen Pokphand Foods. Could you please explain what software is used for marking and tracking products?

CPF representative: at our company, we utilize two main software systems: Blue Yonder and WMS. Blue Yonder is a comprehensive supply chain management software that helps us manage our inventory, logistics, and supply chain processes. WMS, on the other hand, is a warehouse management system that helps us manage our warehouse operations and inventory.

Anton: What is the starting point of product labeling? Is it from the production stage or the packing stage?

CPF representative: in terms of our labeling processes, it can start at both the production stage and the packing stage. For example, if a product is manufactured with a specific label already in place, then that label would remain on the product throughout the supply chain process. However, if a product arrives at our distribution center or warehouse without a label, we would need to re-label the product to ensure that it is properly identified and tracked. Our labeling process begins with an inspection of the product upon arrival at the warehouse. Once the product has been inspected and approved, it is then transferred to the labeling area, where the appropriate label is applied. Finally, the labeled product is stored in its designated location within the warehouse.

Anton: could you please provide a more detailed description of the modes of transport, including the number of intermediaries involved in the process?

CPF representative: currently, our company relies on a 3PL service for transportation of products. This service ensures that our products are transported in dedicated trucks that are not shared with other companies, thus ensuring maximum safety and security for our goods during the transportation process.

Anton: Could you please elaborate on the common problems encountered in the supply chain?

CPF representative: Sure. One of the most common problems in the supply chain is related to packing for frozen products and maintaining the required temperature during transportation. This is especially challenging during extreme weather conditions, and it requires regular re-validation by season to ensure the product quality is not compromised. Another issue that needs improvement is document flow optimization. This involves streamlining the documentation process to make it more efficient and minimize the chances of errors.

Anton: Thank you for the information.

Interview 4. Charoen Pokphand Foods supply chain management representative (Thai Division)

Anton: What software do you use for marking and tracking products?

CPF representative: We use different software to mark and track products, SAP, Blue Yonder. These are specialized tools designed to meet the specific needs of our organization. SAP is an enterprise resource planning software that helps us manage our supply chain and track inventory. Blue Yonder provides real-time visibility into our entire supply chain. We also use other tools such as barcode scanners, RFID tags and scanners, and inventory management software to manage our products in a more effective way.

Anton: Could you provide more information regarding the starting point of product labeling? Is it at the production stage, or is it at the packing stage?

CPF representative: In most cases, product labeling is done at the production stage. This is because it is more efficient to label the products as they are being produced, rather than waiting until they arrive at the packaging stage. Labeling at the production stage helps to ensure that the correct labels are applied to the correct products, which is important for complying with regulations and maintaining customer satisfaction.

Anton: Could you please provide more information about the modes of transport and the delivery process to the end customer?

CPF representative: We utilize a control temperature truck provided by our logistics supplier to ensure that our products are delivered in optimal condition. Our logistic supplier takes care of all the transportation processes after the products are loaded from our distribution center. They use their own transportation means exclusively for Charoen Pokphand Foods, thus ensuring that our products are given priority and reach the end customer as quickly as possible. And of course, we and our partners are trying to perform regular quality checks throughout the delivery process to ensure that our products are still in optimal condition upon arrival.

Anton: What are some of the common problems encountered in the supply chain that can be addressed? Additionally, which specific processes would you like to improve in the supply chain to make it more efficient?

CPF representative: One of the common challenges faced in our case is the inability to maintain product information in case the need arises to input the weight into the system. Currently, the SAP system in place is not able to effectively maintain this information, So, it can cause delays and inefficiencies in the supply chain. Also from my experience, one of the main issues that we encounter in the supply chain is the difficulty of maintaining the right temperature as well as traction of the temperature during transportation from Thailand to Russia. This can lead to spoilage and other quality issues that can impact the overall effectiveness of the supply chain. Additionally, we have noticed that communication can sometimes be a challenge between different partners in the supply chain, which can lead to delays and other complications.

Anton: Thank you a lot for your time and information.