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Towards a self-management supply chain business processes system using blockchain smart contracts

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ABSTRACT

In this research paper, we present the design and implementation of a self-management supply chain business process system utilizing a blockchain smart contract. The system aims to increase efficiency by streamlining and automating supply chain processes through the use of smart contract technology. Through the use of a blockchain-based smart contract, the system is able to provide transparency and security in the management of supply chain processes. The proposed system is evaluated through the implementation of a proof-of-concept and a set of elaborated test scenarios to demonstrate its effectiveness in improving supply chain efficiency. The results of the evaluation show that the proposed system is able to provide an efficient system to manage supply chain business processes in a fully decentralized manner using blockchain and smart contract technologies.

KEYWORDS

Blockchain, smart contract, supply chain, efficiency and business processes.

1 INTRODUCTION AND BACKGROUND

Existing supply chain management systems suffers from many weakness such as lack of transparency, efficiency and trust in traditional systems [Srivastava et al. 2021] that makes them complex and very expensive. Blockchain and smart contracts technologies have appeared recently and their potential impact as a game changer has been proved already in several areas. They have eventually the potential to also revolutionize the way supply chains are managed, resulting in overall improved performance in the industry. Additionally, the proposed dApp can be applied across various industries and can have a positive impact on business process modeling and sustainability [Srivastava et al. 2021]. The aim of the research presented in this paper is the design a novel decentralized application (dApp) for the efficient management of supply chains. The main research question that this addressed is how efficient it is possible to transform supply chain business process specification into smart contracts that execute on a blockchain?". To simplify supply chain process, dApp based on blockchain and smart contract technologies can be used to create a transparent, secure, and efficient system for tracking and managing the movements of goods and products between different warehouses. By using smart contracts. The idea

is that the dApp will automate the process of tracking and managing the supply chain, reducing therefore the need to use any intermediaries or manual processes managed by human operators.

This paper is composed of 6 sections. After this introductory section, section 2 presents the state of art related to the use of blockchain in supply chain management. Section 3 presents the research challenges that need to be addressed beyond the state of art. In the following section 4, we propose a system model for the envisioned solution identifying function and none functional requirements of the solution, Key performance indicators objectives (KPI) as well as a solution architecture. Section 5, presents the implementation of the system including the smart contracts specifications, the specification of the testing and evaluation scenarios as well obtained results w.r.t the initially identified KPI. Finally, a conclusion that discusses the contribution results and highlights some future works.

smart contracts

2 STATE OF THE ART

Actually supply chain management involves a lot of different technologies and techniques, like ERP systems and RFID. Recently, there's been a lot of interest in using blockchain technology for supply chain management. Blockchain's decentralized and unchangeable properties make it great for keeping track of goods as they move through the supply chain [Gaiha 2020]. Companies like BMW, IBM, Walmart, and the Hyperledger project are all looking into using blockchain for supply chain management. However, despite this big interested in the applications of Blockchain technology, there's still a lot of aspect to address as a conclusion of an extensive state of art analysis that has been conducted. In the following, we present a short list of numerous state of art articles that have been published in the area.

- Business Process Redesign Heuristics for Blockchain Solutions [Milani et al. 2020];
- Digital Supply Chain Transformation toward Blockchain Integration [Korpela et al. 2017];
- Understanding blockchain technology adoption in supply chains [Kamble et al. 2019];
- VeChain whitepaper [VeChain 2019].

The lessons learned from these articles is that blockchain technology can be used to facilitate integration and collaboration between different organizations in a supply chain [Korpela et al. 2017]. Blockchain-based systems can also be used to automate and

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streamline data communication between different parties, increasing data transparency and trust between organizations. Another lesson learned from these articles is that blockchain technology can be used to address operational but also to reduce disruption risks in supply chains. By using blockchain-based systems to create backup suppliers, warehouses, and transport channels, supply chains can become more resilient to disruptions [Korpela et al. 2017]. Additionally, blockchain technology can be used to expand the capabilities of supply chains by enabling new business models and services [Milani et al. 2020]. The VeChain whitepaper specifically highlights the potential of blockchain technology to create a new economic model for supply chains, through the use of the VeChainThor Mainnet and matching infrastructure services. It also highlights the importance of regulation and compliance capabilities in blockchain-based supply chain management systems [Vechain 2019]. In terms of data sharing, transparency, and confidentiality, blockchain technology can be used to create a secure and transparent platform for sharing and tracking data throughout the supply chain [Zhaofeng et al. 2019]. Smart contracts can be used to automatically encrypt and decrypt data as it is shared between different parties, ensuring that sensitive information is protected while still allowing for the tracking and monitoring of supply chain activities. In conclusion, supply chain management using blockchain smart contracts is an area of ongoing research and development, with the potential to greatly improve integration, collaboration, data communication, and trust between organizations, as well as providing solutions to operational and disruption risks and creating new business models.

3 SCIENTIFIC CHALLENGES

The identification and description of scientific challenges in the field of supply chain management using blockchain smart contracts is an important aspect of ongoing R&D. Several key challenges have been identified in the literature. Among these challenges, the following are from our viewpoint the most important: Scalability: represents one of the main challenge facing the use of blockchain technology in supply chain management. Blockchain-based systems are built on distributed ledger technology, which allows multiple parties to access and update the same data simultaneously. However, as the number of users and transactions on a blockchain-based system increases, the system's ability to process and validate these transactions in a timely manner becomes a serious bottleneck, making it difficult for blockchain-based systems to keep up with the fast-paced and high-volume transactions that are common in supply chain management [Wamba and Queiroz 2020]. Researchers are currently exploring various solutions to address this problem such as off-chain scaling solutions, sharding and other techniques to increase the throughput of blockchain-based systems [Chang et al. 2022]. Security: the second important challenge facing the use of smart contracts in supply chain management the security assurance of the smart contracts. Smart contracts rely on complex algorithms and code to automatically execute transactions and enforce agreements. This complexity of the design of the smart contract can make their security difficult to identify and to mitigate potential vulnerabilities. Additionally, smart contracts are often used to handle sensitive data, such as financial information or trade

secrets, which can be compromised if the contracts are not properly secured. Researchers are currently working on solutions based on formal modelling and verification but there is still a lot to do [Paliwal et al. 2020]. Interoperability: another challenge in the field of blockchain-based supply chain management is interoperability between different blockchain networks and systems. The lack of standardization and compatibility between different blockchain platforms can make it difficult for organizations to share data and conduct transactions across different networks. Researchers are currently working on solutions to this problem, such as cross-chain communication protocols and standardization efforts to promote interoperability between different blockchain networks. [Kummer et al. 2020]

As a summary, in order to ensure the efficiency and viability of these technology in the area of supply chain management, these challenges should be addressed in a proper way. Blockchain smart contracts based solution must overcome these key difficulties of scalability, interoperability, and security [Chang et al. 2022].

4 SYSTEM MODEL

Based on these learned lessons, the requirements to identify and the system model to propose form the backbone of any successful project. The structure, behavior, and performance expectations of the targeted system should be appropriately specified. The aim of this section section is therefore to outline the general principles of the proposed solution, the identified Key Performance Indicators (KPIs), the specifications of the system, and proposed solution architecture [Dennis et al. 2019]. This section provides first a comprehensive overview of the system requirements and design, which will guide the implementation and deployment of the proposed solution. By describing the general principles, KPIs, system model specifications, and proposed solution, this section will enable the reader to understand the made design choices and the identified objectives of the system. The identified four general requirements of the proposed system to address the identified challenges in supply chain management using blockchain smart contracts are the following: (1) One of the main principles of our system is the use of smart contracts to ensure decentralized and secure validation of transfer between nodes in the supply chain process. Smart contracts are self-executing contracts with the terms of the agreement written directly into code, which can be automatically executed when certain conditions are met [Kummer et al. 2020]. This allows for secure, transparent, and automated validation of transactions within the supply chain, without the need for a central authority. (2) Another key principle of our system is the use of IoT devices to track and verify goods movement from the first node to the end customer. By integrating IoT devices into the supply chain, we can continuously monitor the location and status of goods as they move through the supply chain, ensuring accurate and real-time tracking of products [Zhaofeng et al. 2019]. (3) Our system is also designed to be flexible and allow for the owner to define and assign roles/responsibilities within the supply chain management system. This allows for different levels of access and permissions to be set for different parties involved in the supply chain, ensuring that only authorized parties can access sensitive information and perform certain actions. (4) Finally, our system involves a decentralized shared

ledger to display all products within the system. This allows for a transparent and tamper-proof record of all products, their location, and the parties involved in their transfer, which can be accessed by all authorized parties within the supply chain [Kummer et al. 2020]. Overall, our proposed solution combines the use of smart contracts, IoT, flexibility, and decentralized shared ledger to provide an efficient, secure, and transparent supply chain management system.

4.1 System Functional Requirements

From the general requirements identified in the previous section, we derive in this section the functional and non-functional requirements of the proposed blockchain-based supply chain management system. The functional specifications describe the system's capabilities and functionality, while the non-functional specifications focus on the system's performance, scalability, and other characteristics.

4.1.1 (1)Functional requirements:

- The system should be decentralized and allow for the creation of a shared, distributed ledger among the various actors in the supply chain. This will ensure that all parties have access to the same information and can update it in real-time, thus improving transparency and efficiency.
- The system should be flexible allowing for easy integration with existing supply chain management systems and processes. This will allow businesses to seamlessly integrate our system into their existing operations, without having to make significant changes to their current systems.
- The system should support the integration and interoperability of IoT devices, allowing for the seamless exchange of data and information among these devices and the other actors in the supply chain. This will allow for real-time tracking and monitoring of goods as they move through the supply chain.
- The system should support the creation and execution of smart contracts, which can automatically enforce the terms and conditions agreed upon by the parties involved. This will ensure that all parties abide by the rules and regulations set out in the contract, and will greatly reduce the risk of disputes.
- The system should provide strong security and transparency, allowing for the secure and transparent tracking and verification of transactions within the supply chain. This will help to prevent fraud and ensure that all parties have a clear understanding of what is happening within the supply chain.
- The system should include mechanisms for controlling access to the shared ledger and the smart contracts stored on it. This can help to ensure that only authorized parties can view or modify the smart contract deployed in the blockchain. This will protect sensitive data and ensure that only those who are authorized to access it are able to do so.

4.1.2 (2)Non-functional requirements:

- The system should be user-friendly and easy to use for all parties involved in the supply chain.

- The system should be reliable, ensuring that it is always available and it can process transactions and validate them.
- The system should be secure, protected from any potential cyber attacks and data breaches.

4.2 Key Performance Indicators

The Key Performance Indicators (KPIs) for our supply chain management system using blockchain smart contracts will focus on data sharing, data transparency, and data confidentiality. These KPIs will provide a measurable way to assess the effectiveness of our system in meeting the scenarios that will be mentioned later.

- **Data Sharing:** One important KPI for data sharing will be the number of data sharing events that occur within the system. This will measure the overall level of data sharing that is taking place between different parties in the supply chain. Additionally, we will measure the time it takes for data to be shared between different parties, as well as the percentage of data sharing events that are successful.
- **Data Transparency:** Another important KPI for data transparency will be the number of parties that have access to the data within the system. This will measure the overall level of data transparency that is present in the system. Additionally, we measure the percentage of data that is visible to all parties within the system, as well as the percentage of data that is only visible to specific parties.
- **Data Confidentiality:** is also a crucial aspect of our proposed solution, as it involves the use of smart contract code to control access and protect sensitive data. To measure the performance of data confidentiality, we can track the number of unauthorized access attempts and the number of successful access attempts by authorized users with specific roles defined in the smart contract code. Additionally, we will measure the percentage of sensitive data that is protected and encrypted when it is shared between nodes.

These KPIs will provide a comprehensive view of the performance of our proposed supply chain management system in terms of data sharing, data transparency, and data confidentiality, and will allow us to make adjustments and improvements to the system as needed.

4.3 System Architecture

Based on the requirements identified in the previous sections, the proposed architecture for the system is depicted in figure1. The components of the architecture aims together to provide the required self-management capabilities to the autonomously control behavior of the supply chain business processes using a blockchain and dedicated smart contracts.

The different components introduced in the architecture are described in the following :

- **Smart Contract Layer:** The smart contract code provided would serve as the backbone of the system, implementing the rules and logic for decentralized and secure validation of transfer between nodes in the supply chain process, as well as controlling access to the shared ledger and the smart contracts stored on it.
- **Decentralized Database Layer:** A decentralized database, such as Ethereum blockchain, would be used to store the

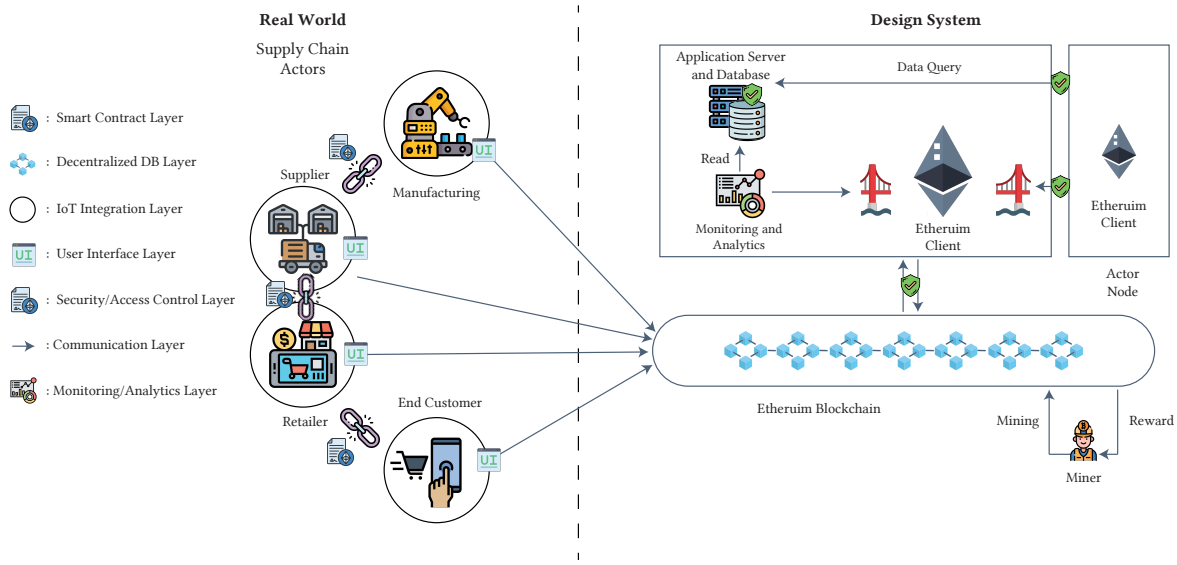


Figure 1: Functional Architecture.

shared ledger and smart contracts, allowing for transparent and tamper-proof tracking and verification of transactions within the supply chain.

- **IoT Integration Layer:** IoT devices would be integrated into the system to enable the seamless exchange of data and information among these devices and the other actors in the supply chain.
- **User Interface Layer:** A user-friendly interface would be provided for the various actors in the supply chain to interact with the system, including the ability to view and update the shared ledger and execute smart contracts.
- **Security Layer:** Strong security measures would be implemented to protect sensitive data, including encryption and secure communication protocols.
- **Access Control Layer:** Role-based access controls would be implemented to ensure that only authorized parties can view or modify the smart contract deployed in the blockchain.
- **Communication Layer:** Communication between the different components of the system would be handled through APIs and messaging protocols, allowing for easy integration with existing supply chain management systems and processes.
- **Monitoring and Analytics Layer:** Monitoring and analytics tools would be used to gather and analyze data on system performance and usage, providing valuable insights for further improvements to the system.

Overall, this solution architecture would provide a decentralized and secure platform for self-management of supply chain business processes, leveraging the capabilities of blockchain technology and smart contracts to enhance transparency, traceability, and automation of the supply chain.

4.3.1 Smart Contract Specification. The behavior of the proposed architecture is specified in term of smart contract that will be deployed in the blockchain. The algorithm specification of the smart contract is presented in the following:

Algorithm 1 Smart Contract Core

Require: variables for owner, roles, goods, and stages

Ensure: deploying smart contract

function DEFINITIONS

- Define functions for adding roles, updating goods' stages, and viewing actor information.

end function

function SHOWSTAGE

- Define function "showStage" to view the stage of a good by providing its unique ID.

end function

function MODIFIERONLYBYOWNER

- Define modifier "onlyByOwner" to restrict certain functions to the owner.

end function

function ROLEBASEDLOGIC

- Implement logic in functions to ensure only eligible roles can execute them.

end function

function TRACKING

- Implement logic to track the number of each role and the stage of each good in the supply chain.

end function

5 IMPLEMENTATION AND RESULTS

The development of the proposed solution leverages a stack comprising JavaScript, React, HTML, CSS, Web3js, Metamask, Truffle, Solidity, and Ganache, ensuring a secure environment for the DApp. Specifically:

- **Frontend:** Utilizes JavaScript, with React for user interfaces, complemented by HTML/CSS for styling.
- **Blockchain Interaction:** Employs Web3js and Metamask for secure, effective Ethereum blockchain backend.
- **Smart Contracts:** Managed through Truffle and Solidity, enabling reliable smart contract development.
- **Testing:** Uses Ganache for local blockchain testnet, ensuring thorough testing and development.

The figure represents the supply chain levels in our system implementation, and it is composed of four key actors: the owner, raw material suppliers, distributors, and customers. The process commences with the supply chain owner deploying a smart contract that performs an automated credit check. Following a successful check, the system registers the owner on the blockchain. Subsequently, the owner establishes the other actors within the blockchain network. These actors, raw material suppliers, and distributors, are created with distinct roles and credit parameters, enforcing a controlled access within the system. As the suppliers dispatch goods, and distributors handle their distribution, each transaction is authenticated via role and credit checks, ensuring compliance with the smart contract's stipulations. Valid transactions are then recorded on the blockchain, allowing for the immutable tracking of the goods. The customers, integrated within this network, can place orders that initiate the distribution process. The supply chain concludes with a final approval before the goods are delivered to the customer, ensuring a secure, transparent, and efficient flow of goods.

Moreover, we introduce a Proof of Concept (PoC) platform as a prototype to demonstrate the feasibility and advantages of the blockchain-based supply chain solution. This platform showcases vital system capabilities, particularly the use of smart contracts for secure, decentralized validation of supply chain transfers, through tracking goods and verifying movements. It serves as a critical instrument for evaluating the solution's practicality before full-scale implementation.

5.1 Testing and evaluation scenarios

In this section, we will be discussing the Proof of Concept (PoC) platform for our proposed solution architecture. The PoC platform will be used to test and validate the key features of our system w.r.t the identified KPIs.

- **Data Sharing :**
 - Testing the decentralized nature of the system: In this scenario, multiple actors in the supply chain are created by the owner to join the network and access the shared ledger. The system should allow for seamless and secure communication and data sharing among these actors, without the need for a central authority.
 - Testing the flexibility of the system: In this scenario, the system is tested for a general supply chain like Supplier Manufacturing Supplier Retailer End Customer.

This can help to ensure that the system can be integrated with a specific supply chain company.

- Testing the integration and interoperability of IoT devices: In this scenario, various IoT devices are connected to the system, for example Scanning QR code by phone, and used to exchange data and information with other actors in the supply chain. The system should support the seamless integration and interoperability of these devices, allowing for the efficient sharing of data and information.
- **Data Transparency :**
 - Evaluating the smart contract functionality: In this scenario, a sample contract is created and executed on the system, with the terms and conditions agreed upon by the parties involved.
 - Assessing the security and transparency of the system: In this scenario, various transactions are simulated within the supply chain, and the system is tested for its ability to securely and transparently track and verify these transactions. This can help to ensure that the system provides the necessary level of security and transparency for all parties involved.
- **Data Confidentiality :**
 - Evaluating the access control mechanisms: In this scenario, various actors are granted different levels of access to the shared ledger and the smart contracts stored on it. The system should enforce these access controls and only allow authorized users to modify the data on the system.

The table1 below provides a summary of the results of the testing scenarios carried out on the supply chain system. The table consists of three columns, which represent the Key Performance Indicator (KPI), the testing scenario, and the result of the test. The KPIs include Data Sharing, Data Transparency, and Data Confidentiality, each with its associated scenarios and test results.

6 DISCUSSION AND CONCLUSION

The results of this study contribute to the field of self-management in supply chain business processes using blockchain smart contracts. Our findings demonstrate the feasibility and effectiveness of implementing a decentralized platform for supply chain management through smart contracts. This has significant implications for organizations, as it enables them to automate and streamline their processes, reducing the risk of fraud and errors, and increasing transparency and accountability. Additionally, this research provides a foundation for future work in the field by highlighting the key challenges and opportunities that arise when implementing blockchain-based solutions for supply chain management. The findings of this study can be of great value to researchers and engineers who are interested in this area, as they can save time and effort by directly using our work as a starting point for their own solutions. Furthermore, the implementation of a real-world case study provides practical insights and a valuable reference for others who are considering implementing similar solutions. This work highlights the importance of considering various factors, such as security,

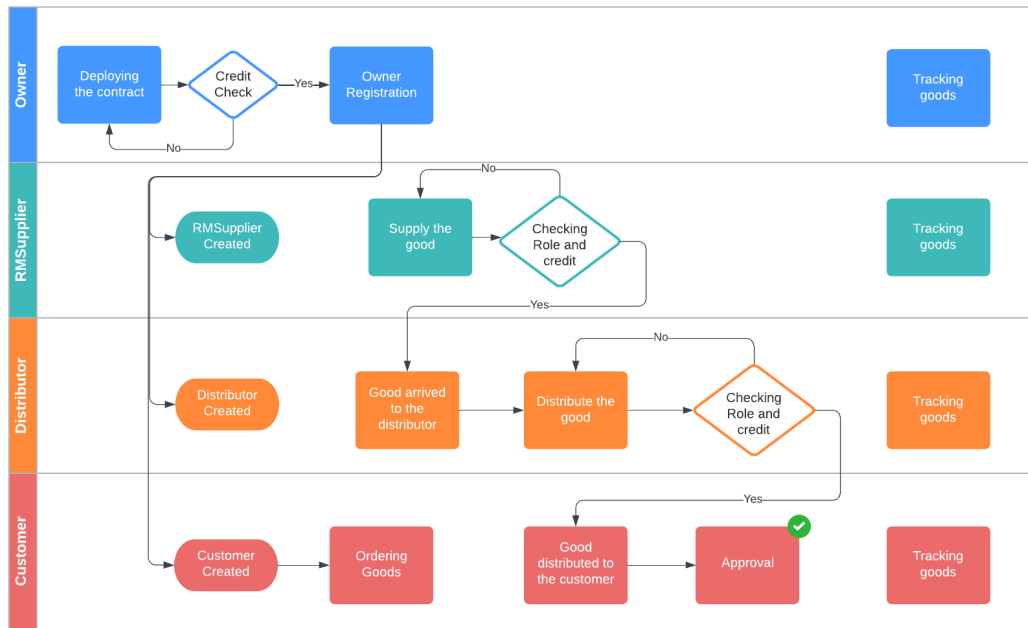


Figure 2: Technical Environment & Architecture.

KPI	Scenario	Test Result
Data Sharing	Testing the decentralized nature of the system	Verified
	Testing the flexibility of the system	Verified
	Testing IoT devices:	Not Verified (Not Done)
Data Transparency	Testing Smart Contract	Verified
	Testing Tracking and Verification	Verified
Data Confidentiality	Testing Access Control	Verified

Table 1: Scenario-based Test results of the proposed solution w.r.t identified KPIs

scalability, and regulatory compliance, when designing and implementing a blockchain-based supply chain management system. The overall assessment of the work completed in the context of the Self-management supply chain business processes using blockchain smart contract shows that the implementation was successful in many aspects. Firstly, the smart contract code was executed without any errors, which shows the reliability and robustness of the code. The implementation of the smart contract in a blockchain network was successful and all the transactions were validated and recorded in a secure and transparent manner. However, there were some limitations to the work. One of the limitations was the lack of integration with IoT devices, which would have allowed for a more seamless flow of data between the smart contract and other systems. Another limitation was the limited testing environment, which could have been improved by conducting more comprehensive testing in different scenarios and with more participants.

6.1 Overall assessment of work completed

The overall assessment of the work completed on the implementation of self-management supply chain business processes using blockchain smart contracts reveals that there were several key successes as well as some challenges faced. One of the main strengths of this project was the successful achievement of the data transparency and data confidentiality requirements. The smart contract code effectively ensured that all relevant information was securely stored on the blockchain and could be accessed by authorized parties, while at the same time maintaining the privacy of sensitive information like personal wallet, and this is done by design. However, the integration of IoT devices proved to be a challenge due to the learning curve associated with the technology and the amount of time required to effectively utilize it. Despite these challenges, the project still successfully demonstrated the potential of blockchain smart contracts in the context of supply chain management. It is

important to note that this work has limitations, as all research projects do. The scope of this project was limited the development of a small-scale supply chain, and further research will be needed to determine the full potential and limitations of using blockchain smart contracts in a wider context. Nevertheless, this work provides a valuable contribution to the field and can help researchers and engineers who want to work on this area by saving them time and effort in developing their own solutions.

6.2 Future works

The results of this study highlight the potential of blockchain smart contract technology in addressing the challenges faced by traditional supply chain management systems. However, much work still needs to be done to fully realize the full potential of blockchain technology in this field. In this section, we outline some directions and areas for future work that may help to build upon the foundation established in this project. Firstly, this project was limited to a small-scale supply chain business process, and it would be beneficial to further explore the implementation of blockchain technology in larger and more complex context. This will provide a better understanding of the scalability of blockchain solutions and their ability to handle real-world challenges. Secondly, the integration of IoT devices into the supply chain process was explored in this project but not done due to the learning curve of technology and time constraints. However, IoT devices have the potential to provide real-time information and improve our data sharing/transparency KPI. Further work in this area is needed to explore the integration of IoT devices with blockchain technology in the supply chain context. Finally, the current study was limited to the development of smart contract and the demonstration of its potential in the supply chain business process. Further research is needed to evaluate the practicality and feasibility of implementing blockchain solutions in complex real-world supply chain scenarios. This will involve conducting case studies, conducting user testing and evaluating the adoption and acceptance of blockchain technology by various stakeholders in the supply chain industry. In conclusion, this study provides a foundation for future researchers and engineers to build upon, and the insights gained through this work can aid in their efforts to advance the use of blockchain in the supply chain industry. The future perspectives for research and areas for future work outlined in this section provide promising opportunities to further explore the potential of blockchain technology in this field and bring us closer to realizing its full potential.

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