VISVESVARAYA TECHNOLOGICAL UNIVERSITY
"Jnana Sangama", Belagavi-590018

A synopsis on

Holistic Business Process with Supply Chain Visibility

Submitted by

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in
COMPUTER SCIENCE AND ENGINEERING

Under the Guidance of

Dr. Umadevi V
Assistant Professor and HOD,
CSE, BMSCE

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1. Abstract

In response to the multifaceted challenges confronting the global supply chain, this system introduces an innovative system that integrates blockchain technology, IoT devices, and QR codes to revolutionise supply chain management. By tackling challenges like product counterfeiting, traceability gaps, and inefficient monitoring, the system uses a decentralised blockchain for secure, transparent record-keeping. Real-time monitoring of product conditions is enabled by IoT sensors, ensuring adherence to quality standards. Additionally, QR codes provide immediate access to verified data, enhancing stakeholder trust and operational efficiency. Together, these technologies significantly boost security, reduce financial losses, and increase consumer confidence.

Blockchain forms the core of our system, creating a secure, immutable ledger for transparent transaction recording. This reduces product history falsification and boosts data security across the supply network, ensuring dependable records without centralised oversight. IoT devices complement this by monitoring product conditions throughout the supply chain, with blockchain integration ensuring secure and verifiable logging of transit conditions. QR codes further streamline access to validated product information, enhancing ease and immediacy across the supply chain.

This research not only modernises supply chains but also sets new standards for global trade and product management, significantly improving transparency, security, and efficiency to rebuild trust and establish a new industry benchmark.

2. Introduction

2.1.Overview

With this project, we aim to revolutionize supply chain management by integrating blockchain technology, the Internet of Things (IoT), and QR codes to enhance transparency, security, and efficiency. Our system comprises several key components:

Blockchain Platform: Serves as the immutable ledger for recording all transactions and data exchanges within the supply chain. It ensures data security, reduces fraud, and enhances traceability from production to consumption.

IoT Integration: Utilizes sensors and devices to monitor product conditions throughout the supply chain, ensuring compliance with quality standards. The IoT devices collect environmental and handling data that are securely logged onto the blockchain.

QR Codes: Facilitate easy and immediate access to product information for all stakeholders in the supply chain. Each product has a dynamically generated QR code that links directly to its blockchain entry, allowing users to verify its authenticity and history with a simple scan.

Mobile and Web Applications: Provide user-friendly interfaces for various stakeholders, including suppliers, transporters, and consumers, to interact with the system. These applications allow users to access real-time data, perform transactions, and track product movements.

Figure 1 provides a visual overview of how these components interact to create a streamlined and secure supply chain management system.

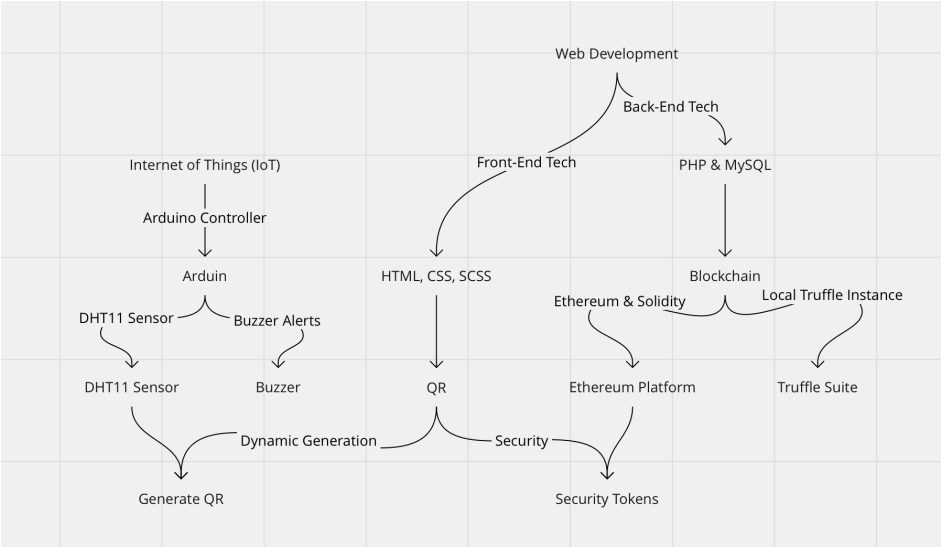

Figure 1. Overview of the supply chain system

2.2.Motivation

Managing global supply chains effectively is a complex challenge that industries face today. It involves numerous stakeholders and requires the seamless handling of goods across diverse geographies, which often leads to issues such as product counterfeiting, inefficient traceability, and inconsistent quality control. Traditional systems struggle with transparency and real-time data access, making it difficult to ensure the integrity and safety of products from production to consumption.

Blockchain technology, combined with the Internet of Things (IoT) and QR codes, presents a transformative solution to these pervasive challenges. Blockchain offers an immutable ledger for recording transactions transparently and securely, reducing the potential for fraud. IoT devices enable real-time monitoring and data collection throughout the supply chain, ensuring that products meet quality and safety standards at every stage. QR codes enhance the accessibility of data, allowing stakeholders to verify product authenticity instantly.

Our research aims to integrate these technologies into a cohesive system that drastically improves the transparency, security, and efficiency of supply chains. Given the absence of a comprehensive dataset that combines blockchain transactions, IoT data, and QR code applications within the supply chain, our project also involves the creation of a unique dataset. This dataset will support further research on the application of these technologies in supply chain management, contributing significantly to the field and paving the way for more secure and efficient supply chain operations worldwide.

2.3.Objective

The following are the objectives for our research project:

- Integration of Blockchain Technology : To implement an immutable ledger system using blockchain technology that will securely record all transactions and data exchanges within the supply chain, ensuring transparency and reducing potential fraud.

- IoT Device Deployment : To deploy IoT devices across the supply chain that will monitor and collect real-time data on environmental conditions and product handling, ensuring that all products meet quality standards from production to consumption.

- Implementation of QR Codes : To develop a system where each product is tagged with a dynamically generated QR code, linking directly to its blockchain entry. This allows stakeholders to verify product authenticity and history effortlessly, enhancing traceability and security.

- Development of User Interfaces : To create mobile and web applications that provide easy access to the system for various stakeholders, including suppliers, transporters, and consumers. These applications will allow users to interact with the system, perform transactions, and access real-time tracking information.

- Creation of a Comprehensive Dataset : Given the lack of a comprehensive dataset that combines blockchain transactions, IoT data, and QR code applications, one of our key goals is to develop and curate a unique dataset. This dataset will not only support our current research but also facilitate future research on integrating these technologies in supply chain management.

- Dynamic Model Training in a Production Environment : To dynamically train and refine our models based on real-world data and user interactions. This objective is crucial for adapting to changes and challenges in the environment, ensuring the system remains effective and relevant.

Through these objectives, our project aims to significantly improve the security, efficiency, and transparency of supply chain management, contributing to safer and more reliable product handling in a global market.

2.4.Scope

This project aims to transform the complexities of supply chain management by deploying a system that integrates blockchain technology, the Internet of Things (IoT), and QR codes. The primary scope of our system includes the following aspects:

- Enhanced Traceability and Transparency : By leveraging blockchain technology, the system will create a secure, immutable ledger that records every transaction within the supply chain. This ensures transparency and allows for easy verification of product authenticity and travel history, enhancing trust among all stakeholders.
- Real-Time Monitoring with IoT : The deployment of IoT devices throughout the supply chain will facilitate the real-time monitoring of product conditions, such as temperature and humidity. This will ensure that products maintain their quality from production to consumption, reducing waste and improving compliance with quality standards.
- Immediate Access via QR Codes : Each product in the supply chain will be equipped with a

QR code that provides immediate access to its blockchain entry. This feature will enable stakeholders to quickly verify the product details, streamlining the process of checking authenticity and compliance.

- User-Friendly Interfaces : The development of mobile and web applications will allow various stakeholders—including suppliers, transporters, and consumers—to interact with the system efficiently. These interfaces will support transaction performance, real-time tracking, and data access.
- Community Engagement and Feedback : While the system currently focuses on enhancing the logistical aspects of the supply chain, future enhancements may include features that allow community interaction, such as feedback mechanisms or forums for discussion among users. This could further improve system functionality and user satisfaction.
- Scalability and Future Enhancements : The system is designed to be scalable to accommodate growing data volumes and additional features such as the integration of nutritional data or more advanced analytics. While the initial implementation focuses on core functionalities, subsequent releases could incorporate advanced features based on user feedback and technological advancements.
- Assumptions : At the development stage, the system assumes that all participants are equipped with basic digital capabilities and connectivity to access blockchain and IoT data. Common standards for data sharing and security are presumed to be established to facilitate seamless integration across different segments of the supply chain.

The success of this system heavily relies on the robustness of the technology infrastructure, and the effective integration of blockchain, IoT, and QR codes. As usage scales and more data becomes available, the system's accuracy and effectiveness are expected to improve, making supply chain management more efficient and reliable.

2.5.Existing System

One of the most compelling existing systems in the supply chain industry is the use of Blockchain-based Supply Chain Solutions. A prime example of this application is IBM’s Food Trust, which utilizes blockchain technology to create a more traceable and transparent food supply chain. This initiative aims to enhance the overall security and traceability of food

products by enabling a tamper-proof and decentralized record-keeping system that is accessible to all parties involved in the supply chain—from the farmers who grow the food to the grocery stores that sell it.

Key Features of IBM's Food Trust :

- Transparency and Traceability: Each transaction or data entry related to the food product is recorded on a blockchain. This includes data on when and where food was grown, processed, stored, and inspected, as well as its journey through the supply chain. This level of detail provides unprecedented transparency and helps ensure the authenticity and safety of the food.
- Security and Immutability: The decentralized nature of blockchain technology means that once information is recorded, it cannot be altered without consensus from all parties involved. This feature drastically reduces the risk of fraud and makes it easier to identify and rectify discrepancies in the supply chain.
- Real-time Data Access: All stakeholders have real-time access to data through the blockchain, allowing for more efficient management and immediate action if issues are detected. This also helps in maintaining compliance with safety standards and regulations.

Advantages Over Traditional Systems:

- Unlike traditional ERP systems that are often centralized and susceptible to single points of failure, blockchain's decentralized structure enhances security and robustness.
- While ERP systems provide real-time monitoring and operational control, they typically do not offer the immutable record-keeping that blockchain systems do. This makes blockchain more suitable for applications where verification of product history is crucial.

IBM's Food Trust exemplifies how blockchain can revolutionize supply chain management by making it more secure, transparent, and efficient. This system shows the practical benefits of blockchain beyond its original financial applications and sets a standard for future blockchain integrations in various industries, including the integration of IoT and QR codes for even more comprehensive solutions. 2.

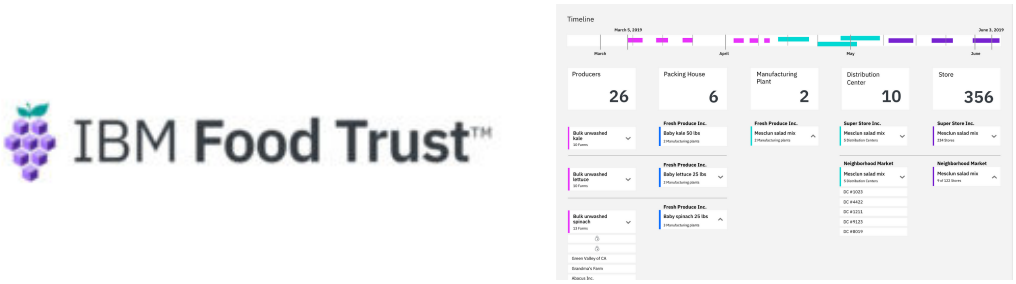

Figure 2. MV 80-Market Dataset

2.6.Proposed System

As we delve into the integration of blockchain, IoT, and QR codes for enhancing supply chain management, the foundation of our system lies in the accuracy and reliability of the data it processes. Traditional datasets used for tracking and verifying supply chain data often lack specificity and context needed for a granular analysis of supply chain dynamics. These datasets might not fully capture the specific environmental conditions or the diverse range of products and their handling procedures that are crucial for precise monitoring and verification in supply chains.

To address this gap, we propose to develop our own comprehensive dataset, the SC 100 Supply Chain Dataset, which will include detailed records of various goods moving through different stages of the supply chain. The dataset will consist of entries for 100 different classes of items, each documented under various conditions and handling scenarios. This dataset will be integral to training our system to accurately track and verify the state and location of products using IoT data, and ensure the authenticity and quality of goods using blockchain-recorded transactions.

Additionally, the incorporation of QR codes will allow easy access to this data, enabling stakeholders to scan and retrieve real-time information about the products, such as origin, batch number, and current status, directly linking to blockchain entries. This will not only enhance transparency but also improve operational efficiency by reducing errors and fraud.

Our proposed system will utilize this dataset to:

- *Train and refine the blockchain algorithms* to ensure they effectively record and secure all transactions and data entries.

• *Optimize the IoT monitoring mechanisms* to adapt to different products and environmental conditions, ensuring that the data collected is both accurate and relevant.

• *Develop a robust QR code system* that can dynamically generate and read codes, seamlessly integrating with the blockchain and IoT outputs to provide stakeholders with instant access to product histories.

By building and utilizing the SC 100 Supply Chain Dataset, our research aims to set a new standard in supply chain management, providing a system that is not only efficient and secure but also adaptable to the varied needs of modern supply chains. This dataset will be pivotal in overcoming the limitations of existing systems and will pave the way for future advancements in supply chain technology.

3. Design

3.1.High Level Design

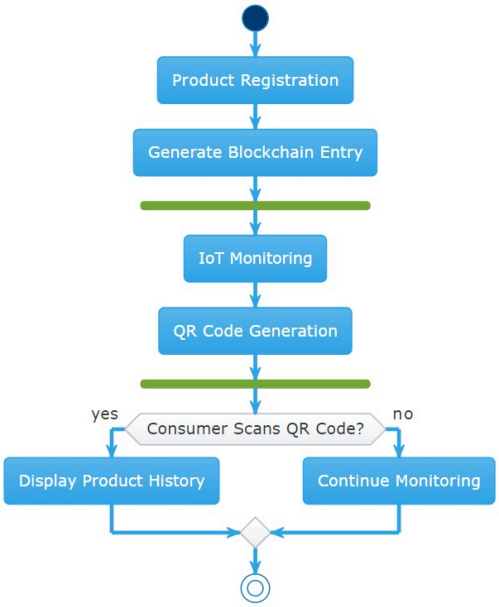

Figure 3. High Level Design of supply chain system

Figure 3 The high-level design system diagram outlines the workflow for our supply chain management system that utilizes blockchain, IoT, and QR codes. Below is a description of each step in the process.

1. Product Registration: This is the initial step where a product is registered into the system, marking the beginning of its journey in the supply chain.
2. Generate Blockchain Entry: Once the product is registered, an entry for the product is created on the blockchain. This entry is immutable and serves as the source of truth for all information related to the product, ensuring transparency and security.
3. IoT Monitoring: IoT devices are used to continuously monitor the product throughout its journey in the supply chain. These devices can track various conditions like temperature, location, handling, and more, and record this data back to the blockchain.
4. QR Code Generation: A QR code is generated for the product. This QR code contains encoded information that links back to the blockchain entry. It can be scanned at any point in the supply chain to retrieve real-time, verifiable data about the product.

5. Consumer Scans QR Code?: This decision point checks if a consumer (or any stakeholder) scans the QR code.
    - Yes: If the QR code is scanned, the system displays the product history. This includes all relevant data that has been recorded on the blockchain, providing transparency about the product's journey and current status.
    - No: If the QR code is not scanned, the system continues to monitor the product via IoT devices.

The system continues to loop the monitoring and QR code scanning steps until the end of the product's journey in the supply chain, allowing for real-time updates and checks at any point. This design ensures a robust mechanism for maintaining and verifying product integrity, compliance, and quality from production to consumption.

3.2.System Architecture

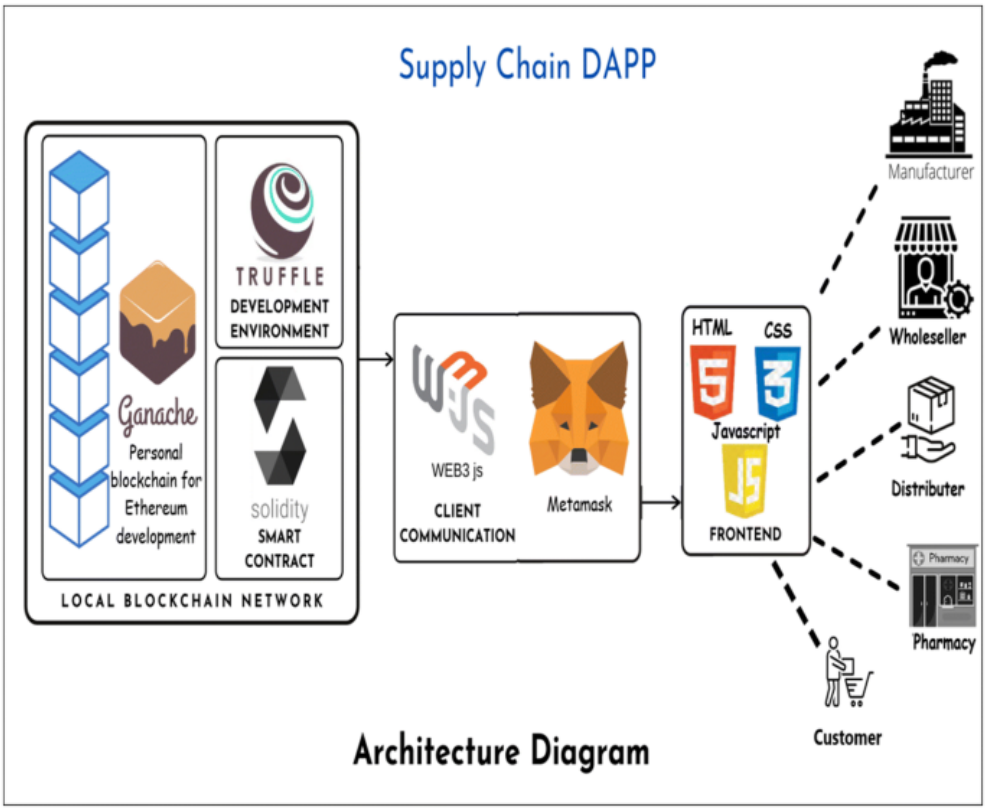

Figure 4. System Architecture of the proposed system

- Local Blockchain Network (Ganache):

  Ganache is used as a personal blockchain for Ethereum development, which allows developers to deploy contracts, develop applications, and run tests. It provides a simulated environment that mimics the behavior of a public blockchain but in a private setting. This tool is particularly useful for development and testing without the need for real cryptocurrency or impacting the actual Ethereum blockchain.

- Truffle Development Environment:

  Truffle is an integrated development environment and testing framework for blockchain and Ethereum applications. It supports the deployment of smart contracts written in Solidity (Ethereum's programming language) and assists in managing contract artifacts. Truffle interacts with Ganache to deploy and manage the smart contracts during the development process.

- Solidity Smart Contract:

Solidity is the programming language used to create smart contracts that run on the Ethereum Virtual Machine (EVM). In this architecture, Solidity is used to write the business logic of the supply chain processes, which is then deployed to the blockchain via Truffle.

- Client Communication (Web3.js and Metamask):

  Web3.js is a JavaScript library that allows the client-side application to interact with the blockchain via a web browser. It communicates with Ethereum nodes (like Ganache in development or other Ethereum networks in production) using JSON RPC calls.

  Metamask is a crypto wallet and gateway to blockchain apps. It allows users to interact with the Ethereum blockchain, manage identities, and secure login without a central server. In this system, Metamask is used to handle transactions and Ethereum account management for interacting with the smart contract.

- Frontend (HTML, CSS, JavaScript):

  The frontend of the application is built using standard web technologies: HTML for structure, CSS for styling, and JavaScript for functionality. This part of the system provides the user interface through which users (manufacturers, wholesalers, distributors, pharmacies, and customers) can interact with the supply chain application. It communicates with the backend smart contract via Web3.js and displays information fetched from the blockchain.

- Supply Chain Stakeholders:

  The system architecture outlines various stakeholders in the supply chain including manufacturers, wholesalers, distributors, pharmacies, and customers. Each of these stakeholders interacts with the DApp through the frontend interface, enabling them to access and update information on the blockchain as products move through the supply chain.

Overall, this architecture leverages blockchain technology to ensure that all transactions and data in the supply chain are immutable and transparent. It allows all parties involved to trace the product journey securely and in real-time, enhancing trust and efficiency in the supply chain.

4. Implementation

4.1.Overview of Technologies Used

Technologies Used

- Ethereum : A decentralized platform that supports smart contracts, enabling automated, transparent, and immutable interactions within the supply chain.
- Solidity : A high-level language for writing smart contracts on the Ethereum blockchain, allowing for complex business rules to be embedded directly within the blockchain.
- Ganache : A personal blockchain for Ethereum development, crucial for testing and developing contracts in a secure, isolated environment.
- Remix IDE : An open-source application that simplifies the process of writing, testing, and deploying smart contracts in Solidity.
- MetaMask : A crypto wallet and gateway that allows for direct interaction with the Ethereum blockchain, enabling secure management of identities and transactions.
- HTML/CSS/JavaScript : Foundational web development technologies used to build the frontend of the application, ensuring it is user-friendly, responsive, and engaging.
- Web3.js : A suite of JavaScript libraries that facilitates communication between the Ethereum blockchain and the frontend, managing blockchain transactions and dynamic UI updates.
- Arduino : The microcontroller used to connect various IoT devices like sensors and actuators, providing real-time data and responses based on environmental conditions.
- DHT11 Sensor : Monitors temperature and humidity, ensuring products are stored and transported within safe parameters.
- Buzzer : An alert system activated when monitored conditions deviate from set thresholds, enabling rapid response to potential issues.
- Dynamic QR Code Generation : Generates QR codes for each product, encoding URLs that point to the blockchain records of the products, enhancing security and immediate access to product histories.

Enhanced Workflow

- Smart Contract Development and Deployment : Using Remix IDE, smart contracts are written in

Solidity and deployed on the Ganache test network for thorough testing before live implementation.

- Product Registration and QR Code Generation : Products are registered through a user interface, with details securely recorded on the blockchain. Each product is associated with a unique QR code, linking directly to its blockchain entry.
- IoT Monitoring and Alerts : IoT devices continuously monitor environmental conditions. Data collected by Arduino and DHT11 sensors trigger alerts if conditions exceed thresholds, notifying managers of potential issues.
- User Interactions via Frontend : Users access real-time data and manage transactions through a web interface developed with HTML, CSS, and JavaScript. Web3.js facilitates interaction with the blockchain, allowing users to verify product history via QR codes.
- Blockchain Transactions and MetaMask : Transactions within the supply chain are managed through MetaMask, which provides a user-friendly platform for approving and broadcasting transactions on the blockchain.

This system sets a new standard in supply chain management by integrating state-of-the-art technologies to address modern challenges in global trade, providing stakeholders with unparalleled transparency, security, and efficiency.

4.2.Implementation details of modules

The proposed supply chain management system embodies a sophisticated blend of blockchain technology, the Internet of Things (IoT), and QR code technology, engineered to fortify traceability, security, and efficiency in modern supply chains. This integration is detailed below:

Blockchain Technology

Central to the system is the use of the Ethereum blockchain, renowned for its robust support for smart contracts which automate and secure complex transactions across the supply chain. Smart contracts are meticulously crafted in Solidity, facilitating complex business logic embedded directly on the blockchain. The Truffle suite, including Ganache, provides a development and testing environment that simulates real-world blockchain operations, ensuring all smart contracts are rigorously tested and functional prior to their deployment on the live Ethereum network. Stakeholders interact with the blockchain via MetaMask, a digital wallet that manages identities and secures transactions, streamlining secure interactions within the supply chain ecosystem.

Internet of Things (IoT)

The IoT framework incorporates Arduino microcontrollers paired with DHT11 sensors to monitor essential environmental parameters like temperature and humidity, crucial for maintaining product integrity during storage and transit. The real-time data collected are secured and relayed to the blockchain, providing a continuous audit trail of environmental conditions. Additionally, a buzzer system is integrated to trigger immediate alerts when monitored conditions deviate from predefined safety thresholds, enabling proactive management of potential risks.

QR Code Technology

To streamline access to product data, QR codes are dynamically generated for each product upon registration. These QR codes embed URLs that point directly to specific blockchain records, ensuring secure and instant access to detailed product histories. Security tokens within these URLs guarantee that data access is both authenticated and authorized, preserving data integrity and confidentiality.

Web Development Technologies

The system's frontend is developed using HTML, CSS, and JavaScript, creating an intuitive and accessible user interface for stakeholders to engage with the system effectively. This frontend serves as the gateway for registering products, verifying data, and monitoring system operations. The backend, powered by PHP, handles essential operations like business logic, user management, and session handling, interfacing with a MySQL database for storing non-blockchain related data such as user credentials and system settings.

Security and Data Integrity

The architecture is designed to maximize security and data integrity. Advanced cryptographic techniques safeguard data during transmission, while blockchain’s inherent security features manage access control based on user roles and permissions. Pseudonymization is employed to protect privacy, replacing personally identifiable information with artificial identifiers. The decentralized nature of the system eliminates single points of failure, enhancing the reliability and robustness of the supply chain management process.

This holistic system not only addresses operational challenges but also ensures compliance with regulatory standards, making it an invaluable tool for companies aiming to enhance their supply chain operations. By weaving together blockchain, IoT, and QR code technologies, the system sets a new standard for managing the complexities of global supply chains, ensuring transparency, security, and efficiency.

5. Conclusion and Future Enhancements

5.1.Conclusion

Blockchain technology, the Internet of Things (IoT), and QR codes together present a powerful solution to several pressing challenges in supply chain management. Our research has delved into integrating these technologies to create a system that significantly enhances traceability, security, and efficiency within supply chains. This project has provided us with invaluable insights into the complexities of modern supply chains and the transformative potential of these integrated technologies.

Through our literature review, we have explored various existing models and frameworks, gaining a deep understanding of how these technologies are currently being utilized and their limitations. This background has been essential for developing our innovative approach, which aims to surpass existing solutions in terms of scalability, reliability, and user accessibility.

The process of designing and implementing our own system, from developing smart contracts in Solidity to deploying IoT sensors and creating dynamic QR codes, has been as enlightening as it has been challenging. It has underscored the importance of rigorous testing, thoughtful system design, and continuous refinement. Moreover, constructing our own dataset has not only tailored our system more closely to our specific requirements but has also positioned us to contribute valuable resources to the broader research community.

In conclusion, our journey through this research project has been a profound learning experience. We have navigated the intricate landscape of supply chain management technologies and emerged with a robust, scalable, and secure system that stands to redefine industry standards. As we continue to refine our system and expand its capabilities, we are excited about the future possibilities and the impact our work will have on global supply chain practices.

5.2.Future Enhancements

Our integrated supply chain management system, which combines blockchain, IoT, and QR code technologies, has shown great promise in enhancing transparency, security, and efficiency. Moving forward, we plan to extend its capabilities to ensure it operates effectively even in areas with poor internet connectivity, improve its scalability and user-friendliness, and make it more

accessible and affordable for businesses of all sizes. We also aim to enhance its sustainability by reducing its environmental impact. These future enhancements will make our system more robust, versatile, and widely applicable across various industries globally.

6. References

[1] Abbas, K., Afaq, M., Khan, T. A., & Song, W. (2020). A Blockchain and Machine Learning-Based drug supply chain management and recommendation system for smart pharmaceutical industry. *Electronics*, *9*(5), 852. https://doi.org/10.3390/electronics9050852

[2] Agbo, C. C., Mahmoud, Q. H., & Eklund, J. (2019). Blockchain Technology in Healthcare: A Systematic review. *Healthcare*, *7*(2), 56. https://doi.org/10.3390/healthcare7020056

[3] Bekrar, A., Cadi, A. a. E., Todosijević, R., & Sarkis, J. (2021). Digitalizing the Closing-of-the-Loop for Supply Chains: A Transportation and Blockchain perspective. *Sustainability*, *13*(5), 2895. https://doi.org/10.3390/su13052895

[4] Benchoufi, M., & Ravaud, P. (2017). Blockchain technology for improving clinical research quality. *Trials*, *18*(1). https://doi.org/10.1186/s13063-017-2035-z

[5] Ehsan, I., Khalid, M., Ricci, L., Iqbal, J., Alabrah, A., Ullah, S. S., & Alfakih, T. (2022). A Conceptual model for Blockchain-Based Agriculture Food Supply Chain System. *Scientific Programming*, *2022*, 1–15. https://doi.org/10.1155/2022/7358354

[6] Huckle, S., Bhattacharya, R., White, M., & Beloff, N. (2016). Internet of things, blockchain and shared economy applications. *Procedia Computer Science*, *98*, 461–466. https://doi.org/10.1016/j.procs.2016.09.074

[7] Jamil, F., Lei, H., Kim, K., & Kim, D. (2019). A novel medical blockchain model for drug supply chain integrity management in a smart hospital. *Electronics*, *8*(5), 505. https://doi.org/10.3390/electronics8050505

[8] Khezr, S., Moniruzzaman, M., Yassine, A., & Benlamri, R. (2019). Blockchain Technology in Healthcare: A Comprehensive review and directions for future research. *Applied Sciences*, *9*(9), 1736. https://doi.org/10.3390/app9091736

[9] Kouhizadeh, M., Sarkis, J., & Zhu, Q. (2019). At the Nexus of Blockchain Technology, the Circular Economy, and Product Deletion. *Applied Sciences*, *9*(8), 1712. https://doi.org/10.3390/app9081712

[10] Lahkani, M. J., Wang, S., Urbański, M., & Egorova, M. (2020). Sustainable B2B E-Commerce and Blockchain-Based supply chain finance. *Sustainability*, *12*(10), 3968. https://doi.org/10.3390/su12103968

[11] Li, X., Tao, B., Dai, H., Imran, M., Wan, D., & Li, D. (2021). Is blockchain for Internet of Medical Things a panacea for COVID-19 pandemic? *Pervasive and Mobile Computing*, *75*, 101434. https://doi.org/10.1016/j.pmcj.2021.101434

[12] Sabbagh, P., Pourmohamad, R., Elveny, M., Beheshti, M., Davarpanah, A., Metwally, A. S. M., Ali, S., & Mohammed, A. S. (2021). Evaluation and Classification Risks of Implementing Blockchain in the Drug Supply Chain with a New Hybrid Sorting Method. *Sustainability*, *13*(20), 11466. https://doi.org/10.3390/su132011466

[13] Shahbazi, Z., & Byun, Y. (2020). A procedure for tracing supply chains for perishable food based on blockchain, machine learning and fuzzy logic. *Electronics*, *10*(1), 41. https://doi.org/10.3390/electronics10010041

[14] Shahbazi, Z., & Byun, Y. (2021). Integration of blockchain, IoT and machine learning for multistage quality control and enhancing security in smart manufacturing. *Sensors*, *21*(4), 1467. https://doi.org/10.3390/s21041467

[15] Song, L., Wang, X., Wei, P., Lu, Z., Wang, X., & Merveille, N. (2021). Blockchain-Based flexible Double-Chain architecture and performance optimization for better sustainability in agriculture. *Computers, Materials & Continua/Computers, Materials & Continua (Print)*, *68*(1), 1429–1446. https://doi.org/10.32604/cmc.2021.016954

7. PO Attainment

BMS College of Engineering.
Department of Computer Science and Engineering.

Batch no. : 35 Date: 1 May, 2024
Project Title: Holistic Business Process with Supply Chain Visibility

PROGRAMME OUTCOMES	Level (1/2/3)	Justification if addressed
PO1	1	Students will demonstrate an understanding of fundamental concepts in supply chain management, including procurement, logistics, and inventory
PO2	1	Students will demonstrate an understanding of ethical considerations and sustainability principles in supply chain management.
PO3	2	Students will be able to analyze and evaluate the impact of technological advancements on supply chain operations and decision-making processes.
PO4	2	Students will be able to assess the impact of supply chain visibility on key performance indicators (KPIs) and propose relevant improvements.
PO5	3	Students will be able to develop and propose innovative strategies for enhancing supply chain visibility and sustainability in a global context.
PO6	3	Students will be able to develop and present a comprehensive business process automation and supply chain visibility prototype, integrating AI, blockchain, and IoT technologies.
PO7	3	Students will be capable of conducting comprehensive supply chain audits and proposing strategic improvements for operational efficiency.
PSO1	1	Students will be able to identify and describe the components of a holistic business process with supply chain visibility.
PSO2	2	Students will be capable of developing and testing the front-end user interface for a supply chain visibility platform.

PSO3	3	Students will be able to iterate on the supply chain visibility system based on feedback and changing business requirements.

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8. Details of list of publications related to this project

8.1.Research Paper

QR-Enhanced Blockchain Supply Chain

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***Abstract*— In response to the multifaceted challenges confronting the global supply chain, this system introduces an innovative system that integrates blockchain technology, IoT devices, and QR codes to revolutionise supply chain management. By tackling challenges like product counterfeiting, traceability gaps, and inefficient monitoring, the system uses a decentralised blockchain for secure, transparent record-keeping. Real-time monitoring of product conditions is enabled by IoT sensors, ensuring adherence to quality standards. Additionally, QR codes provide immediate access to verified data, enhancing stakeholder trust and operational efficiency. Together, these technologies significantly boost security, reduce financial losses, and increase consumer confidence.**

Keywords—Blockchain technology, IoT devices, QR codes, Supply chain management, Real-time monitoring, Traceability, Transparency, Efficiency, Consumer trust

I. INTRODUCTION

A. Overview

Increasing transparency and efficiency in supply chains is crucial. Our system utilises blockchain technology, the Internet of Things (IoT), and QR codes to transform supply chain management globally, addressing challenges such as counterfeiting, the need for enhanced traceability, and consistent quality monitoring from production to consumption [1][2].

Blockchain forms the core of our system, creating a secure, immutable ledger for transparent transaction recording. This reduces product history falsification and boosts data security across the supply network, ensuring dependable records without centralised oversight [3]. IoT devices complement this by monitoring product conditions throughout the supply chain, with blockchain integration ensuring secure and verifiable logging of transit conditions [4]. QR codes further streamline access to validated product information, enhancing ease and immediacy across the supply chain.

This research not only modernises supply chains but also sets new standards for global trade and product management, significantly improving transparency, security, and efficiency to rebuild trust and establish a new industry benchmark [6].

B. Motivation

The global supply chain faces significant challenges that impact efficiency and trust, including widespread counterfeiting, ineffective traceability, and inadequate monitoring of product conditions during transit. These issues, exacerbated by the complexity of international supply chains with numerous stakeholders, demand advanced and scalable solutions.

Our project is propelled by the urgent need to enhance supply chain transparency and security. Integrating blockchain technology, we establish an immutable, secure record-keeping system that significantly cuts fraud and counterfeiting risks [3]. IoT devices throughout the supply chain enable real-time monitoring of conditions, ensuring products adhere to quality and compliance standards from origin to consumer, thus preventing potential losses [6]. QR codes enhance system efficiency by providing immediate access to authenticated product data, facilitating quick decisions by consumers and stakeholders [5]. This holistic approach not only tackles present issues but also equips the supply chain to handle future technological and regulatory changes, redefining global supply chain standards.

II. RESEARCH BACKGROUND AND CONCEPT DEFINITION

A. Research Background

The global supply chain landscape is increasingly complex and interconnected, magnifying traditional challenges like counterfeiting and theft which undermine the efficiency of traditional management systems. Emerging technologies, especially blockchain, offer promising solutions by providing a decentralised and immutable ledger that enhances transparency and secures data across the supply chain [7]. Blockchain's ability to provide a tamper-proof record of all transactions ensures the authenticity of goods from origin to consumer.

Additionally, the integration of Internet of Things (IoT) devices offers real-time monitoring and data collection throughout the supply chain, ensuring compliance with quality standards and improving operational efficiency.. The role of Quick Response (QR) codes has also become critical, enhancing the accessibility and immediacy of data retrieval and bridging the gap between digital records and physical goods [5].

B. System Concept Definition

The efficient management of supply chains has become crucial due to the heightened expectations for transparency, efficiency, and security from consumers and stakeholders. Three such technologies—blockchain, the Internet of Things (IoT), and QR codes—have emerged as transformative tools in the field. Let's delve into each of these technologies to understand their roles and integration into supply chain management.

1) Blockchain : Serving as the backbone of our system, we have employed a decentralised ledger that records transactions in a secure, immutable format. This setup enhances transparency and security, crucial for preventing fraud and ensuring the authenticity of goods throughout their journey. Each transaction is permanently recorded, making the data verifiable by all network participants, thus eliminating the need for intermediaries [12].

2) Internet of Things (IoT) : The Internet of Things encompasses a vast network of physical devices embedded with sensors, software, and other technologies that communicate and exchange data with other devices and systems via the internet. These devices track real-time environmental conditions such as temperature and humidity, ensuring that products maintain their quality from origin to consumer [13].

3) QR Codes : QR codes, or Quick Response codes, enhance the system's efficiency by providing quick access to blockchain-verified product information with a simple scan. Originally developed for tracking components in manufacturing, QR codes are now extensively used to ensure easy access to data regarding product authenticity, origin, and handling history [15]. In supply chain contexts, QR codes are utilised to encode detailed product information, accessible via a simple scan, thereby facilitating easy access to data on product authenticity, origin, and handling history.

The convergence of these technologies — blockchain, IoT, and QR codes—form the backbone of our innovative supply chain management system.

III. Research Methods and Data Selection

The research adopts a mixed-methods approach, combining qualitative and quantitative techniques to gather comprehensive insights and measure the impact of technology integration on supply chain efficiency and transparency. The system employs case studies, literature reviews and experimental prototype development and testing to refine the system components, followed by quantitative analysis to validate findings and assess scalability.

A. Research Design

The research design for this research is structured to methodically assess the integration and impact of blockchain technology, IoT devices, and QR codes within supply chain management systems.

Literature Review : Several businesses across different sectors—including manufacturing, retail, and logistics—participated as case studies. These businesses implement the integrated ERP, blockchain, and IoT systems within their existing supply chain frameworks. The selection of case study participants is based on criteria such as supply chain complexity, readiness for technology integration, and geographic diversity.

Case Study Analysis : Simulated environments were created to model supply chain processes under controlled conditions. These simulations allowed the research team to manipulate various factors, such as supply chain disruptions and data flow interruptions, to test the resilience and responsiveness of the technology framework.

Prototype Development and Testing : Several businesses across different sectors—including manufacturing, retail, and logistics— participate as case studies. These businesses implement the integrated ERP, blockchain, and IoT systems within their existing supply chain frameworks. The selection of case study participants was based on criteria such as supply chain complexity, readiness for technology integration, and geographic diversity.

B. Data Collection Methods

- IoT Sensor Data : Real-time environmental data are collected using IoT sensors, such as the DHT11 sensor. These sensors monitor critical conditions including temperature and humidity, crucial for ensuring that products meet quality and safety standards throughout their journey in the supply chain.
- Blockchain Transaction Logs : Data from blockchain transaction logs are extracted to analyse key attributes such as the immutability, traceability, and security of each transaction.
- User Interaction Logs : We gather logs that record how users interact with the system, focusing specifically on their engagement with QR codes and their access to blockchain-stored information. This data provides insights into user behaviour, system usability, and the effectiveness of interface design.

C. Data Selection and Screening Criteria

In our study, we rigorously employ both primary and secondary data sources to assess the efficiency of our system that integrates blockchain, IoT devices, and QR codes [13]. Primary data is gathered through IoT sensors that monitor real-time environmental conditions, ensuring that product standards for quality and compliance are maintained throughout the supply chain [15].

For secondary data, we leverage existing industry benchmarks and reports to conduct a comparative analysis of the prototype's performance. This approach allows us to utilise established industry benchmarks and reports to perform a comparative analysis of our system's performance [16].

D. Data Analysis Techniques

We adopt a dual approach to data collection, merging both quantitative and qualitative methods to provide a

comprehensive evaluation of the system's performance [15]. Quantitatively, we collect detailed metrics on critical operational aspects such as transaction times, error rates, and responses to security threats, which are pivotal in assessing the system's technical efficiency and reliability. Qualitatively, we gather feedback from users to understand their experiences, focusing on the ease of use, satisfaction with security measures, and overall efficiency of the system [17].

To analyse these data sets, we apply statistical analysis tools to the quantitative data, utilising techniques such as regression analysis, performance benchmarking, and error rate analysis to methodically enhance the system's reliability and efficiency [18]. For the qualitative data, content analysis is conducted to identify underlying themes and sentiments, which provide deeper insights into user satisfaction and the practical usability of the technologies.

IV. Detailed Description of the System

In the proposed research, a synergy of advanced technologies including blockchain, the Internet of Things (IoT), and QR codes is meticulously integrated to significantly enhance the security, traceability, and efficiency of supply chain management and create a robust system designed to meet modern supply chain challenges effectively.

Blockchain Technology : Our system, as seen in (Fig. 1), employs Ethereum, noted for its robust support for smart contracts developed in Solidity, a programming language tailored for constructing intricate contractual agreements on blockchain platforms [13][16]. The development and testing phases are facilitated by the Truffle suite, which provides a local environment (Local Truffle Instance) for meticulous testing before live deployment, ensuring the system's integrity and functionality [17][29].

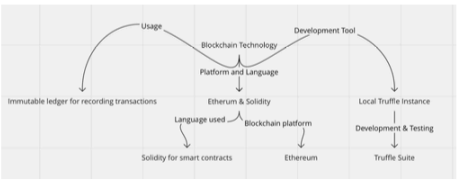

Fig. 1. Blockchain Technology working

Internet of Things (IoT) : The integration of IoT devices, specifically the Arduino microcontroller and the DHT11 temperature and humidity sensor, significantly improves the system's ability to respond promptly to potential hazards, reinforcing its overall effectiveness and reliability in supply chain management (Fig. 2). The Arduino acts as the core control unit, interfacing flawlessly with other devices to ensure data is efficiently transmitted to the blockchain, facilitating seamless supply chain tracking and management [22]. The DHT11 sensor is critical, continuously monitoring essential environmental conditions like temperature and humidity, which are vital for preserving the integrity of sensitive goods during transit [25]. An embedded buzzer system further enhances the system's functionality by issuing auditory alerts when environmental thresholds are breached. This feature is instrumental in signalling potential risks to product integrity, thereby prompting logistics personnel to undertake necessary corrective measures [29].

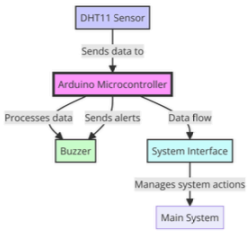

Fig. 2. IOT integration

QR Codes : QR codes are dynamically generated, embedding a URL that directly points to specific entries on the blockchain. These URLs incorporate security measures like encrypted tokens (e.g., https://yourdomain.com/product?token=encrypted_token_here). These tokens are essential for accessing the blockchain data, ensuring that each access is securely authenticated and authorised by the server before access is granted. Additionally, the QR codes can incorporate security tokens or cryptographic hashes, which must be decrypted or authenticated to access the underlying data.

Fig. 3. QR code Generation

Web Development Technologies : To complement the backend technologies, the system utilises front-end web development technologies such as HTML, CSS, and SCSS to craft a user interface that is both functional and user-friendly. On the backend, PHP is employed to manage critical functionalities including business logic, user management, session handling, and interactions with the MySQL database - utilised for storing essential non-blockchain data, such as user credentials and system settings, which do not require the immutability feature of blockchain.

A. Data Structure and Transaction Management

The system's architecture leverages blockchain technology to serve as the backbone for transaction management by creating an immutable ledger of all transactions that occur within the supply chain.

• *Immutable Ledger:* Each transaction recorded on the blockchain is permanent and unchangeable. This

immutability secures the data against tampering and guarantees the reliability and accuracy of transaction histories, thereby safeguarding the system's integrity [5].

• *Smart Contracts:* Utilising Ethereum's smart contracts, our system enhances transaction management. These contracts automatically execute based on predefined conditions, such as the successful delivery or confirmation of goods received, minimising the need for manual intervention and speeding up the operational process to reduce errors and increase efficiency [11][33].

• *Decentralised Transactions:* The system's decentralised nature ensures that it remains robust and resilient, with no single point of failure able to compromise the integrity of transaction data. By distributing transactions across a network rather than centralising them in one database, we enhance the security and reliability of data handling [24].

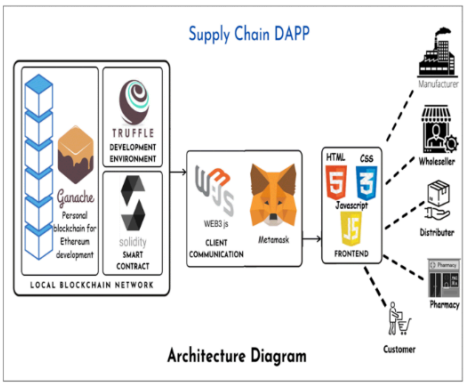

Fig. 4. Proposed Architecture

Source : Adapted from [4]

B. Data Security and Privacy

The system enhances data security and privacy through several integrated measures. Data is encrypted using advanced *cryptographic techniques* to secure sensitive information like product details and transaction records from unauthorised access during transmission, bolstered by stringent access control measures that utilise blockchain's inherent security features to limit data access based on user roles and permissions [23]. Furthermore, privacy is reinforced through *pseudonymisation*, replacing personally identifiable information with artificial identifiers to protect user privacy without compromising system functionality [17] [29]. Additionally, QR codes embedded with *security tokens* ensure that access to blockchain-stored data is restricted to users with the correct credentials, effectively preventing unauthorised access [4][18].

These comprehensive security measures ensure the integrity, security, and privacy of the data throughout the supply chain management process, addressing both operational needs and regulatory compliance.

C. Detailed Workflow and URL-Encoded QR Code Generation

The integration of blockchain, IoT, and QR codes within the supply chain management system presents a formidable framework designed to bolster transparency, security, and operational efficiency.

1) Product Registration : Upon a distributor or retailer registering a product within the system, a new blockchain entry is created. This entry encapsulates essential product details such as origin, batch number, and specifications, ensuring that every piece of data is transparently recorded and tamper-proof. Concurrently, a URL-encoded QR code is generated for each product. This QR code is uniquely linked to the blockchain record of the registered product, enabling easy access to detailed product information through a simple scan.

2) IoT Monitoring and Data Recording : As the product navigates through the supply chain, embedded IoT devices like Arduino controllers and DHT11 sensors diligently monitor and record environmental conditions such as temperature and humidity. This real-time data is crucial for maintaining product quality and is periodically uploaded to the blockchain, securing it against tampering and unauthorised alterations.

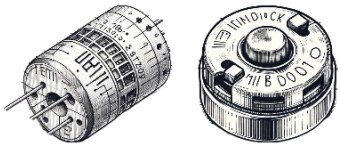

Fig. 5. (a) DHT11 sensor ; (b) Alert buzzer

3) Logistics Updates : Logistics personnel interact with the system to log updates regarding the product's transit status at various checkpoints. These updates are instantly recorded on the blockchain, offering a real-time, unalterable ledger of the product's movement.

4) Consumer Interaction : At the point of sale or upon delivery, consumers can scan the QR code associated with the product. This scan provides them direct access to a comprehensive history of the product's journey and conditions throughout the supply chain, as recorded on the blockchain. This level of transparency significantly enhances consumer trust and satisfaction.

5) URL-Encoded QR Codes and Security : The security of data transactions is paramount to maintaining integrity and trust across the network. As part of our integrated system combining blockchain, IoT, and QR codes, several sophisticated security measures have been implemented to ensure the safety and privacy of data. These measures not only protect against unauthorised access but also ensure that all interactions within the system are transparent and accountable.

• *Controlled Access:* The inclusion of security tokens within the URL ensures that only authenticated and authorised users can access the blockchain data. This

mechanism prevents unauthorised data breaches and enhances data integrity.

- *Data Encryption:* Parameters within the URL can be encrypted, safeguarding the data even if the QR code is intercepted. Without the correct decryption keys, the data remains inaccessible, ensuring that sensitive information is protected.
- *Traceability and Non-repudiation:* Direct linkage of each QR code to specific blockchain transactions ensures traceability and non-repudiation. This setup guarantees that all data accessed via QR codes can be traced back to its blockchain record, ensuring accountability and verifiability.
- *Audit Trails:* Every data access request initiated via QR codes is logged, creating a detailed audit trail that records access timings and the identities of the users accessing the data. This log enhances security and transparency, providing insights into data access patterns and potential security breaches.

Incorporating URL-encoded QR codes significantly strengthens the security framework by marrying the accessibility of QR technology with the robust security features of blockchain. This strategic approach not only secures transaction data but also fosters enhanced user engagement through transparent and easy-to-access product histories.

D. Findings and Implications

The deployment of the integrated system comprising blockchain, IoT, and QR code technologies has yielded significant insights across various dimensions of supply chain management.

System Performance:

Referencing Fig. 6, the data collected during the research execution phase, including transaction processing times, error rates, and QR code response times, demonstrates substantial advancements in system robustness across varied operational contexts. The graph shows a consistent improvement in processing speeds and a decrease in error rates, underscoring the system's enhanced reliability.

The analysis emphasises the efficiency of QR code scans in expediting access to blockchain-stored data, thus boosting user experience and operational efficiency. The data shows marked improvements in processing speeds and reduced error rates, enhancing system reliability. This rapid access to data is vital in contexts like perishable goods logistics, where swift decision-making is crucial for adapting to changing market conditions.

Preliminary findings indicating that the system's ability to reduce fraud and enhance product quality has led to significant cost savings throughout the supply chain. These benefits stem from minimised losses due to counterfeiting, reduced waste through better perishable handling, and more efficient logistics. Additionally, increased transparency and security have bolstered consumer trust, making the system a valuable investment for companies seeking to innovate and enhance their supply chain management.

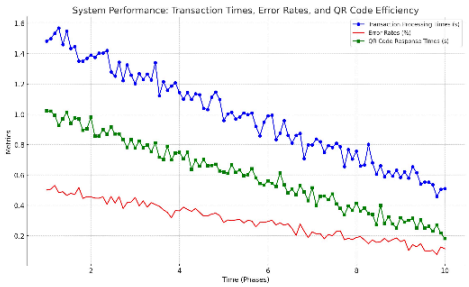

Fig. 6. System Metrics graph

V. Discussion

Our findings illustrate a robust performance of the integrated system, with marked improvements in transparency, security, and operational efficiency.

A. Strengths and Limitations

One of the primary strengths of the system is its scalability. The modular design allows for the integration of additional IoT devices and adaptation to various segments of the supply chain across different industries. However, there are limitations that need addressing. The reliance on high-quality internet connectivity for real-time data updates and blockchain transactions could be a constraint in regions with poor infrastructure. Additionally, the complexity of the system demands significant initial training and investment, which could be a barrier for smaller enterprises.

B. Future Research and Development

Future research should focus on enhancing the system's usability and reducing its dependency on constant connectivity. Exploring hybrid models that can operate in offline modes or in low-connectivity environments could vastly increase the system's applicability. Furthermore, investigating more cost-effective solutions for small to medium-sized enterprises could democratise access to this advanced technology, broadening its impact.

VI. Conclusions

Blockchain technology, IoT devices, and QR codes are integrated to enhance transparency, security, and efficiency in supply chain management. Each product is registered on a blockchain, forming an immutable ledger with detailed information such as origin, batch number, and specifications, paired with a URL-encoded QR code that links directly to its blockchain record for secure, immediate access. IoT devices track environmental conditions like temperature a humidity during transit, with data securely recorded on t blockchain.

The system leverages dynamically generated QR codes improve data security and access, with blockchain ensuri immutability and transparency. Encrypted QR codes w security tokens provide controlled access to sensiti information, supported by comprehensive audit trails that

bolster security and facilitate anomaly detection. Economically, the system reduces fraud and boosts efficiencies, leading to significant cost savings throughout the supply chain, supporting its wider adoption.

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References

[1] Abbas, K., Afaq, M., Khan, T. A., & Song, W. (2020). A Blockchain and Machine Learning-Based drug supply chain management and recommendation system for smart pharmaceutical industry. Electronics, 9(5), 852. https://doi.org/10.3390/electronics9050852

[2] Agbo, C. C., Mahmoud, Q. H., & Eklund, J. (2019). Blockchain Technology in Healthcare: A Systematic review. Healthcare, 7(2), 56. https://doi.org/10.3390/healthcare7020056

[3] Alam, S., Shuaib, M., Khan, W. Z., Garg, S., Kaddoum, G., Hossain, M. S., & Zikria, Y. B. (2021). Blockchain-based Initiatives: Current state and challenges. Computer Networks, 198, 108395. https://doi.org/10.1016/j.comnet.2021.108395

[4] Bandhu, K. C., Litoriya, R., Lowanshi, P., Jindal, M., Chouhan, L., & Jain, S. (2022). Making drug supply chain secure traceable and efficient: a Blockchain and smart contract based implementation. Multimedia Tools and Applications, 82(15), 23541–23568. https://doi.org/10.1007/s11042-022-14238-4

[5] Bekrar, A., Cadi, A. a. E., Todosijević, R., & Sarkis, J. (2021). Digitalizing the Closing-of-the-Loop for Supply Chains: A Transportation and Blockchain perspective. Sustainability, 13(5), 2895. https://doi.org/10.3390/su13052895

[6] Benchoufi, M., & Ravaud, P. (2017). Blockchain technology for improving clinical research quality. Trials, 18(1). https://doi.org/10.1186/s13063-017-2035-z

[7] Cao, B., Li, Y., Zhang, L., Long, Z., Mumtaz, S., Zhou, Z., & Peng, M. (2019). When Internet of Things Meets Blockchain: Challenges in distributed Consensus. IEEE Network, 33(6), 133–139. https://doi.org/10.1109/mnet.2019.1900002

[8] Choi, T. (2020a). Supply chain financing using blockchain: impacts on supply chains selling fashionable products. Annals of Operation Research/Annals of Operations Research, 331(1), 393–415. https://doi.org/10.1007/s10479-020-03615-7

[9] Choi, T. (2020b). Creating all-win by blockchain technology in supply chains: Impacts of agents' risk attitudes towards cryptocurrency. Journal of the Operational Research Society, 72(11), 2580–2595. https://doi.org/10.1080/01605682.2020.1800419

[10] Cui, L., Xiao, Z., Wang, J., Chen, F., Pan, Y., Dai, H., & Qin, J. (2021). Improving vaccine safety using blockchain. ACM Transactions on Internet Technology, 21(2), 1–24. https://doi.org/10.1145/3388446

[11] Du, M., Chen, Q., Xiao, J., Yang, H., & Ma, X. (2020). Supply chain finance innovation using Blockchain. IEEE Transactions on Engineering Management, 67(4), 1045–1058. https://doi.org/10.1109/tem.2020.2971858

[12] Ehsan, I., Khalid, M., Ricci, L., Iqbal, J., Alabrah, A., Ullah, S. S., & Alfakih, T. (2022). A Conceptual model for Blockchain-Based Agriculture Food Supply Chain System. Scientific Programming, 2022, 1–15. https://doi.org/10.1155/2022/7358354

[13] Hervani, A. A., Nandi, S., Helms, M. M., & Sarkis, J. (2022). A performance measurement framework for socially sustainable and resilient supply chains using environmental goods valuation methods. Sustainable Production and Consumption, 30, 31–52. https://doi.org/10.1016/j.spc.2021.11.026

[14] Huckle, S., Bhattacharya, R., White, M., & Beloff, N. (2016). Internet of things, blockchain and shared economy applications. Procedia Computer Science, 98, 461–466. https://doi.org/10.1016/j.procs.2016.09.074

[15] Iftekhar, A., Cui, X., Hassan, M., & Afzal, W. (2020). Application of blockchain and internet of Things to ensure Tamper-Proof data availability for food safety. Journal of Food Quality, 2020, 1–14. https://doi.org/10.1155/2020/5385207

[16] Jamil, F., Lei, H., Kim, K., & Kim, D. (2019). A novel medical blockchain model for drug supply chain integrity management in a smart hospital. Electronics, 8(5), 505. https://doi.org/10.3390/electronics8050505

[17] Khezr, S., Moniruzzaman, M., Yassine, A., & Benlamri, R. (2019). Blockchain Technology in Healthcare: A Comprehensive review and directions for future research. Applied Sciences, 9(9), 1736. https://doi.org/10.3390/app9091736

[18] Kouhizadeh, M., Sarkis, J., & Zhu, Q. (2019). At the Nexus of Blockchain Technology, the Circular Economy, and Product Deletion. Applied Sciences, 9(8), 1712. https://doi.org/10.3390/app9081712

[19] Lahkani, M. J., Wang, S., Urbański, M., & Egorova, M. (2020). Sustainable B2B E-Commerce and Blockchain-Based supply chain finance. Sustainability, 12(10), 3968. https://doi.org/10.3390/su12103968

[20] Li, X., Lu, W., Xue, F., Wu, L., Zhao, R., Lou, J., & Xu, J. (2022). Blockchain-Enabled IoT-BIM platform for supply chain management in modular construction. Journal of Construction Engineering and Management, 148(2). https://doi.org/10.1061/(asce)co.1943-7862.0002229

[21] Li, X., Tao, B., Dai, H., Imran, M., Wan, D., & Li, D. (2021). Is blockchain for Internet of Medical Things a panacea for COVID-19 pandemic? Pervasive and Mobile Computing, 75, 101434. https://doi.org/10.1016/j.pmcj.2021.101434

[22] Luo, S., & Choi, T. (2021a). Operational Research for Technology-Driven Supply Chains in the Industry 4.0 Era: Recent development and Future studies. Asia-Pacific Journal of Operational Research, 39(01). https://doi.org/10.1142/s0217595920400217

[23] Luo, S., & Choi, T. (2021b). Operational Research for Technology-Driven Supply Chains in the Industry 4.0 Era: Recent development and Future studies. Asia-Pacific Journal of Operational Research, 39(01). https://doi.org/10.1142/s0217595920400217

[24] Musigmann, B., Von Der Gracht, H. A., & Musigmann, B. (2020). Blockchain Technology in Logistics and Supply Chain Management—A Bibliometric Literature Review from 2016 to January 2020. IEEE Transactions on Engineering Management, 67(4), 988–1007. https://doi.org/10.1109/tem.2020.2980733

[25] Niknejad, N., Ismail, W., Bahari, M., Hendradi, R., & Salleh, A. Z. (2021). Mapping the research trends on blockchain technology in food and agriculture industry: A bibliometric analysis. Environmental Technology & Innovation, 21, 101272. https://doi.org/10.1016/j.eti.2020.101272

[26] Pandey, V., Pant, M., & Snášel, V. (2022). Blockchain technology in food supply chains: Review and bibliometric analysis. Technology in Society, 69, 101954. https://doi.org/10.1016/j.techsoc.2022.101954

[27] Ren, S., Choi, T., Lee, C. K. M., & Lin, L. (2020). Intelligent service capacity allocation for cross-border-E-commerce related third-party-forwarding logistics operations: A deep learning approach. Transportation Research. Part E, Logistics and Transportation Review, 134, 101834. https://doi.org/10.1016/j.tre.2019.101834

[28] Sabbagh, P., Pourmohamad, R., Elveny, M., Beheshti, M., Davarpanah, A., Metwally, A. S. M., Ali, S., & Mohammed, A. S. (2021). Evaluation and Classification Risks of Implementing Blockchain in the Drug Supply Chain with a New Hybrid Sorting Method. Sustainability, 13(20), 11466. https://doi.org/10.3390/su132011466

[29] Shahbazi, Z., & Byun, Y. (2020). A procedure for tracing supply chains for perishable food based on blockchain, machine learning and fuzzy logic. Electronics, 10(1), 41. https://doi.org/10.3390/electronics10010041

[30] Shahbazi, Z., & Byun, Y. (2021). Integration of blockchain, IoT and machine learning for multistage quality control and enhancing security in smart manufacturing. Sensors, 21(4), 1467. https://doi.org/10.3390/s21041467

[31] Song, L., Wang, X., Wei, P., Lu, Z., Wang, X., & Merveille, N. (2021). Blockchain-Based flexible Double-Chain architecture and performance optimization for better sustainability in agriculture. Computers, Materials & Continua/Computers, Materials & Continua (Print), 68(1), 1429–1446. https://doi.org/10.32604/cmc.2021.016954

[32] Song, Q., Chen, Y., Zhong, Y., Lan, K., Fong, S., & Tang, R. (2021). A supply-chain system framework based on internet of things using blockchain technology. ACM Transactions on Internet Technology, 21(1), 1–24. https://doi.org/10.1145/3409798

[33] Tian, Z., Zhong, R. Y., Barenji, A. V., Wang, Y., Li, Z., & Ye, R. (2020). A blockchain-based evaluation approach for customer delivery satisfaction in sustainable urban logistics. International Journal of Production Research, 59(7), 2229–2249. https://doi.org/10.1080/00207543.2020.1809733

[34] Xu, Z., Zhang, J., Song, Z., Liu, Y., Li, J., & Zhou, J. (2021). A scheme for intelligent blockchain-based manufacturing industry supply chain management. Computing. https://doi.org/10.1007/s00607-020-00880-z