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ROBUST AND EFFICIENT SUPPLY CHAIN MANAGEMENT USING IMPROVED PROOF OF USEFUL WORK (POUW) CONSENSUS ALGORITHM

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ABSTRACT

Recently, blockchain technology has been integrated with other emerging technologies, including data science, artificial intelligence, and the Internet of Things (IoT). Blockchain will be the best alternative for maintaining data security and transparency, enhancing network management. This paper presents an improved consensus algorithm, an extension of the existing PoUW, to address scalability issues in blockchain technology. The proposed consensus algorithm includes two additional modules, authorisation and storage availability, to maintain the scalability of the blockchain network. The proposed method is applied explicitly to the supply chain management framework to analyse how it overcomes the limitations of the traditional system. Measuring the supply chain framework using blockchain is facilitated by several key parameters, including latency, transaction throughput, and computational energy. Authorised people can only access and update the chain details. Based on the storage availability, it adds a new block to the blockchain. The primary objective of the proposed methodology is to enhance network scalability and improve blockchain usability in real-time applications, such as supply chains, thereby reducing the risk of counterfeiting. From manufacturer to end-user, introducing blockchain technology will help maintain transparency among all parties, including manufacturers, distributors, retailers, and customers. The proposed algorithm provides security to the network and confidentiality to sensitive information.
Keywords: *Consensus Algorithm, Authorization, Storage Availability, Supply Chain Management*

1. INTRODUCTION

Blockchain technology has gained significant popularity and is utilised to implement numerous business solutions in the current technological era. Security and privacy are essential concerns in any organisation. The key feature of the blockchain is transparency. Integrating and maintaining blockchain with other emerging technologies is difficult because performance overhead will be a limitation in conventional systems. As more nodes are added to a blockchain, its performance will degrade in terms of scalability. To avoid this problem, several solutions are available regarding a few key parameters, including latency, transaction throughput, and computational energy.

1.1 Supply Chain Management

Information about raw materials and product delivery is usually maintained manually in traditional supply chain management, i.e., from the supplier to the customer. Blockchain technology can serve as an alternative method to automate the process and enhance tracking, thereby preventing delays in product delivery by reducing the risk of counterfeit goods. A network that guarantees product authenticity from the initial state to the final customer is desperately needed to address challenges. Traditional approaches often fail to keep up with advanced counterfeiting techniques. This necessitates a reliable and flexible system to adjust to the constantly changing retail environment. As shown in Figure 1, the basic supply chain management structure encompasses product-related activities from raw materials to the customer. This will help integrate with other emerging technologies to overcome traditional system barriers [1][2][3][4][5].

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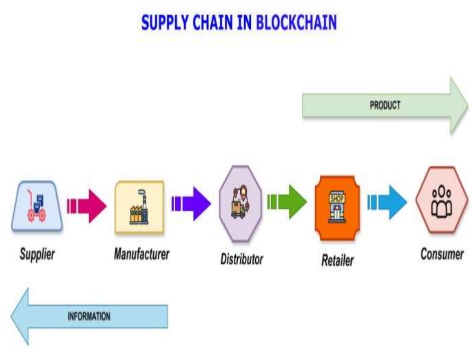

Figure 1 Traditional Supply Chain Management

1.2 Consensus Algorithms

Blockchain consensus algorithms play a crucial role in verifying the correctness of transactions, which is essential before adding a block to a blockchain's main chain. Improved consensus algorithms are also being used to improve a blockchain's overall performance.

1.2.1 Proof of useful work (pouw)

A blockchain consensus technique, PoUW, requires nodes to perform computational tasks that are inherently useful in real-world applications, thereby overcoming the shortcomings of conventional PoW. PoUW enables nodes to focus on valuable tasks like machine learning, scientific research, or other computationally demanding procedures rather than wasting energy on pointless computations. PoUW has difficulties confirming that the work is beneficial and ensuring that the outcomes cannot be fabricated or altered. Furthermore, some nodes may lack the necessary resources to contribute successfully, and task specialisation may reduce the degree of decentralisation, thereby increasing the risks and vulnerabilities associated with centralisation. To mitigate the drawbacks of existing PoUW, our proposed methodology centers on an enhanced consensus algorithm incorporating mining capabilities. Additionally, features such as authorisation and storage availability checks are also included [6].

1.2.2 Hybrid consensus algorithms

Improved consensus algorithms in blockchain real-world applications, particularly in healthcare and supply chain management, are anticipated to be necessary to deal with complex applications transparently and distributedly. Several improved consensus algorithms and many solutions are available to maintain the blockchain network as scalable. Improved consensus algorithms make decentralised networks scalable, secure, and efficient. To address existing problems such as scalability, our proposed work focuses on enhancing consensus and its performance in terms of computational energy, latency, and transactional throughput. Blockchain technology in supply chain management can improve efficiency, traceability, and transparency. Blockchain provides end-to-end transaction details from the manufacturer to the end user by offering a decentralised and immutable ledger.

The following sections provide a brief overview of the literature available in related work, the methodology of the improved consensus algorithm, and the results and discussion of the supply chain management framework. After careful examination of available blockchain literature, it becomes apparent that the scalability and usability of various applications are lacking. The blockchain performance will be reduced when the highest number of nodes are added to the chain. Multiple parameters are available to avoid the problem of scalability. The proposed methodology primarily drives the overall scalability of the blockchain, leveraging an improved consensus algorithm and blockchain architecture. Enhancing the scalability of blockchain technology is driven by multiple essential considerations. Transactions cannot be altered once recorded, so fraud and errors can be rectified quickly.

Supply chain management is one of the many industries where blockchain technology has demonstrated great potential in improving transparency, traceability, and trust. While PoW, PoS, and PoUW are three traditional consensus techniques that guarantee the security and immutability of blockchain systems, they have significant disadvantages, including high energy consumption, limited productive utility, and centralisation issues. In this regard, PoUWAS presents itself as a new consensus paradigm in which miners' computing efforts directly address domain-relevant issues like demand forecasting, route planning, logistics optimization, authorisation, and storage availability check.

1.3 Scope of the Study

This paper focuses on using PoUWAS to solve supply chain optimization issues related to distribution and transportation. Manufacturing, procurement, and retail-side logistics are not thoroughly covered. Based on the suggested

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methodology, simulations of decentralised route optimization are mentioned. The goal is to quantify the utility, blockchain integrity, and computing efficiency of labor completed in a decentralised setting.

1.4 Research Contributions

The following are this paper's main contributions:

- A domain-specific PoUWAS framework incorporating route optimization issues into the
- consensus process of blockchain-based supply chain platforms.
- A technique for decentralised verification that enables validators to confirm optimization
- outcomes without disclosing private information.
- A comparison of PoUWAS computational usefulness, scalability, and energy efficiency in a
- logistics environment with that of the conventional consensus model PoUW. 4. A PoUWAS-based assessment of incentive alignment, fairness, and trust in a supply chain simulation.

1.4.1 Practical implications

The suggested PoUWAS model provides valuable advantages for supply chain ecosystems by: Facilitating energy-efficient consensus while concurrently resolving realistic operational issues.

- Increasing resource efficiency in blockchain systems by substituting logistics calculations for arbitrary hashing.
- Facilitating decentralised logistics planning could lessen dependency on centralised third-party logistics systems.
- Because of the blockchain's visible and verifiable optimisation outcomes, confidence across distributed supply chain players has increased.

2 RELATED WORK

The implementation of blockchain in healthcare applications, its application framework for supply chain management, and its future directions in blockchain are discussed.

Recent developments in blockchain technology have significantly impacted supply chain management (SCM), with more research focusing on integrating blockchain to enhance stakeholder confidence, transparency, and traceability. Several consensus techniques, including PoW, PoS, and PBFT, have been explored to ensure safe and decentralised decision-making in these systems. However, a thorough performance-related comparison of consensus algorithms tailored to supply chain dynamics is lacking in most current research, which often focuses on theoretical assessments or specific industry case studies.

Zhang et al. (2023) [7] offer a comprehensive overview of research on blockchain technology in supply chains. It highlights key benefits such as enhanced transparency, improved traceability, increased efficiency, reduced fraud, and better stakeholder collaboration. Additionally, the review addresses challenges related to scalability, interoperability, regulatory uncertainties, and the need for industry collaboration. Ultimately, it aims to clearly understand current research and suggest future directions in this evolving field.

Hussein et al. (2023) [8] present a thoughtful overview of the development of consensus mechanisms in blockchain technology. It skilfully traces the journey from earlier algorithms, such as Proof of Work (PoW), to more contemporary innovations, including Proof of Stake (PoS) and various Byzantine Fault Tolerance (BFT) protocols. The review provides a balanced analysis of the strengths and challenges of these different approaches, emphasizing their implications for security, scalability, efficiency, and decentralization. Furthermore, it offers valuable insights into the current landscape and prospective future avenues for research in blockchain consensus algorithms.

Sabry et al. (2023) [9] employed PoUW to solve the Multiple Traveling Salesmen Problem (mTSP) in a blockchain context to optimise delivery routes. Despite its great potential for logistics and route optimisation, this work lacks evaluation in diverse, real-world settings, including changing weather conditions, dynamic traffic data, and multimodal transportation networks. The lack of integration with current supply chain management platforms and ERP systems is another significant flaw restricting its industrial usefulness.

A PoUW consensus mechanism was presented by Haouari et al. (2021) [10] that substitutes NP-hard transportation optimisation problems for conventional hash-based puzzles. The model is tested on several datasets and simulation environments, although this method demonstrates better computational usefulness and applicability in transportation logistics. Its scalability and flexibility to large-scale, real-time supply chain networks with varied participants and dynamic inputs represent a significant need. Furthermore, it remains unclear how privacy-preserving features and smart contracts can be combined to automate task distribution.

The lack of a performance-driven, comparative examination of blockchain consensus algorithms, specifically designed for supply chain contexts, is the issue this work aims to address. This gap hinders effective decision-making when selecting suitable consensus methods for practical deployments. The current study proposes a methodology that augments two additional modules to PoUW across various supply chain scenarios, evaluating scalability, fault tolerance, transaction latency, and energy consumption metrics. The study seeks to respond to:

- How is supply chain management incorporated with blockchain technology?
- How can the design and implementation of secured and efficient supply chain management be improved using an improved consensus algorithm?

This paper makes a theoretical contribution by delivering a systematic critique of consensus models and a practical one by providing a decision-support tool for implementing blockchain in supply chain management.

2.1 Critique of Literature

Supply chain management (SCM) is being revolutionised by blockchain technology, which provides solutions to persistent problems, including data transparency, counterfeiting prevention, and unreliable stakeholder participation. Blockchain integration in supply chain management has been the subject of numerous studies, focusing on the advantages of real-time auditing, tamper-proof record-keeping, and traceability. Specifically, consensus algorithms—the fundamental mechanisms ensuring consistency and trust in decentralised blockchain networks—have garnered considerable attention in technical and applied research contexts.

Nevertheless, the current literature has several shortcomings. First, most of the literature focuses on general advantages of blockchain technology rather than exploring how various consensus algorithms affect key performance indicators in supply chain settings. For instance, although PoS and PBFT are frequently mentioned as energy-efficient alternatives to PoW (Proof of Work), limited comparative research assesses these algorithms under actual supply chain workloads.

Thakur et al. (2024) [11] According to this study, establishing trust, guaranteeing data transparency, and abiding by governance rules are some of the main obstacles to implementing blockchain technology in supply chains. It highlights how crucial it is to address these issues to deploy blockchain technology successfully.

Singh et al. (2024) [12] To integrate blockchain technology into Industry 4.0 applications, the study "Blockchain Consensus Mechanisms: Performance Metrics and Selection Criteria for Industry 4.0" thoroughly examines several consensus algorithms. It explores the performance metrics for assessing consensus systems' effectiveness and dependability, including throughput, latency, scalability, fault tolerance, and security. The study highlights the importance of choosing the proper consensus methods for industrial needs, considering variables like network resilience, transaction speed, and energy economy. The study offers essential insights into maximising blockchain adoption for improved operational efficiency and security in industrial settings by comparing these processes to the requirements of Industry 4.0.

Finally, despite recent research comparing consensus models, these studies often employ overly simplistic simulation environments or theoretical assumptions that may not apply to real-world SCM systems, where throughput constraints, node failures, and inconsistent data are typical.

2.1.1 Problem statement

Blockchain possesses significant potential to enhance supply chains. There is an opportunity to develop a comprehensive performance-based framework for evaluating and comparing consensus algorithms specifically designed for supply chain operational needs. This absence can sometimes lead to uncertainty for decision-makers when selecting consensus mechanisms that best meet their efficiency, security, and scalability requirements. This paper proposes a unified benchmarking approach that assesses improved consensus algorithms against key supply chain performance metrics, including throughput, fault tolerance, energy consumption, and transaction latency, to address this important issue. The aim is to assist practitioners in identifying the most suitable consensus protocols for their unique supply chain configurations and constraints. Although blockchain's relevance in supply chain management is growing, a thorough comparative analysis of consensus algorithms tailored to real-world supply chain environments remains an area for further exploration. Existing research often emphasizes general blockchain benefits or provides technical descriptions of consensus processes, while frequently overlooking their applicability to supply chain operations such as transaction speed, latency, scalability, and fault tolerance under varying supply chain conditions. This disconnect may hinder the ability of supply chain researchers and practitioners to make informed decisions regarding the most appropriate blockchain designs for their specific use cases. Additionally, earlier research has focused on domain-specific issues or theoretical simulations that may not directly translate to practical applications. This study aims to bridge the gap between technical blockchain research and the practical needs of supply chains by offering a decision-support system to evaluate and select consensus algorithms based on quantitative performance measures aligned with supply chain requirements.

Objectives:

- To design and implement PoUWAS, an improved version of the PoUW consensus algorithm.
- To obtain a more secure, transparent, and tamper-proof blockchain-based supply chain management system.

Research Gap:

Scalability and Efficiency: The scalability challenges inherent in blockchain technology may become more complex when integrating Proof of Useful Work (PoUW), particularly given the significant computational demands associated with useful work tasks. It is important to find a balanced approach that efficiently manages extensive supply chain data while also ensuring optimal performance—a task that requires careful consideration and expertise.

Data Privacy and Security: Upholding data privacy while promoting transparency is vital in supply chain management (SCM). Innovative frameworks such as PrivChain have been developed to address this need through the application of zero-knowledge proofs. However, further research is necessary to effectively achieve a balance between privacy and the utility of shared data, especially in the context of PoUW.

Governance Mechanisms: The successful integration of on-chain and off-chain governance is essential for achieving effective supply chain management. Governance models should be thoughtfully designed to adapt to the evolving nature of supply chains, considering the potential of PoUW and the complexities involved in this process.

2.2 Supply Chain Management

(M.S. Islam et al. 2024[13]; F. Tian et al. 2016 [14]) Demonstrated a specified consensus mechanism for supply chains by presenting optimised consensus algorithms and a secure blockchain structure, enabling quick and controlled contributions. Developed a trackable technique for the agri-food supply chain, addressing significant food security and quality issues. This approach provides transparency and a secure, protected framework for monitoring and authenticating each phase within the supply chain.

(Sheriff et al., 2025[15]; Gulen et al., 2024[16]; Saberi et al., 2019) [17]) Introduced a safe and secure blockchain-enabled platform for food supply chain management, leveraging a synergistic IDEA algorithm to ensure the authenticity and traceability of food products throughout the supply chain. Analysed the implementation of blockchain-based technology in the agrifood supply chain to ensure the transparency and legitimacy of agro-based commodities. Discussed the connection between blockchain technology and feasible supply chain management and proposed a system that integrates security elements at every stage of the process.

(M. Tajima et al., 2007[18]; H.R. Hasah et al., 2018)[19] Proposed and evaluated the strategic value of RFID in SCM, which enhanced instant monitoring, reduced defects, and improved performance. Proposed a blockchain-based approach to verifying the delivery of tangible assets, ensuring the delivery of goods between buyers and sellers.

Toyoda et al. (2017)[20] proposed a Product Ownership Management System (POMS), an advanced technique that leverages blockchain technology to enhance the security and traceability of products using RFID tags. The practical deployment of this system on the Ethereum

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platform further demonstrated its viability and affordability.

2.3 Proof Of Useful Work

Milan Todorović et al. (2022)[21] approach synchronises mining operations with the resolution of real-world optimisation issues, such as those arising in scientific research, logistics, and healthcare. The authors describe PoUW's algorithmic architecture in depth, investigate how it integrates with blockchain protocols, and evaluate its scalability, security, and usefulness.

T. Davidović et al. (2022)[22] present a consensus on Computational Problems (COCP) architecture. In contrast to traditional Proof-of-Work (PoW) systems, which involve solving random cryptographic puzzles, COCP focuses on directing processing resources toward resolving significant real-world issues, such as machine learning and optimisation tasks. The effectiveness, scalability (Elshair et al., 2024[23]; E. Aruna et al., 2024[24]; L.F. Naz et al., 2024[25]; Delphi Hanggoro et al., 2024[26]), and adaptability of COCP to various application domains are assessed, indicating its potential to make blockchain mining a resource-efficient and socially beneficial process.

The studies provide a comprehensive overview of various frameworks and techniques in supply chain management and blockchain integration. Our proposed approach ensures an efficient and transparent supply chain management system by introducing a novel consensus algorithm that handles a broader range of issues while building upon existing foundational efforts.

3. METHODOLOGY

3.1 Introduction

Blockchain technology in supply chain management maintains the system as efficient and immutable. End-to-end transaction-related activity will be traced and updated to the blockchain. This transformative combination paves the way for a more connected and trustworthy global trade ecosystem. With this proposed methodology, our work highlights the strength of the proposed consensus algorithm compared with the existing system.

3.1.2 Process flow of proposed methodology

All nodes, from the supplier to the end customer, are connected to the blockchain network. As the adoption of blockchain technology continues to grow, the development of smart contracts for various applications has also increased. Many products utilise blockchain technology in supply chain management to transform multiple industries, handling data securely, transparently, and in a decentralized manner. Combining blockchain technology with supply chain management creates significant opportunities for enhancing efficiency, reducing fraud, and fostering stakeholder trust.

3.1.1 Architecture of proposed methodology

Figure 2 indicates the three-tier architecture of the proposed methodology. The core part of this architecture is a distributed ledger, i.e. inbuilt blockchain technology. The second layer comprises the proposed consensus algorithm, which supports all the features of blockchain technology. The outer layer is the application layer, where all nodes of the supply chain, from raw materials to customers, are controlled by a secure blockchain.

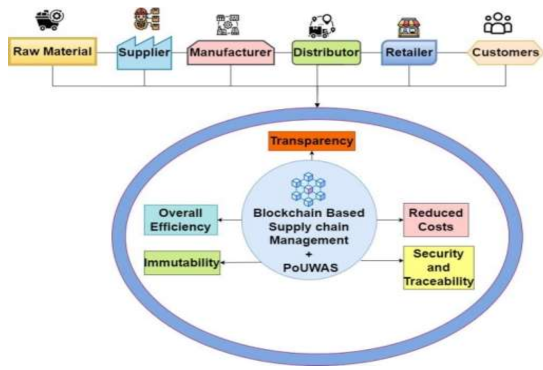

Figure 2: Architecture of Proposed Methodology

Blockchain technology utilises the proposed consensus algorithm, POW, to validate and add blocks to the blockchain. This POUWAS works in three stages. Firstly, it verifies the authentication of the user who initiated the transaction. At this stage, the proposed methodology eliminates fraudulent blocks, thereby reducing the cost of processing. After verification of the authenticity of the transaction, the proposed methodology checks storage availability in the second stage. This methodology addresses scalability issues by stopping the transaction when storage is unavailable, as proceeding further would be futile during the second stage.

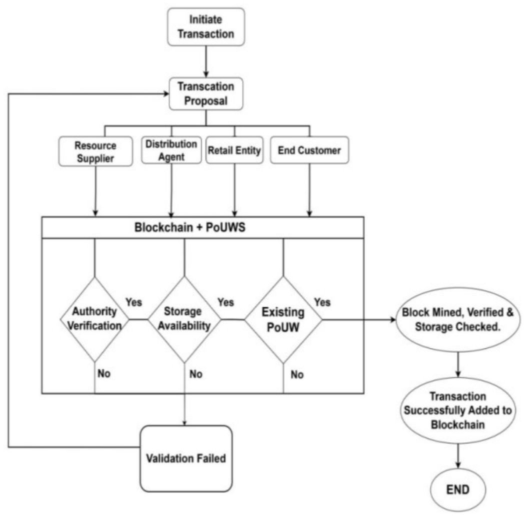

Figure 3: Process Flow Of The Proposed Methodology

After these two stages, the PoUW consensus algorithm validates and adds the block to a blockchain. The primary objective of this enhanced algorithm is to prevent fraudulent blocks at the initial level and to mitigate scalability issues by reducing processing costs. As shown in Figure 3, the supplier, distribution agent, retailer, and end customer are connected to a blockchain network to facilitate product-related transactions. After that, transaction-related information should be stored on the blockchain through several phases, including authorisation, storage availability check, and mining. If the functions performed by these members are valid, then only the block will be successfully attached to a blockchain; otherwise, it will be rejected.

3.2 Proposed Consensus Algorithm

This is the improved version of Proof of Useful Work (PoUW). In this work, additional features, such as authorisation and storage availability, are added to PoUW. These features are described by two different procedure algorithms, namely Authorization and Storage availability. This improves efficiency and overcomes the scalability issues. The extended three algorithms are described below.

3.2.2 Authorization

Jun Wook Hen et al. (2024)[27]. The authorization approach enhances blockchain security by reducing the likelihood of fraudulent activity through the verification of identities and reputations of validators. Because authorization networks rely on a limited number of verified and identified validators, any fraudulent conduct could jeopardise their real-world reputations and expose them to fines, such as having their authority revoked. A validator is deterred from committing dishonest acts, such as altering transaction history or attempting to initiate a double-spend attack. Furthermore, real-time monitoring and timely identification of irregularities are made possible by an authentication-based small group of validators, which makes it more difficult for attackers to compromise the network without being immediately detected. The authorisation method for fortifying the blockchain network is illustrated in Algorithm 1.

Algorithm 1. Procedure _Authorization

Input: #pre_blockIndex, #blockID, Data, pre_blockData, pre_hash)

//#pre_blockID:

//#blockIndex:

//#Data: New transaction data.

// pre_blockData:

// pre_hash

Output: Verifies authorisation of block

1. hashCode ← SHA (data) // The current block's hashCode, calculated using the SHA algorithm.
2. if pre_blockID + 1 ← blockID
   3. if SHA (pre_blockData) ← pre_hash:
      4. return true //node is authorised
3. Otherwise reject the transaction & return false
4. End Procedure

3.2.3 Storage availability

To avoid scalability issues, it is necessary to verify storage availability before adding a new block or transaction. Blockchain and decentralised networks utilise storage availability checks, a cryptographic technique and consensus process, to confirm that storage providers are indeed retaining the data. A storage availability check requires storage nodes to regularly demonstrate that they still possess data blocks by producing cryptographic proofs, as opposed to relying on computing power (Proof of Work) or monetary stakes (as in Proof of Stake). Encoding or hashing stored data and then validating it on the network creates these proofs, which are tiny, readily

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verifiable pieces of evidence. (Algorithm 2) provides a step-by-step procedure for maintaining storage availability checks on a blockchain.

Algorithm 2. Procedure_Storage_Availability

Input: Data, block_hash, #node_id, challenge [], req_storage,

Output: Verified block with proof of storage capability

1. hashCode ←SHA (data) // current block's HashCode using SHA algorithm.
2. If available storage ≥ req_storage:
    3. if req_chunk= challenge[chunk_data]
        4. if response_hash=hash(req_chunk)
            5. if validator_hash =hash(requested_chunk)
6. return true //storage availability got checked
7. Otherwise reject the block & return false
8. End Procedures

3.2.4 Pouw consensus algorithm

This algorithm is executed after the first two algorithms. By requiring nodes to do computationally demanding activities to validate new blocks, this algorithm increases the productivity and efficiency of blockchain mining operations. (Algorithm 3) explores the validation of the block concept applied to multiple transactions. The given program implements a consensus mechanism called Proof of Useful Work for blockchain validation. It attempts to find a valid proof by performing computationally practical work—specifically, identifying a prime number and refining it into a proof that meets a specified difficulty. The process begins by selecting a random number between 1000 and 10,000 as a prime candidate. Then, it checks whether this candidate is prime, incrementing it until a prime number is found or the maximum allowed iterations (max_iterations = 100000) are reached. If the limit is exceeded, an exception is raised. Once a prime number is identified, it is converted into a string (proof_string). The program then adjusts the proof value further to ensure that its string representation starts with a certain number of leading zeros, dictated by the difficulty parameter. Again, if this process exceeds the maximum iterations, it stops. Finally, the program calculates the latency and the time taken to perform this entire computation. The function returns both the proof (the valid prime number with the required string property) and the latency, evaluating the efficiency of the proof-generation mechanism. If this proof meets the blockchain's verification requirements, the block is added. Otherwise, it is rejected.

Algorithm 3. Procedure_POUW

Input: block_transactions, prev_hash, #node_id, useful_task

Output: The block is either verified and added to the blockchain or rejected if the useful work is insufficient.

1. Procedure proof_of_useful_work (difficulty, max_iterations=100000):
2. start_time = current_time
3. prime_candidate = random (1000 to 10000)
4. iteration_count =0

Step 1: Find a prime number

// checks prime_candidate is a prime number

5. WHILE prime_candidate is NOT a prime AND iteration_count < max_iterations:
    6. INCREMENT prime_candidate by 1
    7. INCREMENT iteration_count by 1
    8. IF iteration_count equals max_iterations:
9. THROW Exception "Exceeded maximum iterations for useful work."
10. proof= prime_candidate

Step 2: Find proof string starting with the required difficulty

converts proof into string

11.proof_string = string(proof)

12. WHILE proof_string does NOT start with '0' repeated difficulty times AND

    13. iteration_count < max_iterations:

        INCREMENT proof by 1

    14. proof_string = string(proof)

    15. INCREMENT iteration_count by 1

Calculate latency

16.Latency = current time - start_time

17. APPEND latency TO self. latency

18. RETURN proof, latency

3.2.5 Proposed improved consensus algorithm - pouwas

This method explains blockchain in the context of supply chain-related activities, along with its results. Storing product-related information in the blockchain provides concrete security and avoids counterfeits. There are many phases from the raw material to the customer, and safeguarding shipping and delivery information is essential. The adaptability of blockchain in supply chain management will reduce costs and delays in completing the entire product distribution process. Ultimately, the proposed work, specifically the use of blockchain in supply chain management, will be the most effective solution for overcoming its traditional barriers. Transparency in product deployment and payment-related activities is essential for maintaining a clear understanding of sales reports, and it is also crucial to maintain trust among the various parties. Blockchain will provide a trustless environment for all product-related information. (Figure 2) depicts the entire blockchain process, i.e., the importance of recording transactions related to raw materials, suppliers, factories, distributors, retailers, and customers within the blockchain. Failed transactions and defects can be easily traced and identified when the initial state of the product and order-related information is stored in the blockchain. (Algorithm 4) The proposed algorithm PoUWAS includes two additional modules: authorization, storage availability check, and an extension of PoUW. To better understand a blockchain-based supply chain management system, this research study integrates three key concepts: authorisation, storage availability, and validation through proof of work. These three key concepts are elaborated and discussed in (Algorithm 1 to Algorithm 3). The suggested approach emphasises the use of a simplified Python implementation to highlight the usefulness of each component in the supply chain product delivery process. The proposed PoUWAS algorithm implementation is intended to reduce computational energy consumption and provide security for the entire application. Using an improved consensus algorithm in the supply chain aims to achieve improved scalability.

Algorithm 4: Procedure_POUWAS

Input: Calling (Algorithm 1 to Algorithm 3)

#There are three modules used in the proposed algorithm

Output: Verifies authorisation, storage availability, and validation of the block

1. Boolean is_allowed ← procedure_AUTHORIZATION (#pre_blockIndex, #blockID, Data, pre_blockData, pre_hash)
2. boolean is_available ← procedure_Storage_Availability (Data, block_hash, #node_id, Challenge)
3. Boolean is validated ← Procedure_POUWAS (block_transactions, prev_hash, #node_ID, useful_task)
4. if is_allowed ← TRUE &is_available ← TRUE &is validated ←TRUE
5. Broadcast the new validated block
6. else
7. Reject the block & return FALSE.
8. End Procedure

3.3 Threats to Validity

Addressing any risks to the study's validity is essential when assessing the efficacy and suitability of the suggested PoUW model in a supply chain setting enabled by blockchain. These risks include external and internal elements that may compromise the results' generalizability and dependability.

3.3.1 Internal validity

Internal validity is known as whether the reported results are caused by the suggested PoUW mechanism instead of confounding variables or experimental design problems. The dangers listed below were considered:

- Algorithmic Bias: Performance comparisons may be skewed by the optimisation problems used for PoUW, such as transportation scheduling or traveling salesperson, which may be biased toward solution types.
- Benchmark Selection: The study used publicly available supply chain datasets for the assessment. However, these datasets may not adequately represent the intricacy of real-world supply chains, encompassing the dynamics of multi-stakeholder trust and the unpredictability of real-time logistics.

- Reason for Simulation Over Real Deployment: The model was assessed in a simulated environment due to resource limitations. The simulation may not accurately represent real-world unpredictability or system interoperability issues, even when it approximates supply chain realities.

3.3.2 External validity

External validity is the capacity of the results to be applied outside the setting in which the study was conducted.

- Domain-Specific Customization: Although the PoUW model has demonstrated efficacy in logistics, its applicability to other supply chain elements, such as procurement, demand forecasting, and warehousing, remains to be confirmed.
- Industry Integration: The model's effectiveness is evaluated separately from enterprise systems like SAP or Oracle SCM. This restricts inferences on its deployability in real-world business settings.
- Scalability Issues: A major issue in global supply chain networks is the scalability of addressing significant, real-time optimisation problems over thousands of nodes, which is not adequately considered by existing implementations.

3.3.3 Validity of Constructs

This type of validity checks to see if the experimental design appropriately represents the theoretical ideas it is meant to test.

• POUW Selection of Workload: When transportation-related optimisation problems are selected as "useful work," all supply chain nodes are assumed to need the same optimisation issues. This might not meet the varied needs of various stakeholders.

• Consensus and Security Assumptions: Although PoUW is intended to replace energy-intensive PoW, it may not be reliable in distributed and partially trusted networks due to assumptions about miner honesty, problem difficulty tuning, and verification fairness.

3.4 Justification of Critique Criteria

The following critique standards were chosen to evaluate the literature and the suggested model methodically:

1. Computational Usefulness: Whether the PoUWAS makes a valuable computational contribution to the field, explicitly resolving supply chain logistics optimisation issues.

2. Security Guarantees: The extent to which PoUWAS upholds the integrity of the blockchain and defends against Sybil and 51% assaults.

3. Energy Efficiency: Evaluation of computational energy expenses of conventional PoUW.

4. Practical Applicability: Evaluating the feasibility of integrating supply chain applications, considering latency, throughput, and compatibility with smart contracts.

5. Verifiability and Trust: The capacity of validators to quickly confirm findings without needing access to private company information.

4. IMPLEMENTATION

4.1 Implementation Of the Existing Algorithm Pouw

The Proof of Useful Work (PoUW) algorithm is applied to a healthcare supply chain management system using Python for block validation. Every block contains key attributes, such as the index, previous hash, data (product details), timestamp, proof (the result of PoUW), and valuable work. The Blockchain initiates with a genesis block, and new blocks are added by solving a proof-of-work (PoW) challenge, which involves generating a prime number and verifying it against a difficulty level, defined by the number of leading zeros. Each block contains product information, including ID, name, batch number, and expiry date, which are randomly generated. The blockchain maintains performance metrics, tracking latency and transactional throughput. Using the Ethereum platform, precisely the Remix IDE, gas costs, transaction costs, and execution costs are measured based on the existing consensus. Using the Spyder Python IDE, a supply chain-based blockchain was created, measured, and utilised for product-related activities.

(Figure 4) represents 5 Blocks to calculate the average latency and transactional throughput

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based on the traditional PoUW. A healthcare-based supply chain for delivering different block elements, including Index, Timestamp, Data, Previous Hash, Hash, and Proof of Useful Work details, has been generated. In each block, the data element contains attributes such as Product ID, Product Name, Batch Number, Manufacture Date, Expiry Date, and Quantity. The average latency for five blocks is 0.0220 seconds, and the average transactional throughput per block is 21.60 TPS. Latency and transactional throughput are key performance metrics, and this type of information is essential for measuring the overall performance of a blockchain.

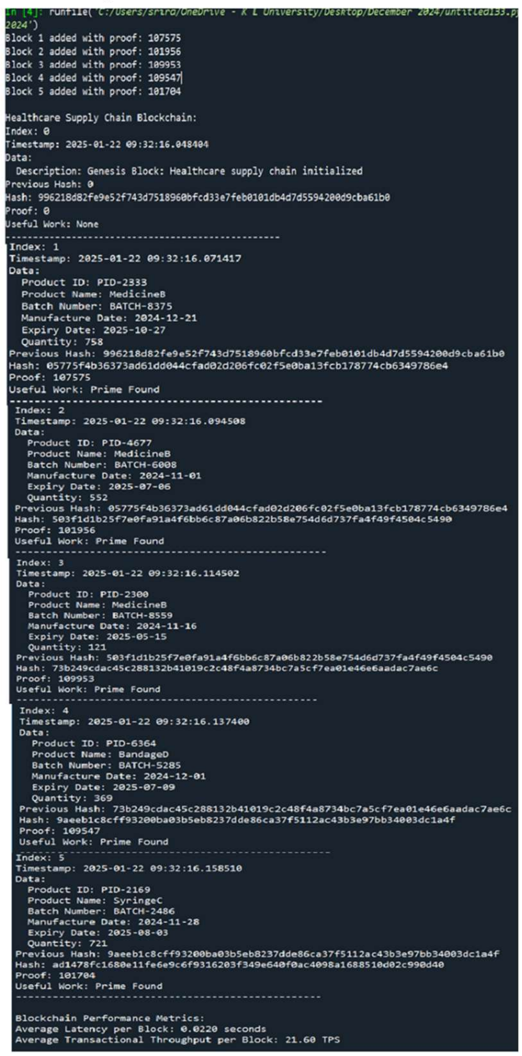

Figure 4 Latency And Transactional Throughput In Pouw-Based Supply Chain Management

4.2 Implementation Of the Proposed Algorithm

Python is used to apply the PoUWAS algorithm to a healthcare supply chain management system. It utilises the Proof-of-Useful-Work Authentication Storage (PoUWAS) technique for validation, verifying storage availability, and authorising blocks. Key properties, including the index, previous hash, data (product details), timestamp, proof (the outcome of PoUW), helpful work, authorisation, and storage availability checks, are all present in every block. New blocks are added to the blockchain by completing a PoUW challenge, which entails creating a prime number and comparing it to a difficulty level (number of leading zeros). The Blockchain starts with a genesis block. Product details, such as ID, name, batch number, and expiration date, are randomly generated and contained in each block. The blockchain tracks performance metrics that measure transactional throughput and latency. Additionally, the program incorporates chain validation techniques to guarantee the blockchain's integrity. Existing and enhanced consensus are used to measure the gas, transaction, and execution costs using the Ethereum platform, which includes the Remix IDE. A supply chain-based blockchain was developed, measured, and used for product-related activities using the Spyder Python IDE.

(Figure 5) represents five blocks to calculate the average latency and transactional throughput based on the improved PoUW, i.e., PoUWAS. In every healthcare-based supply chain, product delivery involves different block elements, including Index, Timestamp, Data, Previous Hash, Hash, and Proof of Useful Work, for which details have been generated. The data element of each block contains attributes such as Product ID, Product Name, Batch Number, Manufacture Date, Expiry Date, and Quantity. The average latency for five blocks is 0.0218 seconds, and the average transactional throughput per block is 46.60 TPS. Latency and transactional throughput are key performance metrics, essential for the overall performance of a blockchain. Additionally, authorisation and storage availability checks are performed to improve the security and performance of a blockchain.

(Figure 4 and Figure 5) These results are from five blocks implemented using the Spyder Python IDE, based on existing PoUW and proposed PoUWAS consensus algorithms, with latency and transactional throughput as parameters for the healthcare supply chain blockchain. Latency was reduced and transaction throughput improved. It is observed that in the performance of a consensus algorithm. Initially, the information on healthcare-related products was stored in blocks, including Product ID, Product Name, Batch Number, Manufacturing Date, Expiry Date, and Quantity. Maintaining authorisation, ensuring storage availability, and validating this data will be essential for the overall performance of blockchain-based supply chain management, as shown in Figure 4. Latency and transaction throughputs are noted as 0.0220 seconds and 21.60 TPS. In (Figure 5) Latency and transaction throughput are noted as 0.0218,46.60 TPS. It is an alternative solution to solve scalability issues by considering these parameters.

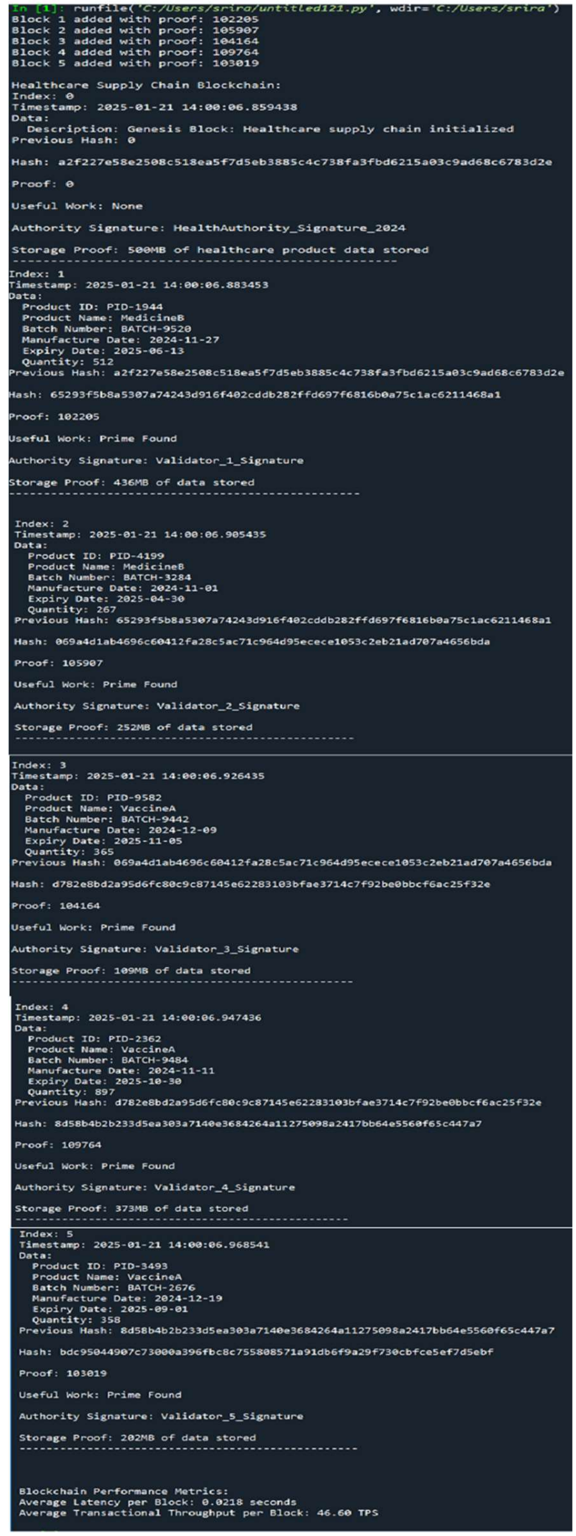

Figure 5 Latency And Transactional Throughput In POUWAS-Based Supply Chain Management

5. RESULTS DISCUSSION

Table 1: Comparative Analysis With The Existing System

Study	Focus Area	Consensus Algorithms Compared	Supply Chain Specific	Performance Evaluation	Contribution Type
Saberi et al. (2019) [28]	Blockchain in Sustainable SCM	No	Yes	No	Conceptual framework
Wang et al. (2019) [29]	Blockchain adoption in SCM	No	Yes	No	Systematic review
Hussein et al. (2023) [30]	Evolution of Consensus Algorithms	Yes	No	No	Comparative taxonomy
Casino et al. (2019)[31]	Blockchain Applications Review	No	No	No	Landscape of applications
Zhongli Dong et al. (2019)[32]	Blockchain framework	Yes	No	Yes	Blockchain-based dApp using PoUW
Proposed Study (Your Work)	Blockchain in SCM with Consensus Focus	Yes (PoUWAS)	Yes	Yes (Simulation-based)	Decision-support + benchmarking

5.1 Principal Contributions

1. Performance examination of the primary consensus algorithms (PoUW and PoUWAS) in a supply chain setting, categorised by domain.
2. Benchmarking based on simulation under varying supply chain stresses, offering helpful performance indicators.
3. A decision-support model that helps choose the best consensus methods based on SCM features.
4. Providing industry-relevant guidelines by bridging the gap between supply chain operational requirements and theoretical blockchain research.
5. Identifying crucial trade-offs between speed, energy efficiency, and decentralisation is essential for practical implementations

According to blockchain consensus methods, computational energy refers to the quantity of processing power required by network users to reach a consensus on the legitimacy of transactions and secure the blockchain. The speed at which transactions are processed and verified throughout the network is influenced by latency and transactional throughput, two critical performance measures in blockchain consensus methods. Depending on the consensus algorithm, latency is defined as the amount of time it takes for a transaction to be verified and added to the blockchain. Transactional throughput, commonly expressed in transactions per second (TPS), refers to the number of transactions that a blockchain can process within a specific time frame. A crucial component of maximising blockchain performance is striking a balance between low latency and high throughput, particularly for applications that require frequent and rapid transactions.

The proposed work primarily focused on three key parameters: computational energy, latency, and transactional throughput. With the help of Remix IDE, gas costs, transaction costs, and execution costs were factored in. When the proposed method performs transactions, it utilises fewer computational resources than the existing approach, resulting in lower latency and higher transaction throughput. The efficiency of this method was assessed by computing energy, latency, and transactional throughput. Spyder Python IDE was used to measure transactional throughput and blockchain latency. Because the

the proposed approach uses less computing power than the existing one, transaction throughput is increased, and latency is decreased.
When it comes to result comparison interms of smart contracts existing PoUW and proposed PoUWAS got compared and at the same time latency and scalability wise python framework got used to measure.

5.2 Computation Energy:

This calculation takes into account parameters such as gas costs, transaction costs, and execution costs.

5.2.1 Gas Cost:

Money is utilised for transaction processing and validation to determine the computational work. Nodes utilise gas in the Ethereum blockchain network for transactions (1). Ensuring the scalability of the blockchain will depend on the computational energy required, which determines the overall cost of completing a transaction. The proposed methodology not only concentrates on the applicability of blockchain but also measures the transaction computation energy.

$$Gas\ cost = Gas\ price * Gas\ units\ Consumed \quad (1)$$

5.2.2 Transaction cost

The amount of cryptocurrency required to execute a transaction by a node on the blockchain will be considered the transaction cost. Not only will it cover the gas price, but it will also cover any other charges applied by the network or service provider. The transaction cost will be calculated as the product of the gas consumed and the gas price, based on the formula given below (2). It is also essential to calculate the execution cost. Overheads include gas costs for storing input or output data (3).

$$Transaction\ cost = Total\ gas\ used * Gas\ Price \quad (2)$$

$$Total\ gas\ used = Execution\ cost + overheads \quad (3)$$

5.2.3 Execution cost

The cost required from the initiation to the completion of a transaction is ultimately known as the execution cost. When it comes to smart contracts, they contain several operations; execution cost is also a part of determining the overall cost. With the help of (4), the execution cost will be identified in all these algorithms.

$$Execution\ cost = Total\ gas\ used - base\ gas\ fee \quad (4)$$

These parameters can be included in the output of smart contracts once each transaction has been

completed successfully. Following the implementation of supply chain management smart contracts, the parameter-

Related outcomes listed below were also taken into consideration in this work.

(Table 2) depicts different consensus algorithms, gas costs, transaction costs, and execution costs. The proposed work aims to compare individual algorithms with improved consensus algorithms. The improved consensus algorithm utilises less processing power. It incorporates features for authorisation checking and storage availability, resulting in lower gas, transaction, and execution costs compared to the current consensus algorithm.

Table 2: Computational Energy In Pouw And Improved Consensus Algorithm

Computational Energy	**PoUW(32)**	**Improved Consensus Algorithm (PoUWAS)**
Gas Cost	0.902390698	0.875066785
Transaction Cost	1797718	877813
Execution Cost	1622244	768145

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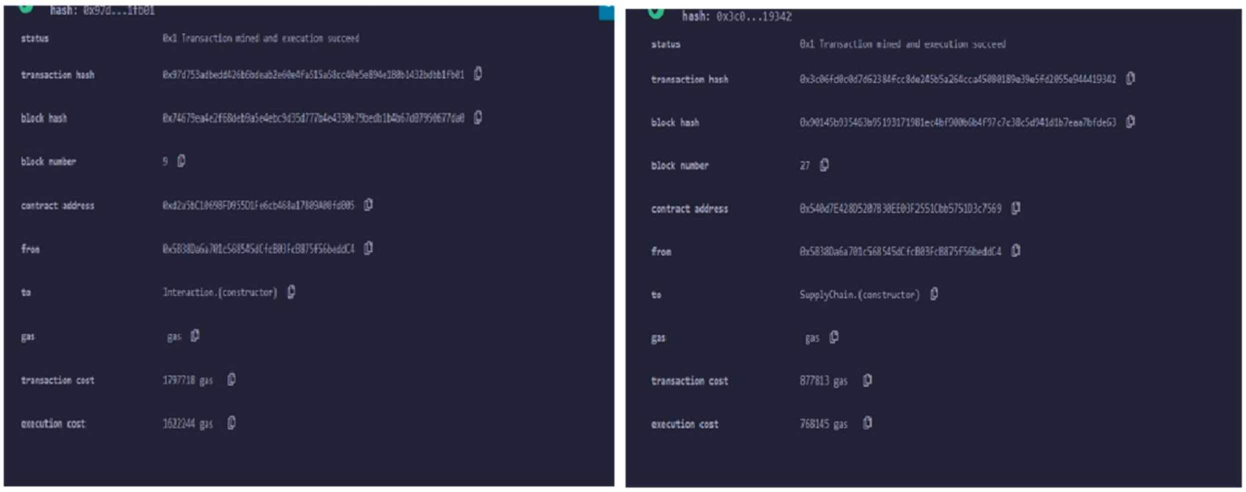

Figure 6 Computation Energy Comparison In Different Consensus Algorithms

(Figure 6) Compares computation energy in mining-based, authorization-based, and storage-based algorithms, as well as an improved consensus algorithm for supply chain management. Comparing all these algorithms also reveals the apparent improvement in the mining algorithm with the enhanced consensus algorithm. In addition to mining, security, and scalability depend heavily on preserving authorisation and storage availability. Both transaction and execution costs are evaluated by algorithms based on the parameters. Ultimately, a smart contract in the Remix IDE enables an improved consensus method, resulting in lower transaction and execution fees.

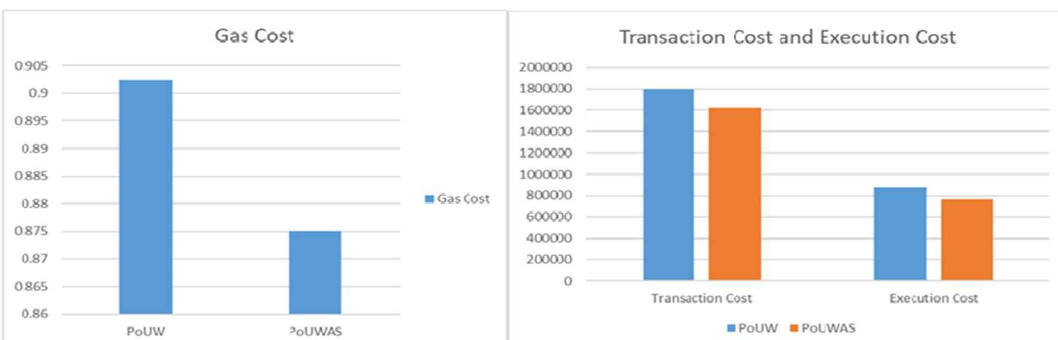

Figure 7: Pouw And POUWAS Computation Energy In Supply Chain Management

(Figure 7) depicts the computational energy of different consensus algorithms in terms of transactional cost, execution cost, and gas cost, compared with existing and proposed consensus algorithms. Integrating all the key features of the mentioned algorithms into an enhanced consensus algorithm results in an improvement in overall performance.

5.3 Latency And Transaction Throughput

5.3.1 Pouw on Supply Chain

Figure 4 explores the latency and transactional throughput for a PoUW-based blockchain. In the context of blockchain, latency refers to the time interval between submitting a transaction and receiving confirmation that it has been successfully added to a block. Stated differently, it is the amount of time it takes for a transaction to be approved and added to the blockchain ledger once it has been propagated across the network. Here, the motive behind evaluating this kind of integration is to leverage blockchain properties in supply chain management, such as transparency and immutability.

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5.3.2 Pouwas, an improved pouw on supply chain management

(Figure 5, Figure 6, and Figure 8) identified that latency deduction and transactional throughput are raised in an improved consensus algorithm. The overall performance of a blockchain can be improved with the help of these parameters. Maintaining a network that is scalable and secure is also essential when integrating blockchain with other emerging technologies and with real-time applications.

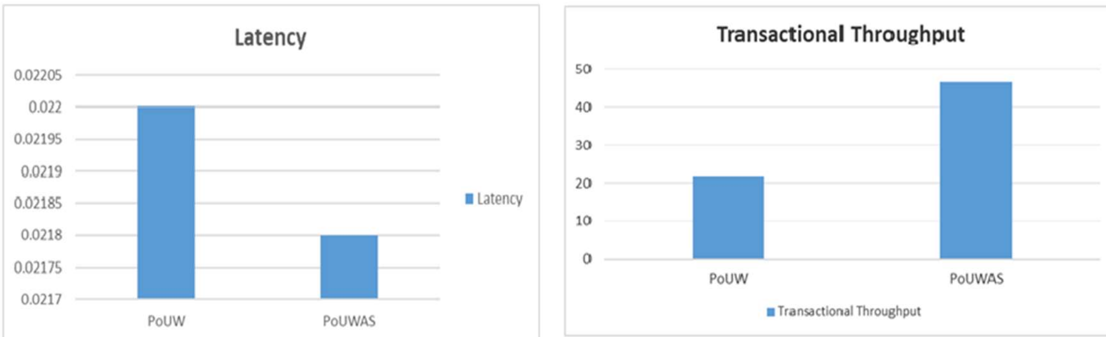

Figure 8 Latency And Transactional Throughput In Pouw And Pouwas

6. CONCLUSION

This article examines the application of blockchain technology in the supply chain for product deployment and discusses the process of storing data in blocks. The proposed work focuses on a novel, improved consensus algorithm and its implementation in a blockchain-based supply chain management system. The functionalities and uses of blockchain are explored to enhance its practical usability. Computation energy with different parameters is also illustrated, along with transaction cost, execution cost, and the end-to-end product delivery status in terms of blockchain, which is clearly stated.

This study introduces a novel application of the PoUWAS consensus mechanism tailored specifically for blockchain-enabled supply chain networks. It demonstrates how consensus mechanisms can serve blockchain integrity and operational efficiency by redirecting the computational power typically wasted in traditional Proof of Useful Work systems towards solving meaningful logistics optimisation problems.

6.1 Novelty of the Work

In contrast to previous general-purpose PoUW schemes, this work's main innovation is its domain-specific adaptation of PoUWAS for supply chains, where:

- The "useful work" addresses optimization issues pertinent to supply chain stakeholders.
- A decentralized verification procedure is suggested that safeguards private logistics data while guaranteeing computational validity
- The model introduces a storage availability that links supply chain performance and blockchain mining.

This work incorporates real-world supply chain restrictions and shows how PoUWAS may function as both a consensus tool and a decentralised logistics planning system, in contrast to earlier works that apply PoUW in theoretical or abstract contexts.

6.1.1 Strengths

- Domain-Specific Evaluation: This study goes beyond general blockchain performance research and offers a focused assessment of consensus algorithms in supply chain management.

- Comprehensive Comparison Framework: To help stakeholders select the best consensus model, a multi-criteria analysis that considers throughput, latency, energy efficiency, fault tolerance, and network suitability is provided.
- Simulation-Based Insights: The findings are more pertinent when simulation settings mimic actual supply chain situations, especially for use cases including logistics, traceability, and inventory.
- Decision Support Tool: The study's findings contribute toward developing a decision-support model that assists organisations in selecting appropriate consensus algorithms based on operational needs.
- Bridging Technical and Practical Gaps: The research bridges the gap between academia and industry by linking blockchain technology with operational supply chain requirements.

6.1.2 Weaknesses

- Limited Scope of Algorithms: The study only considers three consensus mechanisms (PoA, PoS, PoUW), possibly leaving out more recent or hybrid approaches like PoET, Avalanche, or DAG-based protocols.
- Lack of Real-World Deployment Data: Although simulations were used to model performance, actual deployments in genuine supply chains may produce different results due to unpredictable network and environmental conditions.
- Static Network Configuration: The assumption of a fixed number of nodes may oversimplify dynamic real-world environments, where node churn and varying trust models are typical.
- Security Depth: Although basic security criteria are included, the study did not include in-depth threat modelling or attack simulations, which could limit the robustness of security analysis.

6.1.3 Future work

- In the future, the proposed work will integrate more end-to-end business details in the supply chain for fast and secure transactions. Storing these end-to-end details like shipping status, delivery status, and product availability status.
- Extension to Hybrid and Emerging Consensus Models: Future studies could investigate more recent consensus protocols, such as Avalanche, HotStuff, or DAG-based approaches, and compare them under comparable SCM constraints.
- Real-World Testbed Deployment: Applying this framework to an actual blockchain-enabled supply chain (such as agri-food, pharma logistics) will validate results and reveal system limitations that are not visible in simulation.
- Integration with Economic & Cost Factors: A cost-benefit analysis of consensus protocols could be incorporated to guide investment decisions and long-term sustainability.
- Integration with IoT and Edge Systems: Future studies could consider resource-constrained environments and evaluate how lightweight protocols perform under such constraints.

ETHICAL CONSIDERATIONS

Not applicable.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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