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Optimizing Supply Chain Management with Ethereum 2.0: Innovations in Blockchain Technology

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Abstract*— The introduction of viable smart contracts using blockchain technology with Ethereum has greatly impacted the use of supply chain management due to the transparency, automation, and efficiency they have been able to bring. However, decentralized Ethereum was not able to fulfill all demands since it was hampered by high transaction cost, scalability issues and high energy usage. Smart contracts were not able to function properly during real-time supply chain management. But these issues have been dealt with by the introduction of Ethereum 2.0. In this paper, we aim to assess how Ethernet 2.0 can optimize supply chain management by looking into its expected advancements and areas that it can be applied, but most importantly any flaws or limitations that may exist. Furthermore, we also combine AI and IoT with Ethernet 2.0, enabling a range of unaffected supply chain participants to track, decide and enhance their trust with real-time data easily. Finally, by looking into the operations and methodologies of Ethernet 2.0, this research will provide possibility by covering areas of enhanced global supply chain management while also advocating for future areas of implementation and research.

Keywords—supply chain management, blockchain, ethereum, consensus mechanism, ethereum 2.0

Introduction

SCM entails planning, control, and management for the efficient flow of goods from the suppliers to the final customers. Supply chain management encompasses five core activities or pillars: planning, procurement, production, inventory management, and distribution. As described here, SCM includes the following major activities and their components: supplier and material sourcing, inventory control, logistics and transportation, and marketing and sales or demand forecasting [1]. SCM has also improved greatly due to the incorporation of modern technology such as the IoT in SCM for real-time tracking, AI for predictive analysis, and blockchain technology for verification of transactions. Traceability assists in eliminating fraud in pharmaceuticals and food sectors, ensuring product integrity Counterfeiting, scrutiny, and fraud is becoming more cost effective with blockchain technology [2].
Various challenges to a supply chain management process or systems are listed such as disruptions in supply chains due to political events, pandemics, natural disasters, wastage of raw materials, and eco-friendly solutions to SCM. An efficient supply chain management enhances productivity, minimizes waste, and boosts profit margins. Firms such as Amazon and Walmart have completely transformed supply chain management through automation and logistics powered by data. With the increasing global expansion of businesses, SCM will heavily depend on digital transformation and South American solutions like Ethereum to technologically advanced and scale supply chain processes.

Ethereum Blockchain

Ethereum is a decentralized, permissionless blockchain network that supports smart contracts as well as decentralized applications (dApps). It was proposed by Vitalik Buterin in 2013 and subsequently launched in 2015 [3]. With Ethereum, extensions to the blockchain's capabilities was introduced enabling self-executing contracts to be created without the need of a third party.
Like Bitcoin, Ethereum runs on a peer-to-peer network, where nodes serve to validate transactions. Unlike Bitcoin, which is primarily digital currency, Ethereum serves much more purpose with its Ethereum Vritual Machine (EVM), which executes code on a global scale and serves as the backbone of decentralized finance (DeFi) and non-fungible tokens (NFTs) along with various applications based on blockchain technology [4].
The blockchain switched from PoW (Proof of Work) to PoS (Proof of Stake) during its Ethereum 2.0 transition, providing improved scalability and energy usage. Ether (ETH), Ethereum's native cryptocurrency, serves as the transaction fee (gas fee) during transactions as well as for staking.
Ethereum, while also well known for tokenization, helps implement ERC-20 tokens (for fungible assets) and ERC-721 tokens (for NFTs). Polygon is one of the Layer 2 solutions that provides Ethereum with scalability while improving their congestion and fees. The reason Ethereum serves as a fundamental pillar of innovation in blockchain is due to its ability to be flexible and trustless, providing security as well as transparency and immutability. Its Rollups and sharding are just some of the many features Ethereum is constantly upgrading to increase efficiency and aid in the adoption of several niches

including finance, gaming, and supply chain management [5].

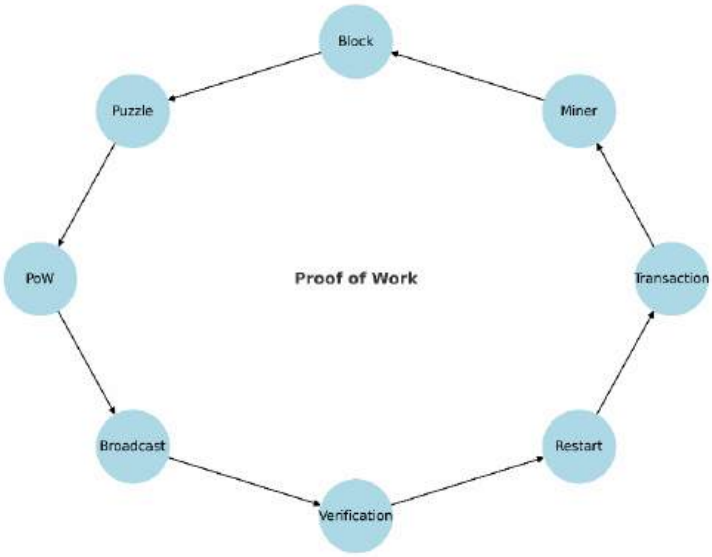


Fig 1. Ethereum Network

Ethereum in Supply Chain Management

With the integration of blockchain technology, Ethereum changes the game in Supply Chain Managing (SCM) with the transparency, automation, and efficiency that comes with the smart contracts and dApps (decentralized Applications). As a programmable blockchain, Ethereum allows companies to track goods, authenticate them, and automate contracts without any middle man.

Companies can use smart contracts to automatically pay talking quotas, assure deliveries, and execute supplier contracts using self-executing, immutable code. This eliminates the need for additional parties and builds more confidence in the processes of the stakeholders. Many assets can be easily tokenized with Ethereum's ERC 20 and ERC 721 standards which provide authenticity as well as track ownership history of the products [6].

With Ethereum's decentralized ledger, all supply chain activities can be seen transparently without delay reducing the chance of fraud and increasing the ease of tracing. Data integrity is guaranteed as every transaction becomes immutable once it is made. Supply chain financing using DeFi on Ethereum permits funding through blockchain based lending contacts providing effortless access to funds.

Through IoT device integration, it is possible to track business processes in real time and automate the entire operation that is specifically enabled by an EVM compatible infrastructure. Scaling Ethereum through layer two platforms such as polygon not only enhances efficiency but also mitigates the impacts of excessive congestion and reduces transaction fees [7].

As a result of using Ethereum, business processes become more efficient, secure, and trustworthy. This makes blockchain technology extremely valuable for optimizing supply chain networks and for enabling effective global business operations.

Objectives of the research

The main objective of this research is to understand the overall working of supply chain management that can be breakdown into following:

- How Ethereum Blockchain Technology can be a solution for supply chain management?
- What are the different features provided by Ethereum 2.0 in supply chain management and blockchain and what are its future scopes?
- What are the limitations of Ethereum in supply chain management that are handle by Ethereum 2.0?
- Providing the details of the available methodologies and features provided by the blockchain in the field of supply chain management system.

To fulfill these objectives, this article reviews various research papers to understand the overall role of Blockchain in the field of Supply chain management.

Literature Survey

As the world economy has now advanced to where it is built upon complex supply chains, the need for tracking systems that are secure, efficient, and transparent has reached another level [8]. For instance, the Ethereum blockchain emerged as one of the most important blockchain technologies because of its innovative smart contracts and decentralized structure; nonetheless, it has serious limitations which will restrict its integration into supply chain management practices [9]. Problems that include scalability, energy consumption, and number of transactions per second however are major problems for companies that desire to obtain real-time information and be agile. Nonetheless, the expectation is that Ethereum 2.0 will

solve such challenges, which include building a computer network over proof of stake to make transactions easier and cheaper while increasing accessibility [10]. Such a change serves not only a new way to go but one that seeks an enhancement in the overall level of performance that they give as well as their level of trust especially those that sit on the top of the supply chains, where integrity is highly wanted. Therefore, it will be argued in this essay how the limitations that exist in supply chain management using Ethereum 2.0 are bounded.

Overview of Ethereum Blockchain and its relevance to Supply Chain Management

Immutability and transparency are key components that can improve supply chain management, and the Ethereum blockchain can help provide solutions to verifying and recording transactions. In regards to traditional systems, goods goods were usually encumbered by the presence of intermediaries. Goods were not easily and conveniently tracked and monitored because of how intermediaries had to be omnipresent in various stages and processes of the supply chain system. Moreover, in [11] it is pointed out that business processes implementations based on blockchain technology can be executed, more so for supply chain management systems which share and validate resources. Additionally, utilizing Ethereum while combining it with IoT increases the supply chain's security and connectivity [12]. Still, this important industry is sensitive to ICO tokens, Ethereum could bring in astonishing effects, especially when Ethereum's current scalability issues are unlocked.

Limitations of the Current Ethereum Blockchain

Ethereum blockchain in Supply Chain Management (SCM) faces several challenges that impact its efficiency, scalability, and adoption.

High Transaction Costs (Gas Fees) – Ethereum's network congestion leads to expensive gas fees, making frequent supply chain transactions costly, especially for businesses handling large volumes of data [13].

Scalability Limitations – Ethereum's processing speed is limited, handling around 15 transactions per second (TPS), which is insufficient for global supply chain operations requiring high throughput [14]. Layer 2 solutions like Polygon help, but adoption remains fragmented.

Energy Consumption (Pre-Merge) – Before the Ethereum 2.0 upgrade, Ethereum used Proof of Work (PoW), consuming large amounts of energy. Although Proof of Stake (PoS) has improved efficiency, concerns about energy use in blockchain networks persist.

Data Privacy Concerns – Public blockchains like Ethereum provide transparency but may expose sensitive business data to competitors. While private or consortium blockchains offer solutions, they reduce decentralization benefits [15].

Smart Contract Vulnerabilities – Errors in smart contracts can lead to irreversible losses, as seen in past DeFi exploits. Businesses must conduct thorough audits, increasing operational costs.

Integration Complexity – Existing supply chain systems rely on traditional databases, making blockchain integration technically complex and expensive. Adoption requires reengineering legacy infrastructures [16].

Enhancements Offered by Ethereum 2.0

Ethereum 2.0 (Eth2) significantly improves Supply Chain Management (SCM) by eliminating major shortcomings of the original Ethereum network with respect to scalability, transaction costs, and energy usage [17].

Sharding brings a higher Scaling Improvement – Eth2 identifies the sharding method, which incorporates splitting the Eth blockchain into multiple smaller chains (shards) and processes transactions in parallel. That raises transactional throughput well beyond 15 TPS, thus allowing Eth to cater to large supply chain operations.

Achieve Lower Transaction Costs – The relocation from PoW infrastructure to PoS considerably reduces congestion within the network and gas costs, further encouraging rampant chain operations [18]. Moreover, PoS enables more cost-effective supply chain operations through Layer 2 solutions such as Rollups, which further increase efficiency of transactions.

Increased Sustainability through Energy Efficiency – Blockchain-based supply chains become more compliant with corporate ESG (Environmental, Social, and Governance) goals because PoS method enables considerable energy reduction by over 99%.

Better Protection Alongside Enhanced Smart Contracts – Strengthened security, thanks to the PoS mechanism, allows Ethereum 2.0 to cope with automated supplier agreements and payments without fear of hacks or leakages within the system [19].

Effortless Synergy: The Enhanced Interoperability and EVM Compatibility features enables easier integration with already existing supply chain platforms and IoT networks for real-time tracking and automation [20].

SCM is made more scalable, economical, and secure with Ethereum 2.0 which enables the swift adoption of decentralized supply chain systems all around the globe.

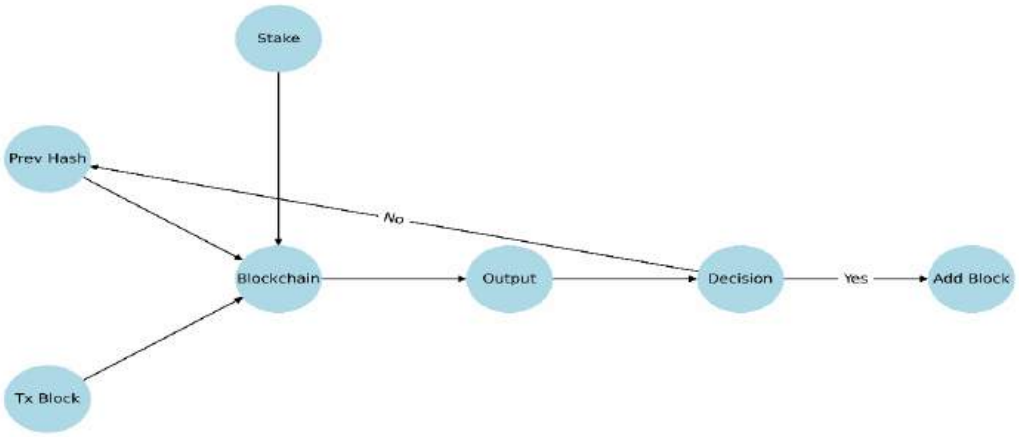


Fig 2. Proof of Stake consensus mechanism

TABLE 1. BRIEF SUMMARY OF SHORTLISTED PAPERS

Author/Year	Data reference	Research Method & tools for Analysis	Findings of the study	Limitation & Future Research
Chien-Chih Chen et al. / 2024	None	• Bayesian Game Theory • Utility Function Formulation • Equilibrium Analysis	• Incentive Compatibility • Guidance for Validator Participation • Stable strategy	• Exclusion of Sync Committee Roles • Extended Model Analysis • Complex Strategy Analysis
Tao Yan et al. / 2024	Harvard Dataverse	• Data Engineering Workflow • Deployment of Archive Nodes • Analysis of Consensus Rewards	• Reduction in Reward Disparity • Technical Validation of Methodology • Applicability of the Dataset	• Data Availability and Scope • Temporal Constraints • Refinement of Decentralization Metrics
Vojislav B. Miši´c et al. / 2024	None	• Simulation of Attacks • Performance Evaluation • Casper FFG (Friendly Finality Gadget)	• Impact of Validator Delays • Vulnerability to Attacks • Effectiveness of Countermeasures	• Complexity of Attacks • Broader Attack Vectors • Protocol Modifications
Muhammad Hilmi Razali et al. / 2024	Election Data	• Blockchain Technology • Cryptographic Techniques • Etherscan	• Decentralization Enhances Security • Anonymity and Integrity of Votes • Potential for Election Fraud Mitigation	• Technical Complexity • Enhanced User Education • Broader Implementation Trials
HAMRA AFZAAL et al. / 2024	None	• Model Checking • Process Analysis Toolkit (PAT) • Communicating Sequential Programs (CSP#)	• Formal Verification Success • Error Identification • Importance of Safety and	• Scalability Issues • Conceptual Exploration • Further Modeling and Verification

		• Linear Temporal Logic (LTL)	Liveness Properties	• Formalization of Safety and Liveness Properties
Jinsong Wang et al. / 2024	None	• Universal Composability (UC) Framework • Statistical Analysis • Data Availability Sampling • Security Analysis	• Improved Throughput • Low Storage Overhead • Data Availability and Retrievability • Experimental Validation	• Data Availability Risks • Storage Overhead for Off-Chain Nodes • Enhancing Data Retrievability • Reducing Merkle Proof Sizes
Eren Yigit et al. / 2024	None	• Technological Stack Analysis • Event-Driven Analysis • Data Structure and Functionality • Integration of Emerging Technologies (AI)	• Enhanced Traceability and Transparency • Increased Reliability • Cost Assessments • Optimization Opportunities	• Technological Workforce Requirement • Robust Rule Establishment • Integration of Multi-Language Support • Performance in Low-Bandwidth Environments
Burhan Ul Islam Khan et al. / 2024	None	• Proposed Computational Model • Standard Simulation Parameters • Performance Metrics	• Performance Improvements • Equilibrium Between Security and Communication • Dynamic Network Adaptation • Empirical Trust Computation	• Resource Constraints • Bandwidth Limitations • Optimization of Blockchain Protocols • Enhanced Trust Computation Models
Alexander Kudzin et al. / 2024	None	• Algorithm Development • Validation Techniques • Parallelization Strategies	• Modification of KZG Proofs • Pairing Checks • Avoiding Polynomial Evaluation	• Computational Intensity • Memory Constraints • Improving Aggregation Efficiency
ILHAAM A. OMAR et al. / 2023	None	• Algorithm Development • Testing and Validation • Use of Remix IDE • Cost and Security Analysis	• Improved Information Sharing • Reduction of Inefficiencies • Enhanced Trust and Security	• Scalability Issues • Governance Challenges • Decentralized Applications • Enhanced Security Measures

Conclusion and Results

In conclusion, moving towards Ethereum 2.0 offers great opportunities in resolving the issues met with the Ethereum based blockchain in supply chain management. The change from proof of work to proof of stake significantly enhances the efficiency of transactions per second and overall network scalability. This is essential for the ever evolving supply chains.

TABLE 2. COMPARISON BETWEEN ETHEREUM AND ETHEREUM 2.0 ON VARIOUS SUPPLY CHAIN PARAMETERS

Parameter	Ethereum 2.0	Ethereum
Consensus Mechanism	Proof of Stake (PoS): Energy-efficient and faster.	Proof of Work (PoW): Energy-intensive and slow.
Transaction Throughput	Up to 100,000 TPS with sharding and optimizations.	~15 transactions per second (TPS).
Scalability	High scalability due to shard chains and PoS.	Limited scalability, often leading to network congestion.
Transaction Costs	Lower and more predictable gas fees.	High and variable gas fees.
Energy Consumption	Significantly reduced due to PoS mechanism.	High due to PoW mining requirements.
Data Processing	Parallel data processing across multiple shards.	Sequential data processing on a single chain.
Integration Complexity	Improved adaptability due to better scalability and cost efficiency.	Requires substantial modifications for legacy system integration.

In addition, the deployment of AI for smart contracts can help in data tracking and verification on the move, which can help in reducing users' integrity issues. This is very helpful when IoT is integrated with blockchain because it can enhance security and efficiency. However, as recent papers have noted, there are concerns in this area that need consideration as well, such as interoperability problems, the need for suitable consensus mechanisms in decentralized networks, and so forth. Ultimately, the gradual roll out of Ethereum 2.0 will allow for much more secure and clearer supply chain models.

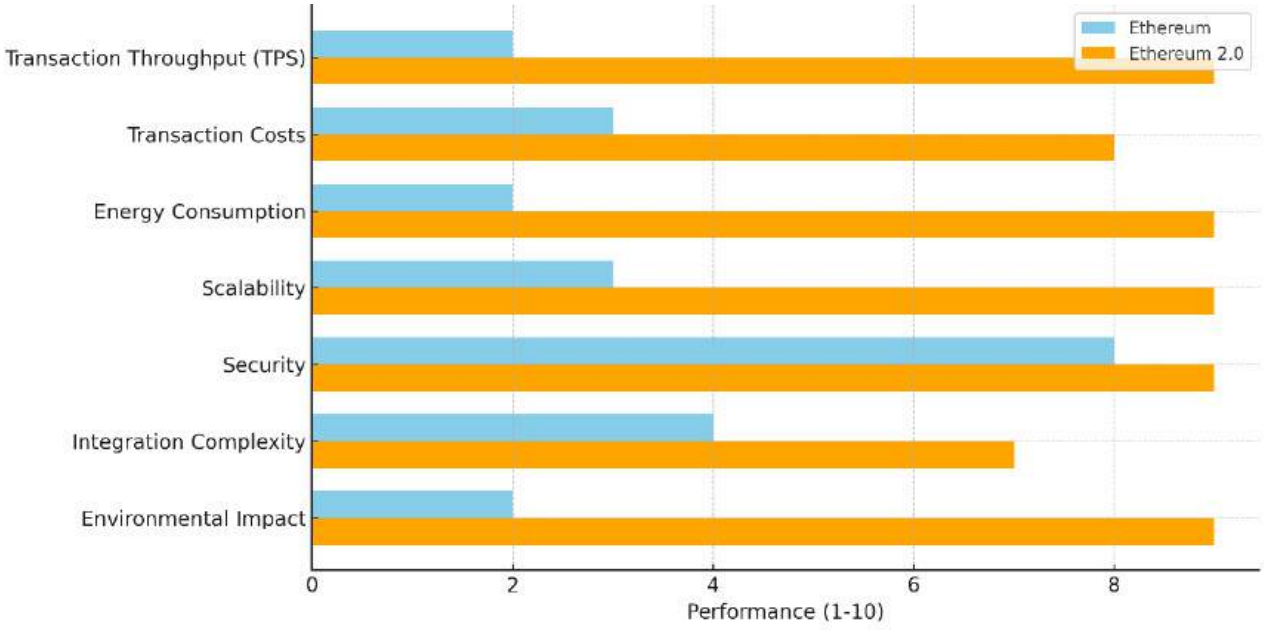


Fig 3. Comparison between Ethereum and Ethereum 2.0 on various supply chain parameters

Future Scope

The effects that Ethereum 2.0 might have on supply chain management processes are undeniably positive because it builds on scalability, efficiency, and sustainability which happens to be the primary weaknesses in traditional blockchain systems. Thanks to processing shards, Ethereum 2.0 is capable of processing up to 100,000 transactions in a single second, and Plurality (PoS) only improves this scaling further. Its energy usage and operational cost reduction makes it ideal for the ever ubiquitous demand for affordable and eco-friendly solutions. This facilitates real time, automated, and transparent monitoring using smart contracts which fosters trust among parties. Moreover, the ease of connectivity and communication provided on the IoT subsystem of Ethereum 2.0 enables better integration with AI and Big Data for more enhanced supply chain functionalities. Whenever blockchain technology is fully accepted, Ethereum 2.0 will help make virtually any industry's supply chains more efficient, transparent, and robust.

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