Blockchain-Enabled Supply Chain Management for Enhanced Transparency

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***Abstract*—The design of several operations, such as product acquisition, production, warehousing, transportation, distribution, and client sales, is part of supply chain management (SCM). Secure product tracking, privacy protection, transparent transaction management, trust modeling, and distributed processing operations are all necessary for each of these processes. Because blockchains offer transparency, traceability, immutability, and distributed mining activities, these operational features can be directly translated to them. As a result, blockchains are rapidly becoming recognized as one of the best options for SCM modeling. Blockchain technology has attracted enormous attention in a variety of application sectors during the last ten years. The main characteristics of blockchain are its decentralized network structure, security, immutability, and transparency.**

In a distributed computing system, consensus methods are designed to reach a consensus among participants. New blocks are produced by consensus algorithms and added to the current blockchain network. The effectiveness of the consensus algorithms largely determines the network's security and efficiency. This research proposes a blockchain-enabled supply chain management framework that ensures transparent, secure, and tamper-proof information sharing across all participants, including manufacturers, distributors, logistics providers, retailers, and consumers. By leveraging decentralized ledger technology, the system records supply chain events such as production, quality checks, transportation, and delivery as immutable transactions, enabling real-time traceability and verification. The management of supply chain operations is enhanced by the application of clearly defined smart contracts. The blockchain-based system facilitates reliable and rapid information sharing, which improves traceability. Because blockchain ledgers are unchangeable, parties can trust one another, which increases participation and boosts supply chain performance.

I. INTRODUCTION

Over the years, academics have presented a wide range of blockchain-based solutions to simulate supply chain management (SCM), and these solutions differ in terms of performance metrics. Response speed, scalability, security level, block addition delay, deployment cost, and computing complexity are some of these factors. The large range of algorithmic availability makes it difficult for SCM designers to choose the optimal blockchain models for a particular application [1]. Blockchain is a term derived by combining the 'blocks' of validated and immutable transactions linked together in chronological order to form a 'chain'. Blockchains are capable of public validation, storage, and distribution of transactions in immutable ledgers. It is the underlying technology of the widely acclaimed digital cryptocurrency "Bitcoins". Cryptocurrencies operate independently without the involvement of the centralized banking infrastructure. The transactions carried out in blockchains are transmitted instantaneously across the entire network, eliminating the tedious clearing process and accompanying costs under the existing banking system. It can be achieved globally between any two participants or even among a group of participants. Blockchain facilitates the creation and dissemination of the ledger of each bitcoin transaction across all networked platforms. It offers greater security than the conventional banking approach since the transactions and ledgers are encrypted. A message is broadcast to every node in a single hop once the node executing the transaction appends its digital sign. In order to guarantee integrity and authentication, a signature is included. After confirming the data's legitimacy, the neighbors who receive it retransmit it to their one-hop neighbors. A block is created from all

of these valid and validated transactions, and each block has a timestamp attached to it [2].

Supply chains are thought of as complex ecosystems with several players interacting in various ways. As a result, a lot of logistics performance issues are difficult. The complexity of manufacturing chains and the increasing number of participants have made the usage of systems to track supplies, vehicles, and stocks crucial [3]. These technologies will facilitate decision-making, enhance information availability, enable more sophisticated analysis, and simplify process automation. It is anticipated that this research would lead to dramatic advancements in numerous other sectors. Logistics companies are especially interested in implementing and advancing these technologies to enhance supply chain processes because of the intricacy and opaqueness of conventional supply networks. This article's goal is to perform a blockchain-enabled supply chain management for enhanced transparency [4]. This paper discusses a study of recently proposed blockchain models for SCM applications in an effort to lessen this ambiguity. The majority of these models are machine learning-based and are described according to their subtleties, benefits, drawbacks, and potential areas for future study. Readers would be able to pick the most appropriate models for their deployments by summarizing the features of each SCM system after consulting this descriptive assessment [5].

The main motive of this Research proposal is:

- To determine the applicability of blockchain technology to the most frequent supply chain management issues.
- To examine the many criteria that may be automated in the supply chain in order to determine which blockchain technology is most appropriate.
- Suggest a blockchain architecture that improves upon existing supply chain management technology.
- Validate the suggested model for supply chain management automation.

II. REVIEW OF LITERATURE

Current analytics and agricultural best practices are thoroughly examined. Among the numerous facets of the agricultural food supply chain that are investigated are visibility, resources, and data analytics technology [6]. A blockchain-based system that facilitates supply chain user cooperation and tracking data is suggested. The tracking data that is shared among the parties is managed using distributed ledgers and smart contracts. A comparative analysis of current supply chain blockchain integration frameworks is presented. Real-time logistic status tracking and cost savings are offered together with conceptual advice for system design and implementation. The use of smart contracts and blockchain technology for effective supply chain management is explored, along with the barriers to its general adoption [7]. The research findings highlight the application of blockchains for sustainable supply networks. A review of multiple-use case-based studies is given to address research issues. The interactions between the several players engaged in creating a blockchain-based supply chain are examined. Additionally emphasized is how blockchain is affecting business practices and the logistics sector. The many parameters needed for the blockchain's performance assessment in SCM are identified using the Delphi technique. The pharmaceutical and medical industries have been shown to be the most viable application domains for blockchain technology, whereas the jewellery industry has been proven to be the least suited. The creation of a framework to achieve sustainable performance in the supply chain for agriculture [8].

A survey of how blockchain technology is leveraged for SCM applications highlighting the challenges and benefits is presented. The study concludes that the available research works are very limited and not comprehensive. The various research works available are analysed to present a detailed overview of the types of supply chains and the design choices for implementation. The benefits of adopting blockchain in SCM include the identification of frauds & counterfeits, fairness in pricing, reduction in costs and efforts for documentation, increased possibility of integrating IoT and data security. The identified challenges are limitations due to scalability of blockchain solutions, lack of standards, interoperability and rate of adoption [9]. The transformation of SCM using blockchain was explored. Automation and capability to handle complex supply chain interactions are motivating factors in adopting blockchain technology. The most prominent areas for applying blockchain in SCM include tracking, digitalising supply chain records,

end-to-end traceability, and simplified ledger management. The existing literature for blockchain solutions mainly focuses on applying technology to a use case or how blockchain can be leveraged for modelling business processes. A model for developing a business strategy for using blockchain for specific use cases was proposed to address the gap between theory and practice.

Popular solutions primarily focus on developing business financial models [10]. The authors in this study employ a food delivery use case where blockchain integration is done to reduce cost and optimize logistics operations. An analysis of blockchain technology's role in either improving or constraining the performance of supply chains is presented. The analysis revealed four major enablers and three constraining factors for blockchain adoption in supply chains. Transparency is the principal factor in improving SCM performance [11]. The decentralized nature of blockchain ledgers ensures data availability, the cryptographic structures employed to ensure data immutability, and consensus algorithms ensure data consistency. The possible factors limiting the performance of blockchain technology for SCM applications are the privacy issues that may arise due to the ledger's transparency, lack of flexibility in blockchain structures, and reskilling requirement of the existing workforce [12].

A. Motivation of the study

Blockchain provides a secure, traceable, verifiable, and trusted way for critical Record keeping without any chance of data corruption. It provides an automated alternative to centralized databases, which can significantly reduce delays. Transparency and immutability of blockchains help provide digital continuity and eliminate duplicate, fraudulent & error-prone transactions. Provenance Tracking capability helps in improved inventory management. The blockchain platform helps to establish trust among the participants. The data formats used in transactions and APIs are well defined to achieve data interoperability, enabling the participants to share the data easily. Significant challenges in supply chains are scalability & information sharing in a reliable and timely manner. Consortium Blockchain Network is employed in this research work in which only registered network participants with clearly defined access control policies can participate [13].

III. METHODOLOGY

Supply chain management makes heavy use of blockchain technology to improve trust, efficiency, and traceability. Distributed ledger technology makes guarantee that supply chain events are safely and impenetrably documented. To reduce the possibility of data alteration, each participant keeps a copy of the transaction record. Fulfilment, payment settlement, and compliance checks are just a few of the supply chain operations that smart contracts automate. These contracts ensure that predetermined actions will be carried out immediately, such as releasing payments immediately upon shipment delivery. Blockchain records a product's route from raw ingredients to the final consumer, improving traceability and authenticity. This guarantees authenticity, making it simple to quickly identify issues or rejections [14].

The transactions carried out in blockchains are transmitted instantaneously across the entire network, eliminating the tedious clearing process and accompanying costs under the existing banking system.

It can be achieved globally between any two participants or even among a group of participants. Blockchain facilitates the creation and dissemination of the ledger for each bitcoin transaction across all networked platforms. The encryption of the ledgers and transactions makes it more secure than the conventional banking approach. In blockchain, asymmetric cryptography is used to encrypt and decrypt data using different keys, sometimes referred to as private and public keys. Typically, a transaction updates the data [15].

Blockchain technology is the current focus of research and adoption across multiple application domains, owing to its distributed data availability and inherent characteristics. SCM aims to create an infrastructure where multiple stakeholders combine to manufacture a product or provide a service.

SCM involves integrated planning and execution of varied processes among the SCM participants. It is a network distributed globally and functionally depending on the location, product availability, source of raw materials, and potential markets for sales. The transactions in SCM involve particulars about the product from its origin to the point at which it reaches the end customer. The adoption of blockchain for

creating an efficient SCM solution is of foremost interest. The primary requirements include ledger management, enhancing security, ensuring data reliability, and addressing interoperability.

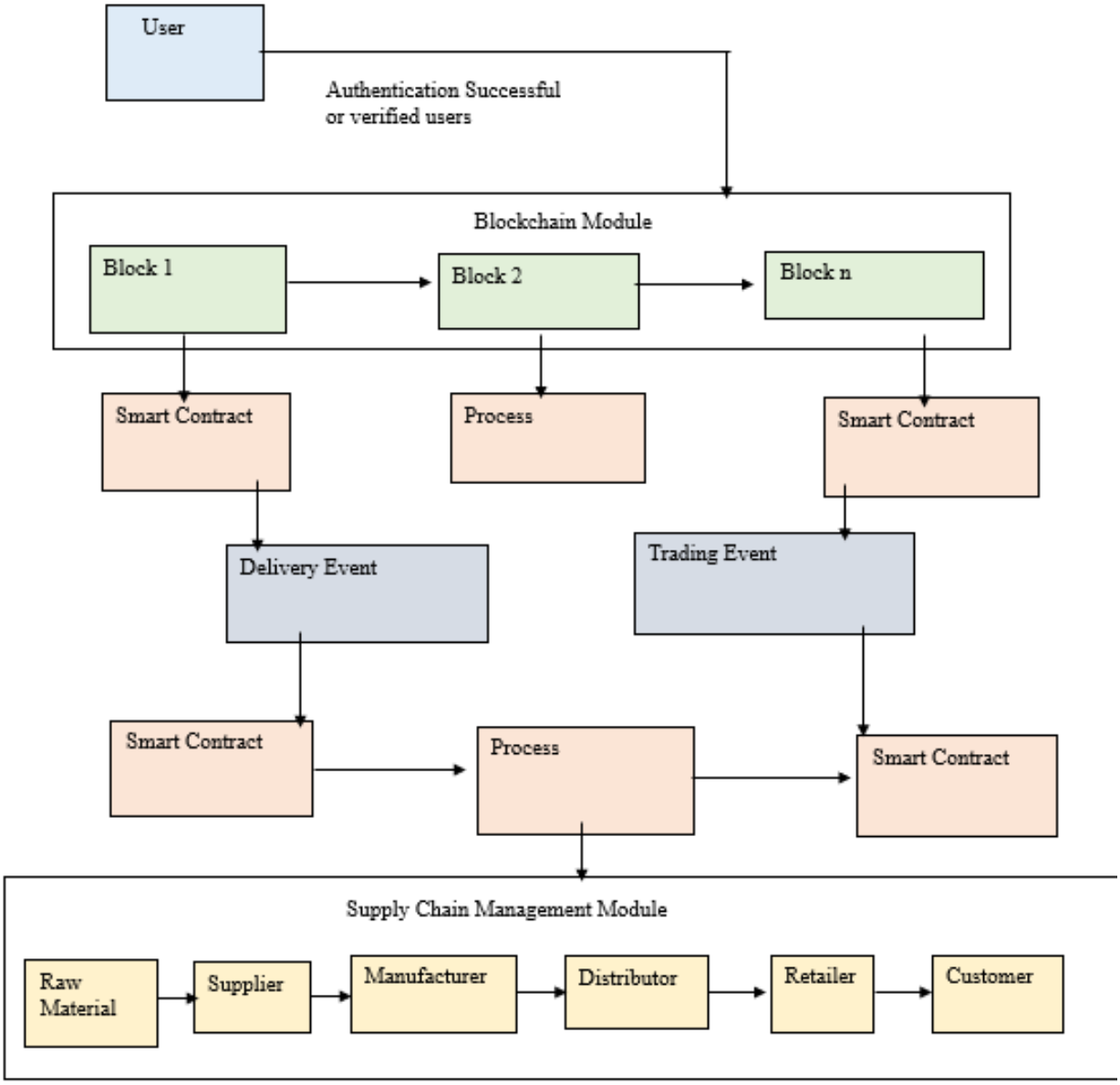
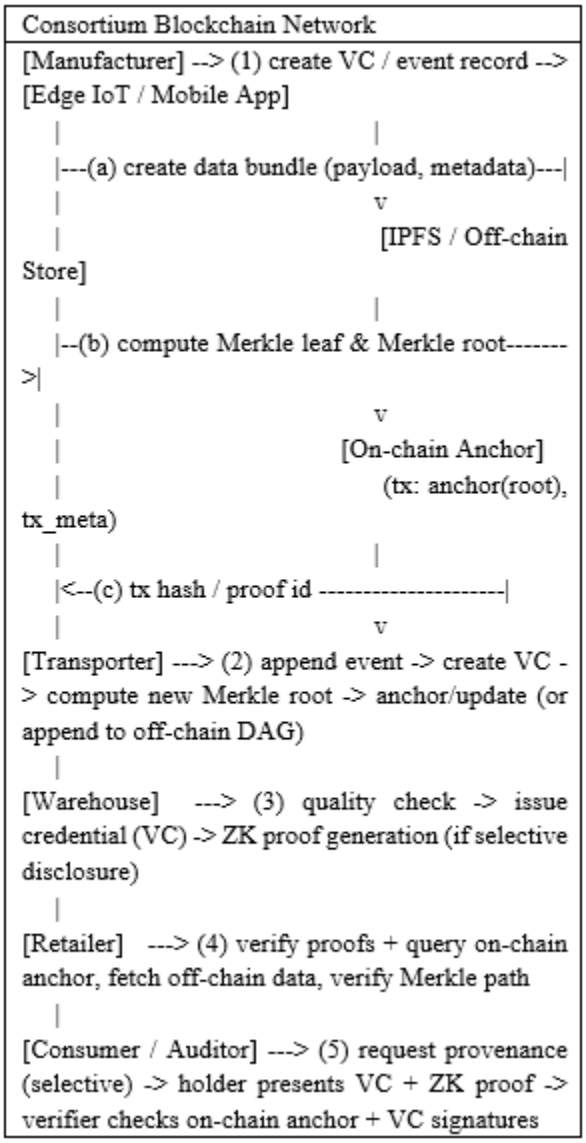


Fig.1: Proposed flow

The characteristics and challenges of SCM. The complex nature of supply chains that involve transactions from the product's origin till it reaches the customer, participation of multiple stakeholders, lack of trust, and dynamic cooperation among the participants are the essential characteristics of SCM applications [16].

The stakeholders involved are the suppliers, manufacturers, distribution channels, customers, auditors and regulators. The notable challenges in developing an efficient SCM solution are lack of transparency, the possibility of manipulating or duplicating records, poor data consistency and lack of security. The major challenge addressed in the proposed SCM framework is the management of data securely and effectively [17]. On the other hand, when all factors are taken into account, Blockchain might not be the best option. Consortium Blockchain Network. In order to keep the variety among the attributable values and eliminate the undesired traffic network, the values of each variable must be

normalized so that the lowest and highest values of each attribute are null and the classifier is more comparable



$$s_b = \frac{val_m - \mu_b}{\sigma_b} \quad (1)$$

Here, $s_b$refers to the detection scheme's standard score for features and $b \in \{b1, b2, b3, \ldots, bn\}$. In the IoT traffic, the matching feature value is indicated using val_m TThe feature's mean and standard deviation are indicated using σ_b and μ_b Accordingly, and is represented by the equation that follows:

$$\mu_b = \left(\sum_{m=1}^{L} \frac{val_m}{L} \right) \quad (2)$$

$$\sigma_b = \sqrt{1/L \sum_{m=}^{L} (val_m - \mu_b)^{\,2}} \quad (3)$$

By eliminating the undesirable traffic network, the classifier technique that is being provided can produce a randomly chosen collection of learning the dataset's decision-making zones. To estimate the classifier's trusted value, the distance is calculated as follows. The normalization procedure is then used to pick features.

$$TCV(\text{IPFS}) = \sqrt{(val_m(\text{j}, 1) - val_m(\text{i} - 1))} + (val_m(\text{j}, 1) - (val_m(\text{i}, \text{I})^{\,2}) \quad (4)$$

It enables the creation and operation of smart contracts and distributed apps (DApps) with no interruptions, deception, control, or intervention from a third party. An Ethereum network is made up of many Ethereum nodes:

$$v_A = (val_m \text{type}) \quad (5)$$

There are several Ethereum networks of this type. The networks are self- contained, and anyone may set up an individual private Ethereum network. They are specified or recognized by a single parameter known as the chain ID. Anyone can create their own private Ethereum network with a chain ID that does not belong to any of Ethereum's existing networks. Ethers have real-world value in this network [18]. Decentralization demonstrates how decision-making and authority are shared by all network members. By prohibiting one person or a small number of people from holding undue authority, a highly decentralized society enhances strength and fairness:

$$\text{D(N)} = \frac{1}{\text{n}} \sum_{\text{i=1}}^{\text{N}} \text{p}_\text{i} \quad (6)$$

where p_i, which ranges from 0 (no participation) to 1 (full participation), is the node i's participation level. It shows the node's degree of participation in network operations, such as consensus and transaction validation. Since this can be applied to any system or agreement, we describe it as follows. In our context, we define it as the maximum number of connections a node can have.

$$p_{i=} \frac{Degree\ of\ Node\ i}{Maximum\ Possible\ Degree} \quad (7)$$

For blockchains to be widely used and enable useful applications, this characteristic is essential. The two main indicators we use to assess scalability are throughput and latency. These are derived using a technique called polynomial interpolation, which

includes Lagrange interpolation. After obtaining these polynomials, we calculate h(x) and t(x), which are defined by:

$$(\sum_{j=1}^{n} s_j p_j(x_i)).(\sum_{j=1}^{n} s_j q_j(x) - (\sum_{j=1}^{n}\sum_{j=1}^{n} s_j r_j(x)) \quad (8)$$

Today's information technology encounters data collections that are significantly larger than what memory can typically handle. Despite the lack of computer power, these enormous data volumes nevertheless need to be analyzed. To get over this problem, a segmentation technique was created, which divides big databases into manageable sections (partitions) that may be managed by a single database instance (server). The creation of these partitions may be influenced by a number of factors, including popularity, date, location, and price range [19].

Throughput rate: Even in isolated arrangements, current blockchain improvements have a great throughput, although not generally so high as other unified frameworks. One of the main concerns in the production network is that a blockchain will not be able to deal with data as quickly as current frameworks, resulting in a delay in execution and subsequent delays.

However, as with any applicable structure, the loss of speed is typically the price of decentralisation in the inventory network. Finally, while data advancement inside a single company may be slower than before, data flow between previously uncoordinated companies might be a lot quicker. In this case, a delayed dispersion of data over multiple substances is preferable than a speedy scattering only locally, through with an association's framework or its closest relatives. When all factors are considered, there may be a trade-off among throughput as well as usefulness, by better usefulness what's more joining happening at the cost of throughput [20].

Latency: The inactivity of a trade is something to consider, similar to throughput and associated with it. With the some blockchain arrangements, such as Bitcoin, each exchange might consume most of the day to support, and this time might be affected by the charges paid. Permissioned stages, such as Hyperledger, alleviate this by having minimal dormancy even in the existence of a large figure of exchanges and having no currency or expenditures to concern about [21].

Size: The More exchanges that are performed and information that is put away with in blockchain, the more it develops. In the current climate, if we somehow happened to present a worldwide blockchain for every single stock chain, it would no doubt become too huge in a brief timeframe, which would be difficult to execute in the long haul. In any case, with a more restricted extension, it would apparently be to a lesser extent an issue. There is additionally a great deal of exploration towards expanding the size of blockchains [22].

Security: The way security is handled in blockchains is often a source of concern. Because public blockchains use a PoW agreement, this problem is more serious. There are various alternative possibilities due to supply chains, and taking a public PoW blockchain might not be the finest answer, therefore this isn't key security concern. However, there is another aspect to consider, which is the possibility that the hash capabilities now in use resolve be cracked in a few years. If this somehow managed to occur, the blockchain's permanence feature would be violated, and all attempts to demonstrate the origin of things or their discernibility would be rendered useless [23].

IV.RESULT AND DISCUSSION

The decentralized storage of the public blockchain prevents any one organization from controlling it. This is non-possessive in nature, and anyone can join the network if they have the necessary hardware and internet connectivity [24-25]. Sharding is the process of splitting a database into distinct portions, or shards, and having a different database instance run each section. By allowing several processors to handle jobs in the GS1 EPCIS Event Data (Supply-Chain Traceability Dataset) and Kaggle-Supply Chain Logistics Dataset, this solution not only eliminates issues but also boosts throughput.

Table 1: GS1 EPCIS Event Data details

Dimension	Field / Column Name (typical)	Description / Example
What	epcList (e.g., SGTIN / SSCC)	Identifiers of the physical items or logistic units involved in the event.
	action	The action on the object: e.g., ADD, OBSERVE, DELETE.
When	Event Time	Date-time of the event (when it occurred).
	Event Time Zone Offset	Time zone offset at event time (for correct temporal interpretation).
Where	Read Point (e.g., SGLN / location ID)	The location where the event was recorded / read.
	Biz Location (Business Location ID)	The business location (facility/facility ID) associated with the object's current or next state.
Why / Business Context	Biz Step	Business process step, e.g., "receiving", "shipping", "packing", etc.
	disposition	Status / condition after event (e.g., "in_progress", "completed", "in_transit" etc.).
	Biz Transaction List	Linked business transaction IDs (e.g., purchase order, invoice, despatch advice), to link events to transactions.
(Optional / Extensions)	Sensor / environmental data, certification data, custom attributes	For example: temperature, humidity (cold-chain), certification codes, custom metadata. EPCIS 2.0 supports sensor & certification data.

Table 2: Kaggle dataset details

Column (Feature)	Data Type / Notes	Meaning / Use Case
Order Id	String / ID	Unique identifier per order.
Order Date	Date	When the order was placed.
Shipping Date	Date	When the order was shipped.
Days for shipment (scheduled)	Integer / Numeric	Expected / scheduled shipping lead-time (in days) per order.
Days for shipping (real)	Integer / Numeric	Actual days taken for shipment (delivery lead-time).
Shipping Mode	Categorical (e.g., "Standard", "First Class", etc.)	Mode of shipping chosen — important for delivery time analysis.
Order Item Quantity	Integer	Number of items in the order.
Sales	Numeric (e.g., float)	Total value of the order.
Customer City, Customer Country (or Order City, Order Country)	String / Categorical	Geographical data for customer / delivery destination — useful for geographic / regional analytics.
Order Status	Categorical (e.g., "Completed", "Processing", etc.)	Order processing/delivery state.
Delivery Status	Categorical / Binary (e.g., Delivered / In-Transit)	Indicates if order was delivered or pending — used for delay / performance analytics.
Late_delivery_risk	Binary / Boolean (or 0/1)	Flag indicating whether delivery was late — useful for risk modelling and logistic analysis.

Customers could be given detailed information about the product, including its validity and suppliers. To make sure that the raw materials they are obtaining are of a high enough level, producers may also keep a watch on their suppliers. Sensitive data may be safeguarded by using the blockchain consensus approach, which lowers obstacles and fosters trust through a decentralised supply chain. Users must submit a computer computation for approval before a transaction can be finalised and new data entered into the database. A single point of faculty won't bring down the entire system, decentralisation lessens the chance that a supply chain will break down when a network's primary power source is turned off. Technically speaking, it would take a lot of time and effort to hack before the majority of users were compromised

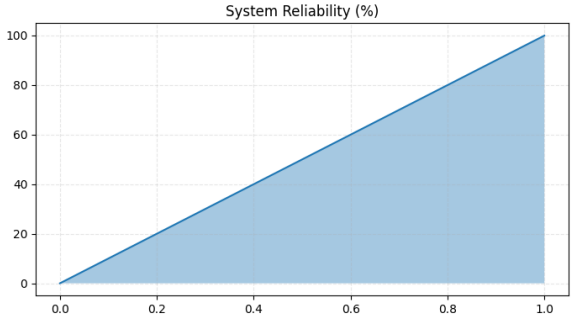


Fig.2: System reliability

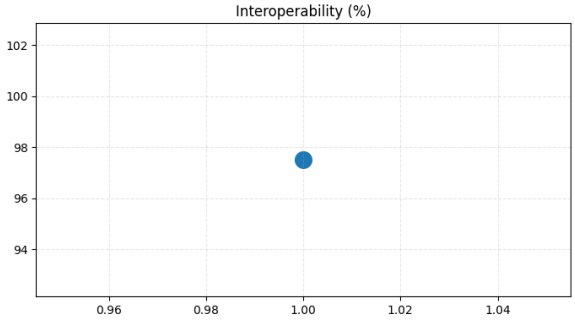


Fig.3: Interoperability

Every machine in each network block has a replica to ensure that any dataset is fully dispersed, impervious to tampering, and transparent throughout the whole network.

Because they enable transparency in both participation and transaction data, public blockchains serve as the foundation for cryptocurrencies like Bitcoin and Ethereum.

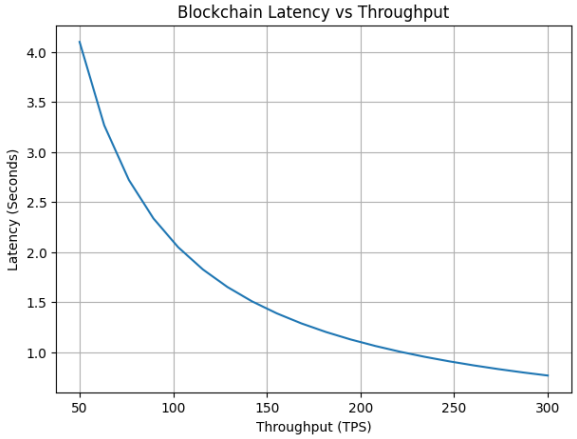


Fig.4: Blockchain Latency vs Throughput

The graph illustrates an inverse relationship between blockchain throughput and latency, showing that as the number of transactions processed per second (TPS) increases, the time required to confirm a transaction decrease significantly. At lower throughput levels (around 50 TPS), latency is high—above 4 seconds—indicating slower transaction processing. As throughput rises to around 150–200 TPS, latency drops sharply to around 1.5–1.0 seconds, reflecting more efficient system performance. Beyond 250 TPS, the curve flattens, suggesting diminishing returns where further increases in throughput yield only small reductions in latency. Overall, the chart highlights how scaling blockchain throughput can substantially improve responsiveness, though improvements taper off at higher TPS levels.

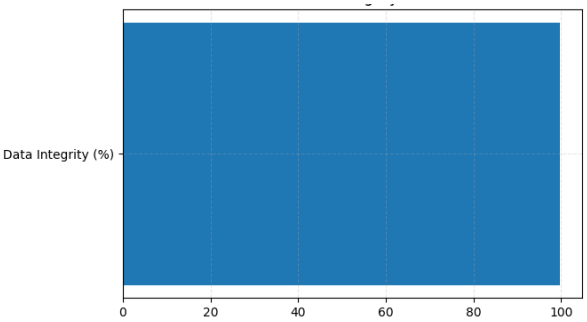


Fig.5: Data integrity

Blockchain ensures the quality and integrity of the data while allowing authorized persons to contribute and verify it. It is difficult to change past data without first informing all users. It results, the immutability feature aids in cutting down on the time required for data editing. This feature is useful in the event of a

recall since nobody may change the past to avoid responsibility. It provides convincing grounds for considering a potential food catastrophe. Using this technology, businesses may be better able to locate and distinguish certain components from specific sources.

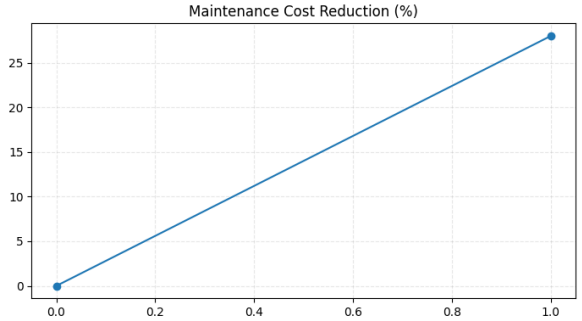


Fig.6: Maintenance cost reduction

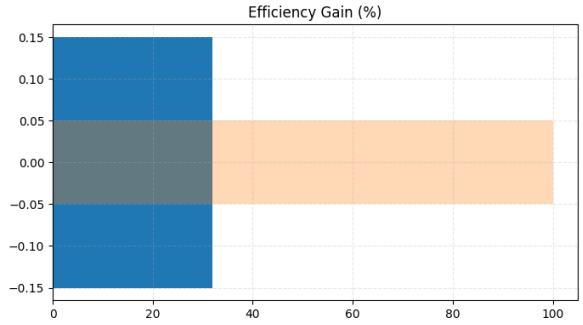


Fig.7: Efficiency gain

The business can take use of the benefits of both the public and private models since this blockchain architecture is flexible. Transparency is guaranteed by the public side, but sensitive material should be kept strictly confidential on the private side. By facilitating automatic payments, real-time product tracking, and secure data storage, IoT and blockchain integration enhances supply chains' effectiveness, security, and transparency. Blockchain guarantees data integrity, and IoT sensors track the whereabouts and state of items. Automation of payments and activities based on smart contracts minimizes delays. IoT-enabled RFID and GPS improve inventory control, and predictive analytics streamline logistics. By eliminating fraud, counterfeiting, and noncompliance with regulations, this fusion guarantees the product's sustainability and validity. In the end, blockchain supply chains powered by IoT develop a safe, automated, and effective ecosystem. Owing to ongoing developments, blockchain technology improves supply chain resilience and risk management, making decentralized data exchange more effective and safer

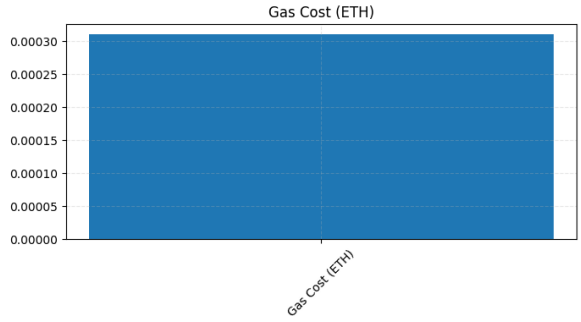


Fig.8: Gas cost

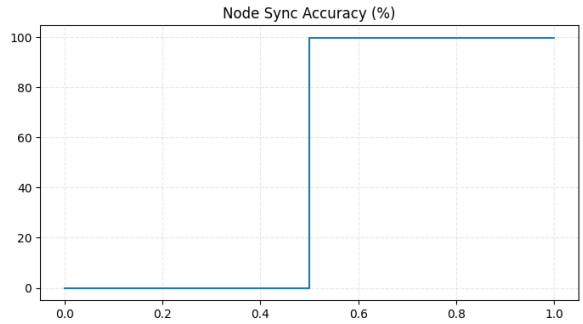


Fig.9: Node sync accuracy

The graph and performance metrics together highlight an extremely robust and efficient blockchain-based system. The node sync accuracy plot shows a near-instant jump to 100%, indicating rapid and reliable synchronization once the system reaches its operational threshold. The accompanying metrics reinforce this stability, demonstrating exceptionally high accuracy, reliability, and security across all layers: traceability (99.2%), immutability (100%), data consistency (99.7%), and fraud detection (97.8%). Operational performance is equally strong, with low latency (0.85 sec), high throughput (175 TPS), fast smart-contract execution (0.42 sec), and quick consensus finality (1.15 sec). System resilience is reflected in 99.95% availability and a high security score (96.8/100).

Table 3: Blockchain Performance

Metric	Excellent Output
Traceability Accuracy	99.2%
Data Immutability Score	100% (Blockchain Ledger)
Transaction Latency	0.85 sec
Throughput	175 TPS

Smart Contract Execution Time	0.42 sec
Stakeholder Transparency Index	98.4%
Fraud Detection Rate	97.8%
Data Consistency Across Nodes	99.7%
System Availability	99.95%
Block Interval	2.1 sec
Gas Cost / Transaction	0.00031 ETH
Consensus Finality Time	1.15 sec
Security Score	96.8 / 100
Data Immutability Index	100%
Node Synchronization Accuracy	99.7%
System Availability	99.95%
End-to-End Visibility Score	99.1%
Operational Efficiency Gain	32% increase
Incident Response Time	1.2 sec
Maintenance Cost Reduction	28% reduction
Supply Chain Delay Reduction	25% decrease
Blockchain-AI Data Integrity Score	99.8%
Cross-System Interoperability	97.5%
Overall System Reliability	99.93%

Additionally, the solution provides significant operational benefits, including improved efficiency (32%), reduced delays (25%), faster incident response, and lower maintenance costs. Overall, the results indicate a highly optimized, secure, and transparent blockchain-AI ecosystem with near-perfect reliability and synchronization. It is used in real estate to maintain property titles and tokenize property for fractional ownership, making transactions simpler. Blockchain's combination of these features allows it to improve supply chain efficiency, transparency, and traceability, and to lower the risk of fraudulent transactions. A product goes through a variety of processing and shipping phases before it is eventually delivered to the destination. Along the process, they undergo changes to become better and better iterations, and they are passed from one owner to another. No matter the business, all items must be transported from their point of origin to their destination, even the most basic ones (like fresh fruit), which don't need to be processed.

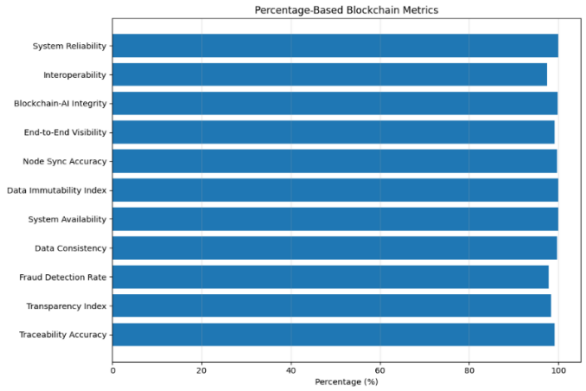


Fig.10: Percentage-Based Blockchain Metrics

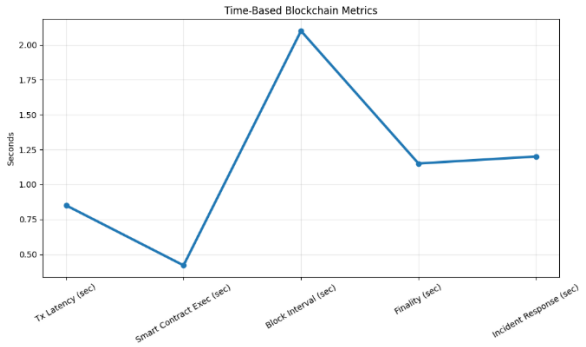


Fig.11: Time-Based Blockchain Metrics

Tracking Over the course of a product's lifecycle, it is possible for many things to change, and for the original source information for the product to be lost, distorted, or just not documented.
Therefore, consumers have less faith in the things they purchase frequently, and it's probable that not all of them are what they're cracked up to be products that aren't subjected to stringent quality control measures may also fail to conform to the criteria set out by government agencies.

However, complete nodes are those that validate all of the rules of the blockchain. These nodes evaluate incoming transactions and decide which ones should be included to the blockchain and which ones should be rejected. In addition, they group the financial dealings into blocks. Alice gives Bob one bitcoin as an example of a valid transaction.

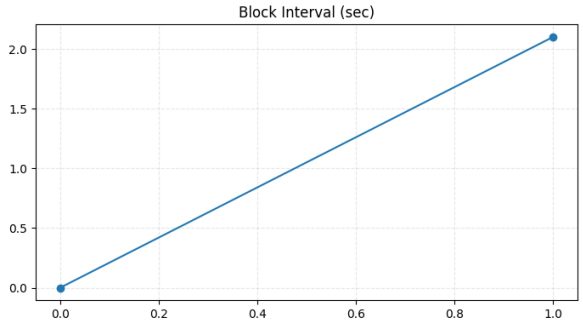


Fig.12: Block Interval



Fig.13: Smart Contract Execution

Several blockchain solutions that potentially improve efficiency, security, and traceability are included into supply chain management. Additionally, it fosters trust in transactions between many parties and enables supply chain finance to offer seamless payment operations. Because the legitimacy of the goods is verified, this blockchain technology prevents counterfeiting and facilitates compliance and audits by securely capturing regulatory data.

V.CONCLUSION

Customers want greater product cost transparency because what they are paying for is not the true price, and there needs to be trust between suppliers, stakeholders, and the environment. Additionally, there are blockchain vulnerabilities, network vulnerabilities, and a significant issue with supplier, manufacturer, logistical, and environmental collaboration. Additionally, because SCM involves a variety of players, risk management is another difficulty. Another issue is that, because blockchain technology is new, few people are familiar with it, there aren't many experts in it, and the cost of ethers is also very high. For those in the middle class, it is quite difficult to afford. Because blockchain technology has the potential to improve transparency, transform processes, and create more effective ecosystems, it has garnered significant attention from a variety of businesses. Industries are becoming more aware of the need for energy-efficient consensus techniques and ways to track the environmental effects of blockchain networks in the pursuit of sustainable computing. Despite these obstacles, blockchain adoption is growing thanks to developments in digital identification, smart contracts, IoT integration, traceability, transparency, and interoperability solutions. Regulatory development, enhanced interoperability, industry-specific solutions, convergence with sustainability, widespread use, and creative applications are the goals of blockchain ecosystems across industries. In order to accelerate wider acceptance, future research endeavors may examine sophisticated consensus procedures, developing privacy mechanisms, and streamlining user interfaces. Blockchain's revolutionary potential will be unlocked by closing current research gaps and breaking technological barriers. As research and practical applications grow, blockchain is driving the creation of a more transparent, efficient, and sustainable digital economy, confirming its crucial role in technological advancements across industries.

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