Emergence of Blockchain Technology and Smart Contracts in Supply Chain Management

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ABSTRACT
Mother of all Bitcoins and cryptocurrencies but why haven't we seen the latent potency this technology could bring to the world in this era. Blockchain is THE revolutionary change which is going to predominantly realign every facet of business and technology. Beginning from storage of data till public voting, a blockchain can drastically transform day to day activities even to a laymen. It is predicted at least 10% of global GDP (Gross Domestic Product) will be stored on a blockchain. Technically briefing, this is not just turning to be an aid to organizations and society but it is employing into a comprehensive replacement of the whole extensive process. Industry 4.0, Web3.0, Decentralized Autonomous Organizations, Smart Contracts are latest modernizations going to dictate the world very soon.

INTRODUCTION
The oversight and supervision of procuring and manufacturing all the commodities, finances, information from the supplier to the manufacturer and then to the wholesaler, to the retailer and finally to the customer or the end consumer denotes supply chains. Traditional supply chains still face many inefficiencies such as safety, security and trust issues. As indicated by many industries traditional supply chains have number of difficulties namely a centralized control throughout the process, highly human involved manual processes which results in higher operational costs, documentation errors and insufficient data sharing capacity. Collection and storage of data by one department seems to be hard to be accessed by other departments, which is the key interconnection for a satisfactory supply chain management. Traditional supply chains show a greater chance of disruptions under uncertainty. Due to siloed information an opportunity of innovations and implementations is being missed.

In the present day, under many circumstances blockchain has proven to be the most ideal solution for all the

hardships above. All the businesses can place themselves at the apex acquiring long term success, sustainability and monopoly in this competitively aggressive landscape. This technology offers peak favourable solutions for difficulties in traceability, transparency and decentralization yet it is not a silver bullet solution. Blockchain combined with ERP, AI (artificial intelligence) and augmented intelligence demonstrates beyond doubt that blockchain could be a top-notch optimal solution. This paper is a compound effort to portray the nature, principles, merits, ill effects and lastly downside of this new technology. No doubts it could only bring untold aids and perks to any industry irrespectively, but understanding potential nooks of this discovery would be a great help to make firms understand if it could be integrated to their supply chain or vice versa.

This study is a try to fully understand the integration of blockchain technology with supply chain management. And this is where the topic of smart contracts fall in. These are normal contracts in a digitalized coded format pre-fed into the system and are executed only when predetermined conditions are met. They eliminate irrelevant intermediaries and unnecessary time loss. Smart contracts ensures certainty of outcome and transparency. When the concept of smart contracts and blockchain technology is triggered into supply chain management a firm can accomplish miracles inside out.

Fig 1.1 Integration of Blockchain and SCM

On a wider area where a blockchain technology can find inventive solutions in the present day subsumes

- **Digital Identity:** The technology offers an uncomplicated manner to prohibit identity theft by providing absolute access control over personal information and manage their digital identities.
- **Voting Systems:** This digital pathway of voting which promises integrity and trust would most certainly avoid tampering and fraud exhibiting the verifying records of votes upheaving democratic systems.
- **Carbon Trading/ Energy Trading:** Buying and selling of energy from one another is made possible with this decentralised peer to peer system which proves renewable energy adoption in the industry

among players.

- **Tokenisation of assets:** Similar to cryptocurrencies, ownership and trading of physical assets such as artwork, real estate assets and other commodities is also achievable through "Tokenization".
- **Decentralized Finance:** Blockchain introduces a new practise of assisting and fostering financial tendencies without the need of traditional banking intermediaries. These DeFi includes borrowing, lending, cross boarder payments and remittances administering utmost autonomy to its users.
- **Decentralized Autonomous Organisations:** These are organisations which are supervised and operated by decentralized decision making processes and smart contracts. They allow non-bureaucratic behaviour substantiating equal participation in every level of management.

- **Supply chain financing and management:** From ensuring ethical sourcing, inventory movements till accessing credit and reducing costs in the supply chain this thesis will deal with a complete element of blockchain technology in supply chain management. As in a brief explanation, supply chain documentation such as the contracts, bills of ladings and other invoices will be digitalized in a format compatible with blockchain to make the storage of information happen in a block. The integration of blockchain with a firm's ERP (enterprise resource planning) will pave prosperous path to an achieved success in every step.

OBJECTIVES OF THE STUDY

- To identify how Blockchain Technology and Smart Contracts aid and facilitate supply chain management.
- To effectively highlight Blockchain Technology and Smart Contracts will be the optimum response for certain challenges and issues in supply chain management.

RESEARCH METHODOLOGY

The research methods specifically applied for this study is DESCRIPTIVE AND EXPLORATORY. Other minor methods of data collection and analysis will include normative research, case study research and comparative case reports. A reasonable amount of extensive document analysis is also done which includes examination of articles, papers, journals, newspapers and other textual sources in order to extract relevant intellectual wisdom about the research topic.

REVIEW OF LITERATURE

Tarun Kumar Agrawal et al. (2022), emphasized in their study due to its high standardized cryptographic functions and block lining mechanisms this technology provides precise accountability and verification of data and information. The smart contracts in supply chain management would administer and furnish solutions for supply disruptions, scheduling, demand forecasting, tariffs, compliance violation, detecting deviation if found and audit fairness. **Ziyoda Mukhamedova and Dilbar Mukhamedova (2023),** described in their article the usage of smart contracts is not only limited to supply chains but protracts to insurance, voting, record storage and

even ownership. **Monzure Khoda Kazi and M.M. Faruque Hasan (2023),** highly focus on the statement that blockchain could be used to track carbon emissions and trade those carbon emission allowances. **Endang Purwaningsih et al. (2024),** revealed in their exploration of study that blockchain technology and smart contracts have appreciatively favourable and substantial impact on supply chain efficiency, export performance and financial performance of SME's (small and medium sized enterprises). **Tan Gurpinar et al. (2024),** adequately indicated the extent of capability of blockchain technology in supply chain management after rigorous research and study generating a process model to integrate it in projects and amounted to the conclusion which illustrates that blockchain technology can make an establishment attain full-scale deployment and can patronage the adaption of information flows principally. **Nur Diana et al. (2024),** justifies the fact that SME (Small and Medium Enterprises) can utilise this technology as well, to increase access to its financing. **Oscar Borgogno and Edoardo Martino (2024),** after critical assessment and evaluation published the theory that this technology have made erupt the Decentralized Autonomous Organisations (DAO's) which are considered to be the new paradigm of business models.

WHY BLOCKCHAIN?

Generally, people want something very powerful always, something which is always better than the other, something which would rule the world for decades. One such newest conception is the Blockchain Technology. To list out the significant importance why this technology is demanded almost everywhere is as follows:

- **Security:** Blockchain utilizes cryptographic techniques to secure transactions and data. Once a transaction is recorded on the blockchain, it is extremely difficult to alter or tamper with it, providing a high level of security. Once a record is made in a blockchain it can never be altered. This makes blockchain suitable for applications requiring secure transactions, such as financial transactions, supply chain management, and identity verification. It offers high levels of security due to its cryptographic design, making it difficult for data to be tampered with or hacked.
- **Decentralization**: One of the primary features of blockchain technology is decentralization. Blockchain eliminates the need for intermediaries by distributing data across a network of nodes, making it more resilient and transparent. It eliminates the need for intermediaries and reducing the risk of a single point of failure.
- **Transparency**: Every transaction recorded on a blockchain is visible to all participants in the network. This transparency helps in enhancing trust among participants and reduces the risk of fraud or corruption. In industries like supply chain management, blockchain can be used to track the movement of goods from the source to the end consumer, ensuring transparency, fostering trust and accountability at every step.
- **Immutability:** Once data is recorded on a blockchain, it cannot be easily changed or deleted. This immutability ensures the integrity of the data and provides a reliable audit trail. In sectors like healthcare and legal services, blockchain can be used to securely store sensitive data and ensure its integrity over time.
- **Global Accessibility:** Blockchain technology operates on a decentralized network, allowing anyone

with an internet connection to participate. This global accessibility opens up new opportunities for financial inclusion and economic empowerment, especially in regions with limited access to traditional banking services.

- **Efficiency and cost reduction**: By eliminating intermediaries and automating processes through smart contracts, blockchain can significantly reduce transaction costs and streamline operations. This is particularly beneficial in industries like banking, insurance, and logistics, where complex processes and multiple intermediaries are involved.
- **Innovation**: Blockchain technology serves as the foundation for a wide range of innovative applications, including cryptocurrencies, decentralized finance (DeFi), non-fungible tokens (NFTs), and decentralized autonomous organizations (DAOs). These applications have the potential to disrupt traditional industries and create new economic paradigms.

SUPPLY CHAIN MANAGEMENT:

Supply chain management (SCM) is the systematic and strategic coordination of activities involved in the sourcing, procurement, production, transportation, warehousing, distribution, and delivery of goods and services from suppliers to customers. It encompasses the planning, execution, monitoring, and optimization of all stages of the supply chain to achieve efficient operations, maximize customer value, and meet business objectives. SCM aims to ensure the seamless flow of materials, information, and finances across the supply chain while minimizing costs, reducing lead times, mitigating risks, and enhancing collaboration among stakeholders.

HOW CAN BLOCKCHAIN AID SUPPLY CHAIN MANAGEMENT SPECIFICALLY?

- **Streamlined Documentation and Compliance:** Supply chains involve a significant amount of paperwork and documentation, such as invoices, contracts, and regulatory compliance documents. Blockchain technology can streamline this process by digitizing and automating the management of documents through smart contracts, reducing administrative overhead and minimizing errors.
- **Inventory management and real time visibility:** By recording transactions on a shared ledger in real-time, blockchain provides stakeholders with up-to-date visibility into inventory levels, shipments, and delivery status. This real-time visibility helps in optimizing inventory management, reducing stockouts, and improving supply chain planning.
- **Traceability:** Blockchain enables the creation of an immutable ledger of transactions, allowing all parties involved in the supply chain to track the movement of goods from their origin to the end consumer. This transparency ensures authenticity and helps in identifying inefficiencies or issues in the supply chain.
- **Compliance and Auditing**: Blockchain's immutable ledger ensures that all transactions and data recorded on the platform are tamper-proof and auditable. This makes it easier for supply chain participants to demonstrate compliance with regulatory requirements and industry standards, reducing the risk of fines and penalties.
- **Provenance Verification**: With blockchain, it becomes easier to verify the authenticity and

provenance of products. Each product can be assigned a unique identifier, and its journey through the supply chain can be recorded on the blockchain. This helps in combating counterfeiting and ensuring the quality and authenticity of products.

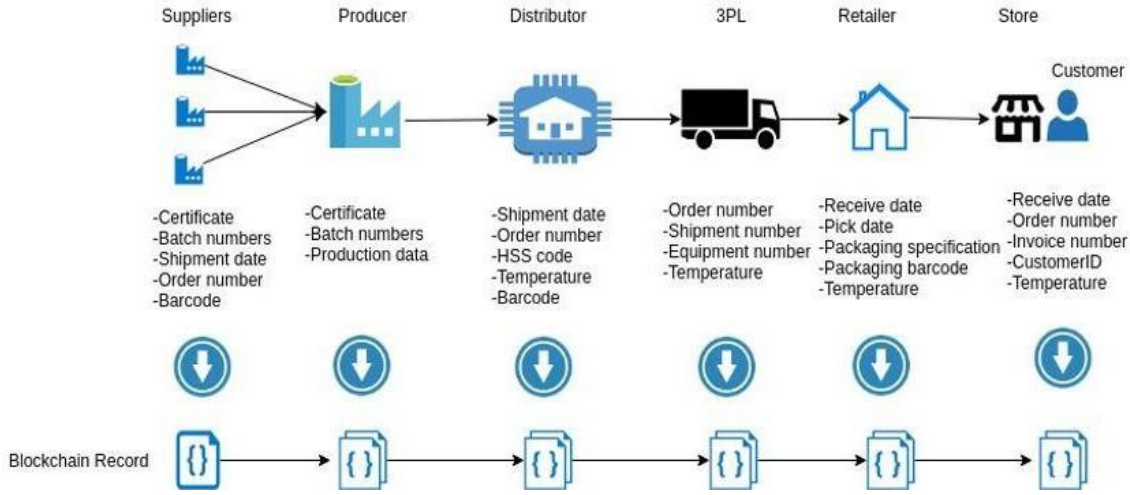


Fig 1.2

How Blockchain aid SCM?

- **Supply Chain Finance:** Blockchain-based supply chain finance solutions can provide secure and efficient methods for financing trade transactions. By digitizing trade finance processes and enabling faster settlement of transactions, blockchain can improve liquidity and reduce the cost of financing for suppliers and buyers.
- **Enhanced Trust and Collaboration**: Blockchain fosters trust and collaboration among participants in the supply chain by providing a transparent and secure platform for sharing information. This enables better coordination and communication between suppliers, manufacturers, distributors and retailers, leading to improved efficiency and responsiveness.

COMPLETE PROCESS OF HOW A TRANSACTION WORKS IN A BLOCKCHAIN:

Following is a step-by-step procedure of how a transaction occurs in a blockchain network.

The Transaction Initiation:
The transaction process begins when a user decides to send digital assets (cryptocurrency) or data to another user. The sender initiates the transaction by creating a transaction message specifying the recipient's address, the amount to be transferred, and any additional data or instructions.

Digital Signature:
To prove ownership and authorize the transaction, the sender digitally signs the transaction message using their private key. This cryptographic signature ensures that only the owner of the private key can initiate and

authenticate transactions associated with their public key (wallet address).

Broadcasting the Transaction:
Once the transaction is signed, it is broadcasted to the blockchain network. In a public blockchain, the transaction message is propagated across the network of nodes, while in a permissioned blockchain, it is sent to designated validators or nodes for verification.

Transaction Pool:
Upon receiving the transaction message, network nodes add it to the transaction pool, also known as the "mempool". The transaction remains pending until it is selected for validation and inclusion in a block by a miner or validator.

Validation and Consensus:
Validators or miners in the network verify the validity and authenticity of the transaction. This verification process involves validating the digital signature, checking for double-spending, ensuring that the sender has sufficient funds, and confirming that the transaction complies with consensus rules.

Block Creation:
Once validated, the transaction is bundled with other validated transactions to form a new block. In proof-of-work (PoW) blockchains, miners compete to solve a cryptographic puzzle (proof-of-work) to add the block to the blockchain. In proof-of-stake (PoS) blockchains, validators are selected to create new blocks based on factors such as stake or reputation.

Block Propagation:
Once a miner successfully mines a new block, it is propagated across the network to other nodes. Each node verifies the integrity of the block and its transactions before accepting and adding it to their local copy of the blockchain.

Consensus Reaching:
The network reaches a consensus on the validity of the newly added block through the consensus mechanism employed by the blockchain network. This process ensures that all nodes agree on the order and content of transactions, maintaining the integrity and security of the blockchain.

Block Confirmation:
After a certain number of subsequent blocks (confirmations) have been added on top of the block containing the transaction, the transaction is considered confirmed. The number of confirmations required may vary depending on the blockchain network's consensus mechanism and security requirements.

Transaction Execution:
Once confirmed, the transaction is executed, and the sender's account balance is debited by the transferred amount, while the recipient's account balance is credited. This update is reflected in the blockchain ledger, which is replicated across all nodes in the network.

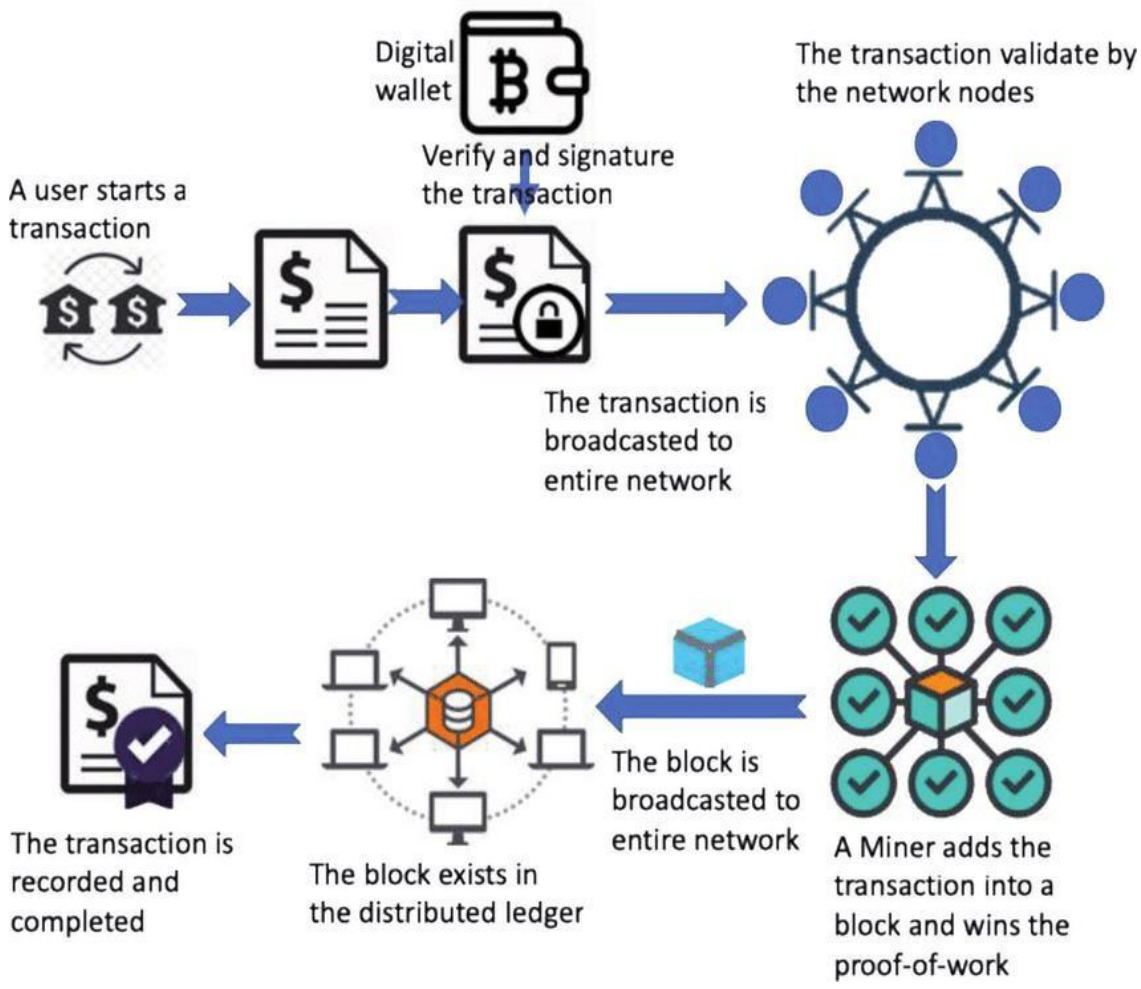


Figure 1.3: Blockchain Work Mechanism

Transaction Finality:
The transaction becomes immutable and irreversible once confirmed and included in multiple blocks. This finality ensures that the transaction history remains tamper-proof and cannot be altered or deleted.

Transaction Notification:
Both the sender and the recipient of the transaction receive notifications confirming the successful execution and inclusion of the transaction in the blockchain. These notifications typically include transaction IDs (TXIDs), timestamps, and other relevant information.

SMART CONTRACTS:
A smart contract is a digital version of a traditional contract, but instead of being written on paper and enforced by people, it's written in code and enforced by computers on a blockchain, like Ethereum. It is a digital agreement between people built on a secure and transparent system called blockchain. A smart contract in a blockchain is a self-executing contract with the terms of the agreement directly written into code. It is a piece of code that resides on a blockchain network and is capable of automatically enforcing and executing the terms of an agreement or a transaction when predefined conditions are met. Smart contracts allow parties to transact directly with each other

without the need for intermediaries, such as lawyers, banks, or other third-party institutions.

Smart contracts are pre written code which can include various conditions or triggers that must be met for the contract to be executed. These conditions are typically coded into the contract and may involve factors such as time, input from external systems, or specific events on the blockchain. Smart contracts can interact with external data sources, known as oracles, to obtain information necessary for their execution. Oracles provide real-world data to the smart contract, enabling it to make informed decisions based on external events.

WORK MECHANISM OF SMART CONTRACTS IN ETHEREUM BLOCKCHAIN:

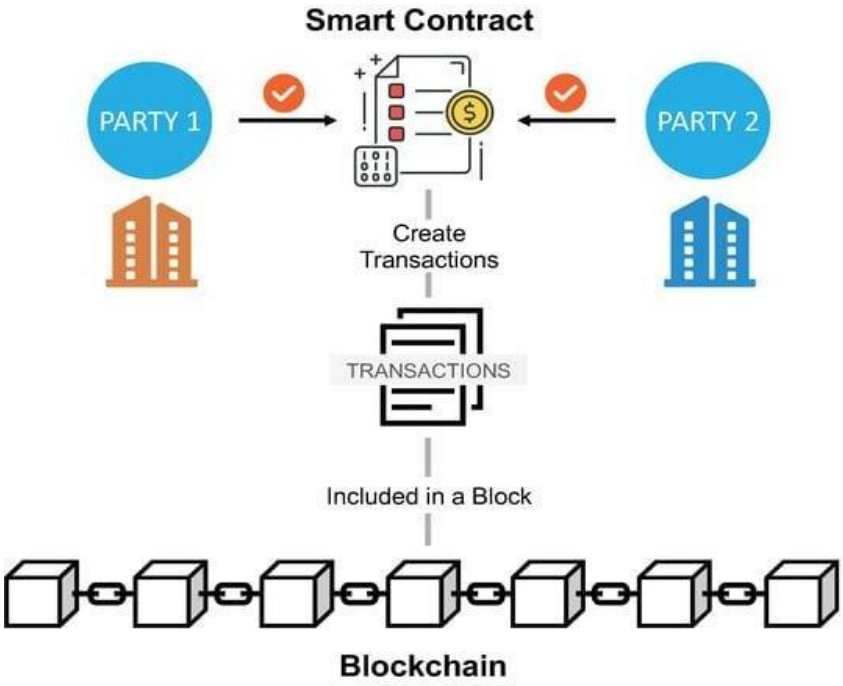
Here is a small illustration of how smart contracts are built and used in the "Ethereum platform" to execute agreements.

- **Writing a smart contract code:** First and foremost the programmers write the code for the smart contract. Ethereum smart contracts are typically written in Solidity, a programming language specifically designed for creating smart contracts on the Ethereum platform. The code defines the contract's functionality, including its variables, functions, and logic.
- **Compiling a smart contract:** Once the code is written, it needs to be compiled into bytecode that can be executed on the Ethereum Virtual Machine (EVM). Solidity code is compiled using tools like the Solidity compiler (solc) to generate bytecode and Application Binary Interface (ABI), which defines the interface to interact with the contract.
- **Deploying a smart contract:** The compiled bytecode is then deployed to the Ethereum blockchain. This process involves creating a transaction that includes the bytecode of the smart contract and sending it to the network. Miners on the network validate the transaction, and if it is included in a block, the smart contract is deployed to the blockchain.
- **Instantiation of a smart contract:** After deployment, the smart contract is instantiated on the Ethereum blockchain, and a unique address is assigned to it. This address can be used to interact with the contract.
- **Interacting with Smart Contract:** Users can interact with the smart contract by sending transactions to its address. Transactions can execute functions defined within the contract, read data stored in the contract, or trigger events. These interactions are recorded on the blockchain and are immutable once confirmed by the network.
- **Execution of smart contract functions:** When a transaction is sent to a smart contract, the Ethereum Virtual Machine (EVM) executes the corresponding function defined in the contract code. The function's logic is executed deterministically by all nodes in the network, ensuring consensus on the contract's state.
- **Updating a contract State: Smart contracts can modify their internal state based on the execution of functions.** For instance, a contract function may transfer tokens between accounts, update a database, or change the contract's variables. These state changes are recorded on the blockchain and are visible

to all participants in the network.

- **Transaction Confirmation and Block Inclusion:** Once a transaction is sent to a smart contract, it is included in a block by miners through the process of mining. **The transaction is confirmed once the block containing it is added to the blockchain,** ensuring the validity and integrity of the contract execution.
- **Event Emission:** Smart contracts can emit events during their execution, which can be observed by external applications or other contracts. Events provide a way for contracts to communicate information to the outside world and can trigger actions in response to specific conditions.

Figure1.4: Smart contract in a blockchain.



INTEGRATING SUPPLY CHAIN MANGEMENT WITH SMART CONCTRACTS BLOCKCHAIN:

Smart contracts can greatly improve supply chain management by enhancing efficiency, transparency, and trust throughout the supply chain process. Some of the areas where it can be utilized for improvement include:

- ***Automated Transactions***:

Smart contracts can automate various transactions within the supply chain, such as ordering, invoicing, and payments. When goods are received, a smart contract can automatically trigger payment to the supplier, reducing the need for manual processing and eliminating delays.

- ***Immutable Record Keeping***:

All transactions recorded on a blockchain through smart contracts are immutable, meaning they cannot be altered or tampered with. This creates a reliable and auditable record of all activities within the supply chain, reducing the risk of fraud and disputes.**Real time tracking:**

Smart contracts can be linked to IoT (Internet of Things) devices and sensors to track the movement and condition of goods in real-time. This enables stakeholders to monitor the status of shipments, verify authenticity, and ensure

compliance with regulations throughout the supply chain.

- ***Supply chain traceability**:*

Smart contracts can provide end-to-end traceability of products, allowing stakeholders to track the journey of goods from their origin to the final destination. This transparency helps ensure the authenticity, quality, and ethical sourcing of products, which is particularly important in industries such as food and pharmaceuticals.

- ***Efficient Dispute Resolution**:*

Smart contracts can include predefined rules and conditions for dispute resolution, such as penalties for late deliveries or non-compliance with quality standards. In the event of a dispute, the contract can automatically execute the agreed-upon resolution, reducing the need for costly and time-consuming legal proceedings.

- ***Inventory Management**:*

Smart contracts can facilitate real-time inventory management by automatically updating inventory levels and triggering reorder requests when stock levels fall below a certain threshold. This helps prevent stock outs and overstocking, optimizing inventory levels and reducing carrying costs.

- ***Supplier management**:*

Smart contracts can streamline supplier on boarding and management by automating the verification of credentials, contracts, and compliance with regulatory requirements. This reduces administrative overhead and ensures that only trusted suppliers are engaged in the supply chain.

- ***Cost Reduction**:*

By automating processes, reducing manual interventions, and minimizing the risk of errors and fraud, smart contracts can help lower operational costs throughout the supply chain. Precisely, smart contracts can help in every step of documentation and execution process too.

Details include,

- **Sourcing and Procurement:**

Automated Purchase Orders and Supplier Management: Smart contracts can automate the creation and execution of purchase orders when predefined conditions are met, such as inventory levels falling below a certain threshold or specific pricing agreements. Smart contracts can verify the credentials and compliance of suppliers before engaging in transactions, ensuring adherence to regulatory requirements and quality standards.

- ***Production and Manufacturing**:*

Quality Assurance and Inventory Management: Smart contracts can include criteria for quality assurance and compliance checks during the production process. If products fail to meet predefined standards, the smart contract can automatically trigger notifications or penalties. Smart contracts can track raw materials and components used in manufacturing, updating inventory levels in real-time and automatically initiating reorders when necessary.

- ***Transportation and Logistics***

Real Time Tracking and Automated Documentation: Smart contracts can integrate with IoT devices and sensors to track the movement and condition of goods in transit. This ensures real-time visibility and transparency

throughout the transportation process. Smart contracts can automate the generation and exchange of shipping documents, such as bills of lading and customs declarations, reducing paperwork and streamlining customs clearance processes.

- ***Warehousing and Inventory Management***

Automated Inventory Updates and Smart Contracts: Smart contracts can automatically update inventory levels as goods are received, stored, and shipped from warehouses. This provides accurate and real-time inventory data, reducing the risk of stockouts or overstocking. Smart contracts can optimize warehouse operations by automating tasks such as picking, packing, and shipping based on predefined rules and conditions.

- ***Distribution and Delivery:***

Proof of Delivery and Dynamic routing: Smart contracts can facilitate proof of delivery by requiring recipients to confirm receipt of goods before payment is released. This reduces the risk of disputes and ensures accountability throughout the delivery process. Smart contracts can optimize delivery routes based on real-time data, such as traffic conditions and delivery schedules, improving efficiency and reducing transportation costs.

- ***Documentation and Compliance:***

Immutable Record Keeping and Automated Compliance Checks:
Smart contracts record all transactions and activities on the blockchain, providing a tamper- proof and auditable record of documentation and compliance throughout the supply chain. Smart contracts can enforce regulatory compliance by automatically validating documentation and ensuring adherence to legal requirements at each stage of the supply chain.

These are some of the instances where smart contracts offer numerous benefits for supply chain management and documentation, including automation, transparency, efficiency, and compliance enforcement. By integrating smart contracts into supply chain processes, organizations can streamline operations, reduce costs, and enhance collaboration with suppliers and partners.

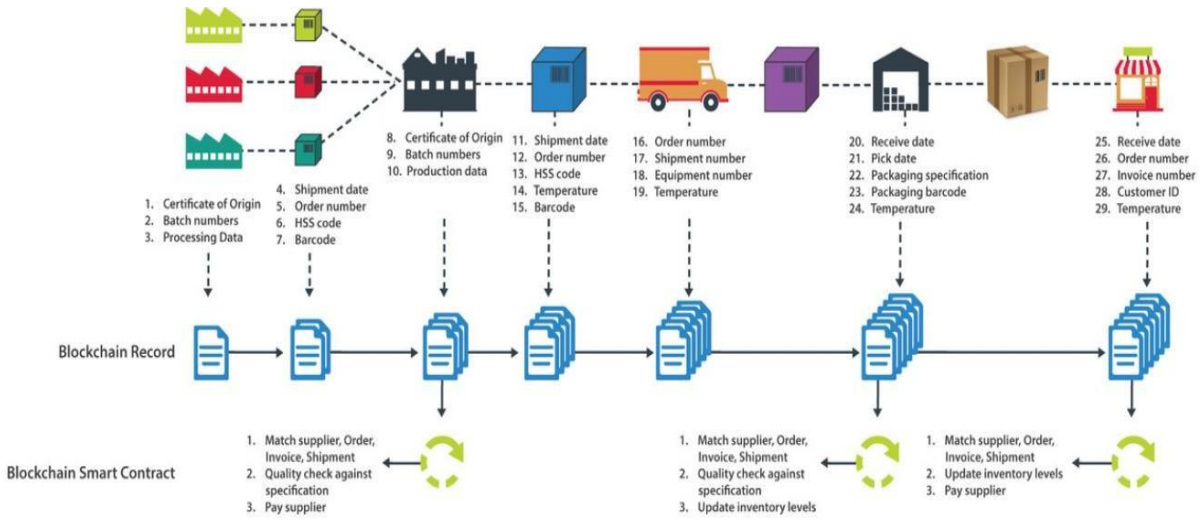


Figure1.5: Smart Contract in Supply Chain Management

BENEFITS OF ADOPTING BLOCKCHAIN AND SMART CONTRACTS INTO A FIRMS SUPPLY CHAIN:

Considering all the factors from the very beginning, adopting blockchain technology and smart contracts for supply chain management can bring a multitude of benefits to a company, revolutionizing the way they manage their supply chains. In this summarized exploration, we'll delve into the numerous advantages that blockchain and smart contracts offer in optimizing supply chain processes, enhancing transparency, ensuring trust, reducing costs, and driving overall operational efficiency.

The most supreme cause to rely on a blockchain technology is because Blockchain provides an immutable and transparent ledger where all transactions are recorded in real-time. This enables stakeholders to track the movement of goods and materials throughout the entire supply chain, from sourcing to delivery. Each transaction recorded on the blockchain is time-stamped and cryptographically linked to previous transactions, creating an audit trail that ensures transparency and accountability. With blockchain-based traceability, companies can quickly identify the origin of products, track their journey through various stages of production and distribution, and verify authenticity, improving visibility and reducing the risk of counterfeiting or fraud.

By leveraging blockchain technology, companies can achieve greater visibility into their supply chains, enabling them to monitor inventory levels, track order status, and identify bottlenecks or inefficiencies in real-time. Smart contracts can automate the exchange of data and trigger actions based on predefined conditions, such as automatic reordering when inventory levels fall below a certain threshold or notifying stakeholders of delays in shipment. Enhanced supply chain visibility enables companies to make data-driven decisions, optimize inventory management, and respond quickly to changing market demands, ultimately improving agility and responsiveness.

Blockchain-based supply chain management ensures compliance with regulatory requirements and industry standards by providing a tamper-proof and auditable record of transactions. Smart contracts can automate compliance checks and enforce regulatory requirements, ensuring that all parties adhere to contractual obligations and quality standards. Auditors can easily access and verify supply chain data recorded on the blockchain, reducing the time and resources required for auditing processes and improving overall transparency and trustworthiness.

Blockchain technology helps combat counterfeiting and fraud by providing a secure and immutable record of product provenance and ownership. With blockchain-based traceability, companies can authenticate products, verify their origin and authenticity, and detect counterfeit goods more effectively, protecting brand reputation and consumer trust. Smart contracts can enforce rules and conditions related to product authentication and verification, ensuring that only genuine products are accepted within the supply chain and automatically flagging suspicious or fraudulent activities.

Blockchain and smart contracts enable real-time tracking of inventory levels, simplifying inventory management processes and reducing the risk of stockouts or overstocking. Smart contracts can automate inventory

replenishment, trigger reorder requests, and optimize inventory allocation based on demand forecasts and production schedules, ensuring optimal inventory levels and minimizing carrying costs. Improved inventory management leads to better resource utilization, reduced wastage, and enhanced operational efficiency, ultimately improving the company's bottom line.

Blockchain technology facilitates secure and instantaneous transactions between supply chain participants, eliminating the need for intermediaries and reducing transaction costs and processing times. Smart contracts automate the execution of transactions based on predefined conditions, ensuring that payments, shipments, and other contractual obligations are fulfilled automatically and without delays. By streamlining transaction processes and minimizing human intervention, blockchain and smart contracts enhance security, reduce the risk of errors, and accelerate the flow of goods and information within the supply chain.

CHALLENGES OF ADOPTING BLOCKCHAIN AND SMART CONTRACTS INTO A FIRMS SUPPLY CHAIN:

While blockchain and smart contracts offer significant potential benefits for supply chain management, they also pose various risks and challenges that need to be carefully managed and mitigated. As it is still in its nascent stage developing, only trial and error methods are being used to put its capability into test. To summarise, some of the difficulties blockchain technology composes,

Implementing blockchain and smart contracts requires significant resources, including financial investment, technical expertise, and organizational commitment. Small and medium- sized enterprises (SMEs) may face challenges in accessing these resources and overcoming barriers to adoption. he costs associated with blockchain implementation, including infrastructure setup, software development, training, and ongoing maintenance, can be prohibitive for some companies. Moreover, the return on investment (ROI) and long-term sustainability of blockchain initiatives may be uncertain or difficult to quantify.

Regulatory uncertainty and compliance requirements pose significant risks for adopting blockchain and smart contracts in supply chain management. Companies need to navigate complex regulatory frameworks related to data protection, consumer privacy, intellectual property rights, and international trade regulations. Non-compliance with regulatory requirements can result in legal sanctions, fines, reputational damage, and business disruptions. Ensuring compliance with regulatory requirements while leveraging blockchain technology requires careful consideration of legal implications, regulatory compliance frameworks, and industry-specific regulations. Sometimes interoperability between different blockchain networks, systems, and legacy technologies is a significant challenge in supply chain management. Companies may need to interact with multiple stakeholders, each using different blockchain platforms or systems, leading to compatibility issues, data silos, and integration complexities. Ensuring seamless communication and data exchange across disparate systems and networks requires standardized protocols, interoperability standards, and effective integration solutions, which may be difficult to achieve in practice.

While blockchain offers enhanced security through its cryptographic features and immutability, it also presents challenges related to data privacy and confidentiality. All data recorded on the blockchain is visible to all participants in the network, which may not be desirable for sensitive or proprietary information. Storing sensitive supply chain data on a blockchain raises concerns about data privacy, compliance with regulations such as GDPR, and protection against unauthorized access or data breaches. Moreover, the permanent and immutable nature of blockchain makes it challenging to erase or modify sensitive information once it is recorded.

Blockchain networks, especially public blockchains like Ethereum, face scalability and performance limitations that can impact their suitability for large-scale supply chain applications. As transaction volumes increase, blockchain networks may experience congestion, slower transaction processing times, and higher transaction fees. Scalability challenges can lead to delays in transaction confirmation, higher costs, and degraded performance, hindering the efficiency and effectiveness of supply chain operations.

Lastly, the concept of cryptography, blockchain and matters relating to it tough and rigorous. Getting to know and learn about all such matters turns out to be very exhausting with is high dynamic nature. Thus implementing blockchain technology and smart contracts requires a deep

understanding of cryptographic principles, distributed systems architecture, and blockchain protocols. Inadequate technical expertise and implementation errors can lead to vulnerabilities and security risks. Smart contracts are susceptible to bugs, vulnerabilities, and coding errors, which can result in financial losses, system failures, or exploitation by malicious actors. The immutability of blockchain makes it challenging to rectify errors or reverse transactions once they are recorded on the blockchain.

Overall, Blockchain technology is poised to revolutionize various aspects of our society, presenting itself as the next transformative force akin to the internet. At its core, blockchain is a decentralized ledger that records transactions across a network of computers. This technology's potential lies in its ability to offer traceability, security, and efficiency in a wide range of applications. As blockchain continues to evolve, its impact is likely to extend to governance, identity management, and beyond. However, challenges such as scalability, interoperability, and regulatory concerns remain hurdles to widespread adoption. Nonetheless, the potential of blockchain to disrupt traditional systems and empower individuals and businesses is undeniable, making it the next new revolution with far-reaching implications for society.

SUMMARY AND CONCLUSIONS

By embracing the complexity of the dual nature of blockchain technology and smart contracts in supply chain management with the description and case studies above we derive the following:

- The **Transparency and Traceability** of the blockchain technology is insurmountably astounding. Blockchain's immutable ledger ensures transparent and traceable transactions throughout the supply chain. By recording every step of a product's journey, from raw materials to final delivery, stakeholders can access real-time data, thereby mitigating the risks associated with counterfeiting, fraud, unethical practices and many more.

➢ A company can gain unique competitive advantage through **Optimization and Visibility** provided by blockchain. By granting instantaneous access to inventory levels, production schedules, and logistics operations, blockchain facilitates proactive decision-making of supply chain processes. This results in reduced inventory holding costs while also improving demand forecasting accuracy and ultimately enhancing customer satisfaction.

➢ No other technology can come close to blockchain when it comes to **Efficiency and Security.** The inherent decentralization of blockchain renders it naturally resistant to data tampering and unauthorized access. By employing cryptographic techniques and consensus mechanisms, blockchain guarantees the verification and storage of each transaction across a distributed network, thereby mitigating the risk of cyber threats and bolstering data integrity. Blockchain streamlines operations by removing intermediaries and automating manual processes, resulting in heightened operational efficiency and cost reductions. Smart contracts integrated within blockchain networks enable the automated execution of agreements, payments, and compliance checks, thereby minimizing paperwork, delays, and manual errors.

➢ Additionally, Blockchain has the potential to advance **Sustainability** efforts by facilitating transparent monitoring of product origins, certifications, and environmental impacts. This promotes accountability throughout the supply chain, encourages ethical sourcing and production methods, and empowers consumers to make informed decisions that align with their values.

➢ In today's highly competitive business landscape, gaining a sustainable competitive advantage is paramount for companies striving to thrive and succeed. Blockchain technology has emerged as a powerful tool that can provide such an advantage, potentially leading to market leadership and even monopolistic positions for forward-thinking organizations. blockchain technology offers companies a leading competitive advantage and the potential to establish monopolistic positions in their respective markets. By leveraging blockchain's security, transparency, efficiency, and innovation capabilities, companies can differentiate themselves, enhance customer trust, drive operational excellence, and foster strategic partnerships. As blockchain adoption continues to grow, companies that embrace this transformative technology will be well-positioned to dominate their industries and shape the future of business.

REFERENCES

- Abidi, M. H., Alkhalefah, H., Umer, U., & Mohammed, M. K. (2020). Blockchain-based secure information sharing for supply chain management: Optimization assisted data sanitization process. *International Journal of Intelligent Systems*, *36*(1), 260–290. https://doi.org/10.1002/int.22299
- Agrawal, T. K., Angelis, J., Khilji, W. A., Kalaiarasan, R., & Wiktorsson, M. (2022). Demonstration of a blockchain-based framework using smart contracts for supply chain collaboration. *International Journal of Production Research*, *61*(5), 1497–1516. https://doi.org/10.1080/00207543.2022.2039413
- Al-Farsi, S., Rathore, M. M., & Bakiras, S. (2021). Security of Blockchain-Based Supply Chain

Management Systems: Challenges and opportunities. *Applied Sciences*, *11*(12), 5585. https://doi.org/10.3390/app11125585

- Agarwal, U., Rishiwal, V., Tanwar, S., Chaudhry, R., Sharma, G., Bokoro, P. N., & Sharma, R. (2022). Blockchain Technology for Secure Supply Chain Management: A Comprehensive Review. *IEEE Access*, *10*, 85493–85517. https://doi.org/10.1109/access.2022.3194319
- Berneis, M., Bartsch, D., & Winkler, H. (2021). Applications of Blockchain Technology in Logistics and Supply Chain Management—Insights from a Systematic Literature Review. *Logistics*, *5*(3), 43. https://doi.org/10.3390/logistics5030043.
- Bottoni, P., Gessa, N., Massa, G., Pareschi, R., Selim, H., & Arcuri, E. (2020). Intelligent Smart Contracts for Innovative Supply Chain Management. *Frontiers in Blockchain*, *3*. https://doi.org/10.3389/fbloc.2020.535787
- Dutta, P., Choi, T., Somani, S., & Butala, R. (2020). Blockchain technology in supply chain operations: Applications, challenges and research opportunities. *Transportation Research Part E: Logistics and Transportation Review*, *142*, 102067. https://doi.org/10.1016/j.tre.2020.102067
- Durach, C. F., Blesik, T., Von Düring, M., & Bick, M. (2020). Blockchain applications in supply chain transactions. *Journal of Business Logistics*, *42*(1), 7–24. https://doi.org/10.1111/jbl.12238.
- Dwivedi, S. K., Amin, R., & Vollala, S. (2020). Blockchain based secured information sharing protocol in supply chain management system with key distribution mechanism. *Journal of Information Security and Applications*, *54*, 102554. https://doi.org/10.1016/j.jisa.2020.102554
- Groschopf, W., Dobrovnik, M., & Herneth, C. (2021). Smart Contracts for Sustainable Supply Chain Management: Conceptual Frameworks for Supply Chain Maturity Evaluation and Smart Contract Sustainability Assessment. *Frontiers in Blockchain*, https://doi.org/10.3389/fbloc.2021.506436
- Hasan, A. S. M. T., Sabah, S., Haque, R. U., Daria, A., Rasool, A., & Jiang, Q. (2022). Towards convergence of IoT and blockchain for secure supply chain transaction. *Symmetry*, *14*(1), 64. https://doi.org/10.3390/sym14010064
- Kazi, M., & Hasan, M. M. F. (2024). Optimal and secure peer-to-peer carbon emission trading: A game theory informed framework on blockchain. *Computers & Chemical Engineering*, *180*, 108478. https://doi.org/10.1016/j.compchemeng.2023.108478
- Khan, S., Loukil, F., Ghedira-Guegan, C., Benkhelifa, E., & Bani-Hani, A. (2021). Blockchain smart contracts: Applications, challenges, and future trends. *Peer-to-Peer Networking and Applications*, *14*(5), 2901–2925. https://doi.org/10.1007/s12083-021-01127-0
- Kopyto, M., Lechler, S., Von Der Gracht, H. A., & Hartmann, E. (2020). Potentials of blockchain technology in supply chain management: Long-term judgments of an international expert panel. *Technological Forecasting and Social Change*, *161*, 120330. https://doi.org/10.1016/j.techfore.2020.120330
- Musigmann, B., Von Der Gracht, H. A., & Musigmann, B. (2020). Blockchain Technology in Logistics and Supply Chain Management—A Bibliometric Literature Review from 2016 to January 2020. *IEEE Transactions on Engineering Management*, *67*(4), 988–1007. https://doi.org/10.1109/tem.2020.2980733
- Nanayakkara, S., Perera, S., Senaratne, S., Weerasuriya, G. T., & Bandara, H. M. N. D. (2021). Blockchain and Smart Contracts: a solution for payment issues in construction supply chains. *Informatics (Basel)*, *8*(2), 36. https://doi.org/10.3390/informatics8020036
- Sund, T., Lööf, C., Nadjm-Tehrani, S., & Asplund, M. (2020). Blockchain-based event processing in supply chains—A case study at IKEA. *Robotics and Computer-Integrated Manufacturing*, *65*, 101971. https://doi.org/10.1016/j.rcim.2020.101971

- Tavares, E. C., De Souza Meirelles, F., Tavares, E. C., Cunha, M. A., & Schunk, L. M. (2020). Blockchain in the Amazon: creating public value and promoting sustainability. *Information Technology for Development*, *27*(3), 579–598. https://doi.org/10.1080/02681102.2020.1848772
- Tsai, W., & Shen, C. (2024). Using a smart contract for the floral supply chain. *Asia Pacific Management Review*. https://doi.org/10.1016/j.apmrv.2023.12.004
- Tokkozhina, U., Martins, A., & Ferreira, J. C. (2022). Uncovering dimensions of the impact of blockchain technology in supply chain management. *Operations Management Research*, *16*(1), 99–125. https://doi.org/10.1007/s12063-022-00273-9
- Tönnissen, S., & Teuteberg, F. (2020). Analysing the impact of blockchain-technology for operations and supply chain management: An explanatory model drawn from multiple case studies. *International Journal of Information Management*, *52*, 101953. https://doi.org/10.1016/j.ijinfomgt.2019.05.009
- Wamba, S. F., & Queiroz, M. M. (2020). Blockchain in the operations and supply chain management: Benefits, challenges and future research opportunities. *International Journal of Information Management*, *52*, 102064. https://doi.org/10.1016/j.ijinfomgt.2019.102064
- Wong, S., Yeung, J., Lau, Y., & Kawasaki, T. (2023). A Case Study of How Maersk Adopts Cloud-Based Blockchain Integrated with Machine Learning for Sustainable Practices. *Sustainability*, *15*(9), 7305. https://doi.org/10.3390/su15097305