Application of Blockchain Technology for Supply Chain Management - The Example of Paper-Based Coffee Cups

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Abstract:
Safety, quality, and sustainability concerns have arisen from global supply chains. Stakeholders incur risk regarding these factors, given their significance and complexity. Thus, each business's supply chain risk management must prioritize product characteristics. Accordingly, an effective traceability solution that can monitor and regulate product and supply chain aspects is crucial, especially in a given scenario. This re-search paper elucidates the potential of smart contracts in blockchain to enhancing the efficacy of business transactions and ensuring comprehensive traceability within the supply chain of paper-based coffee cups The improved levels of transaction transparency and security in traditional supply chains have been achieved through the digitization of supply chain ecosystem interactions and transactions. This approach makes verifying sources, manufacturing procedures, and quality standards easier in complex supply chains. Accordingly, the integration helps stakeholders monitor and track the whole ecosystem, promoting transparency, predictability, and dependability.

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1. Introduction

This article shows an application of blockchain technology to the supply chain of paper-based coffee cups as means to enhance efficiency, safety and security in supply chain management. It emphasizes the growing concerns about product safety and the importance of traceability throughout the supply chain procedure. The process of establishing traceability involves collecting and managing critical data to determine the product's origin and enable the exchange of information [19]. However, the dynamic nature of data in the supply chain poses challenges in monitoring and tracing the products as they go through various stages [12]. In case of product distribution, close coordination among multiple stakeholders is required to identify relevant product characteristics and to intervene in the process, e.g. removal affected products swiftly [17]. However, exchanging information between stages in the supply chain proves to be a challenging and time-consuming coordination process [13].

Consequently, we introduce blockchain technology as a promising solution for ensuring traceability in the supply chain of the case paper-based coffee cups. It explains that blockchain's transparency, immutability, and security can be effectively utilized in supply chain management [25]. The complexity of the supply chain, involving multiple stakeholders, necessitates a secure framework for tracking information about the products, and safety without relying on a centralized authority [6]. Additionally, blockchain technology addresses these challenges and can enhance trust among stakeholders by providing a shared distributed ledger and tamper-proof records [3]. Accordingly, the article also mentions Ethereum, a programmable blockchain platform, which allows for the execution of smart contracts without third-party intervention [20]. It discusses how blockchain and Ethereum smart contracts can efficiently trace and track paper-based coffee cups, integrating business transactions and workflows in the supply chain as shown in Figure 1. Then, we present the system design, architecture, and sequence diagrams, along with the theoretic implementation of smart contract algorithms governing interactions among key stakeholders.

The paper explores the use of blockchain in this specific product supply chain. It discusses some related literature in Section 2, presents the design and system overview in Section 3, describes implementation details including smart contract algorithms in Section 4. The article concludes in Section 5 by outlining research challenges and future work.

2. Literature review by exploring the related works

In this section, we review the existing body of literature concerning the utilization of blockchain technology in the industry of paper-based coffee cups and its associated supply chains. While there has been a steady increase in the amount of literature addressing blockchain applications in areas such as banking, finance, and insurance, existing research on the issue of food and packaging production remains limited but is fast gaining traction.

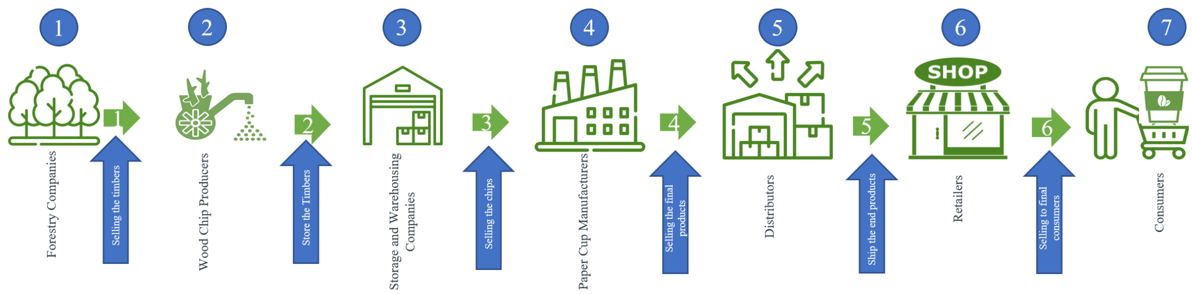

Figure 1-Traditional Participants in Supply Chain of paper-based coffee cup

Bager et al. 2022, highlights the potential of blockchain technology in creating secure and decentralized supply chain management systems. The authors propose an event-based methodology called REALISTIC, along with an event-driven system architecture, for tracking products in supply chain networks. The study focuses on the coffee industry, showcasing a case study and an open-source prototype to validate the proposed approach [1]. The other study examines the potential of blockchain in promoting sustainability in supply chains by Bager et al. 2022. While the pilot implementation highlights certain benefits, it suggests that blockchain is not a one-size-fits-all solution. Digitizing the supply chain using centralized digital solutions can achieve similar outcomes without the high costs associated with blockchain due to the higher cost of implementation. Blockchain may be more suitable for high-end or segregated supply chains, but implementation challenges exist, and the value lies in understanding incentives, trust, technology availability, and data transfer [2]. Additionally, Tian 2017 puts forth a blockchain-based traceability system for the food supply chain, incorporating Hazard Analysis and Critical Control Points (HACCP) and the Internet of Things (IoT) [23]. Tian 2016, also discusses the advantages and disadvantages of RFID and blockchain for traceability in the agricultural food supply chain [22].

Furthermore, IBM has played a leading role in utilizing blockchain technology to enhance supply chain transparency in the food industry. Their solutions have helped food companies improve efficiency, reduce fraud, and ensure the safety and authenticity of food products. Consumer surveys indicate a growing demand for transparency, with a majority valuing knowledge of food origins and willingness to pay more for responsibly sourced products, while brand loyalty is positively influenced by complete transparency [11]. Tse et al. 2017 explore the application of blockchain technology in the food supply chain at a high level and draw comparisons with traditional solutions, emphasizing aspects related to security, integrity, and trust [5].

Düdder and Omri's paper 2017 highlights the significance of using Blockchain technology to address sustainability challenges in supply chains, urging for more research and collaboration in this area. While efforts have primarily focused on finance, the authors advocate for expanding Blockchain applications to promote sustainability and benefit society as a whole [7]. Moreovre, Groschopf et al. 2021, highlight the potential of smart contracts in supply chains, emphasizing their ability to streamline processes, reduce errors, and lower costs. It explores the relationship between smart contracts, sustainability, and supply chain management, noting that research in this area is still limited. The article defines smart contracts, conducts a literature review, proposes a conceptual framework, and suggests research propositions and trade-offs regarding technology development, business processes along the supply chain, and sustainability. Despite its limitations, the paper aims to inspire further research and practical applications in the context of Industry 4.0 ecosystems, promoting the integration of physical and digital worlds in supply chain optimization [10]. Wamg et al. 2019, presents a blockchain-based product traceability system using smart contracts, ensuring immutable records of product transfers. The system allows consumers to participate as nodes, maintaining information flows and reducing data tampering risks. An event response mechanism verifies transaction parties' identities and stores events permanently in the blockchain. A decentralized application (DApp) is developed, and future research focuses on optimizing the system through IoT for error reduction and QR code technology to enhance consumer experience and simplify operations. The system demonstrates data accessibility, tamper-proofing, and resistance to man-in-the-middle attacks according to security analysis results [24]. Mao et al. 2018 introduce a blockchain-based credit evaluation system that employs smart contracts for efficient management in the food supply chain [14].

The aforementioned instances serve as evidence of the increasing inclination towards the utilization of blockchain technology to augment the levels of information security, transparency, and authentication within the supply chains of food production and related sectors. While numerous studies explore the conceptual application of blockchain in product supply chains, our paper aims to bridge the gap by presenting a specific implementation framework and approach. We demonstrate how blockchain and Ethereum smart contracts can provide an efficient, trusted, secure, and decentralized traceability solution for the industry of paper-based coffee cups and its supply chains. Our work highlights the key features of the proposed system, including architecture, metadata, sequence diagrams, and algorithms, which can be applied to various use cases involving multiple stakeholders in the agricultural supply chain.

3. A Blockchain-Based Approach for in Implementing the Traceability in the Mentioned Case

This section will outline the proposed solution for the tracing, tracking, and execution of transactions within paper-based coffee cup supply chains. The solution utilizes the Ethereum blockchain and smart contracts. Our solution eliminates the need for a trusted centralized authority and offers a high level of integrity, reliability, and security for managing and ensuring the safety of products supply chains. Moreover, the solution leverages Ethereum smart contracts to establish an integrated smart system that ensures the safety and quality of products delivered to end consumers as it is shown in Figure 2. The execution of contract functions and code is autonomously performed by globally distributed mining nodes through the utilization of smart contracts on the public Ethereum blockchain platform [16]. These nodes validate and execute transactions, store data, and maintain a replicated ledger synchronized across the network [15]. The smart contracts receive transactions and trigger events, allowing participating entities to monitor, track, and receive alerts for any violations within the product value chain [18]. Specifically, the solution focuses on the paper-based coffee cups supply chain. The system architecture includes key participants such as the Forestry Companies/Tree Farmers, Wood Chip Producers, Storage and Warehousing Companies, Paper Cup Manufacturers, Distributors, Retailers, end End-user Consumers, regarding the Ethereum blockchain with the Ethereum Virtual Machine (EVM) executing the smart contract. Every individual involved in the blockchain possesses an Ethereum account that is distinguished by a distinct Ethereum Address (EA). This EA is responsible for cryptographically signing and verifying the integrity of transactions, thereby establishing a connection between each transaction and a particular account [4]. Accordingly, each participating entity has a role, association, and interactions with the smart contract. The seven participating presented entities in Figure 1 and their role are summarized as follows:

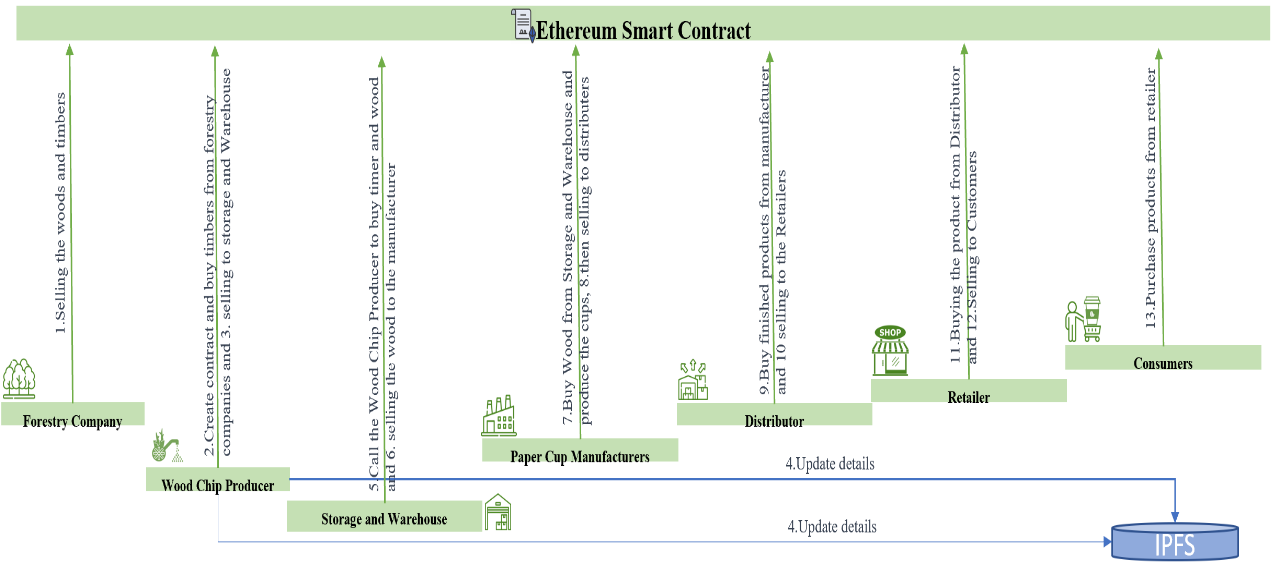

Figure 2-System overview for automating paper-based coffee cup traceability using Ethereum smart contracts

1.Forestry Companies/Tree Farmers: These stakeholders are responsible for managing and harvesting trees mainly in the forests. They ensure a sustainable supply of timber by planting, growing, and harvesting trees specifically for the paper industry. Loggers are also involved in cutting down trees in accordance with forestry regulations. They transport the logs to the next stage of the supply chain.

2.Wood Chip Producers: Once the trees are cut down, the logs are sent to wood chip producers. Their role is to debark the trees (removing the outer layer) and chip them into smaller pieces. These wood chips will serve as the raw material for paper cup production.

3.Storage and Warehousing Companies: These stakeholders provide storage facilities for the chipped wood until it is ready for further processing. They ensure proper inventory management and facilitate efficient supply chain operations.

4.Paper Cup Manufacturers: Paper cup manufacturers receive the chipped wood as their raw material. They have specialized machinery and equipment to process the wood chips into pulp. The pulp is then formed into paper sheets, which are further treated to make them suitable for cup production. The manufacturers convert the treated paper into cups, including shaping, cutting, and forming them with the necessary coating and designs. Then, they provide additional components necessary for paper cup production, such as lids, sleeves, and any branding or labeling materials required by the manufacturers.

5.Distributors: Distributors play a crucial role in the supply chain by transporting the manufactured paper cups from the production facilities to various retailers and wholesalers. They coordinate logistics and ensure the cups reach the intended destinations in a timely manner.
6.Retailers: Retailers, such as coffee shops, cafes, and convenience stores, are the end points where consumers can purchase paper-based coffee cups. They stock and display the cups for consumers to buy.
7.Consumers: Consumers are the ultimate stakeholders in the supply chain process. They purchase and use the paper-based coffee cups to enjoy their hot or cold beverages.

The study provides a supply chain-wide Ethereum smart contract framework to monitor production securely [8]. The foster companies produce trees and records details such as germination, chemical composition, viability, quality, and dormancy. The Wood Chip Producer purchase the tress, documents timber accumulation growth using decentralized file systems and timestamps, and debarks the timbers in a Warehouses, considering factors like temperature and moisture. The manufacturer refines the woods, analyzes its quality, eliminates moisture, and prepares the finished product as coffee-cups. The distributor buys the final product and serves as a point of contact for prospective purchasers. The distributor then sells the items to the retailer, who ultimately sells them to customers directly.

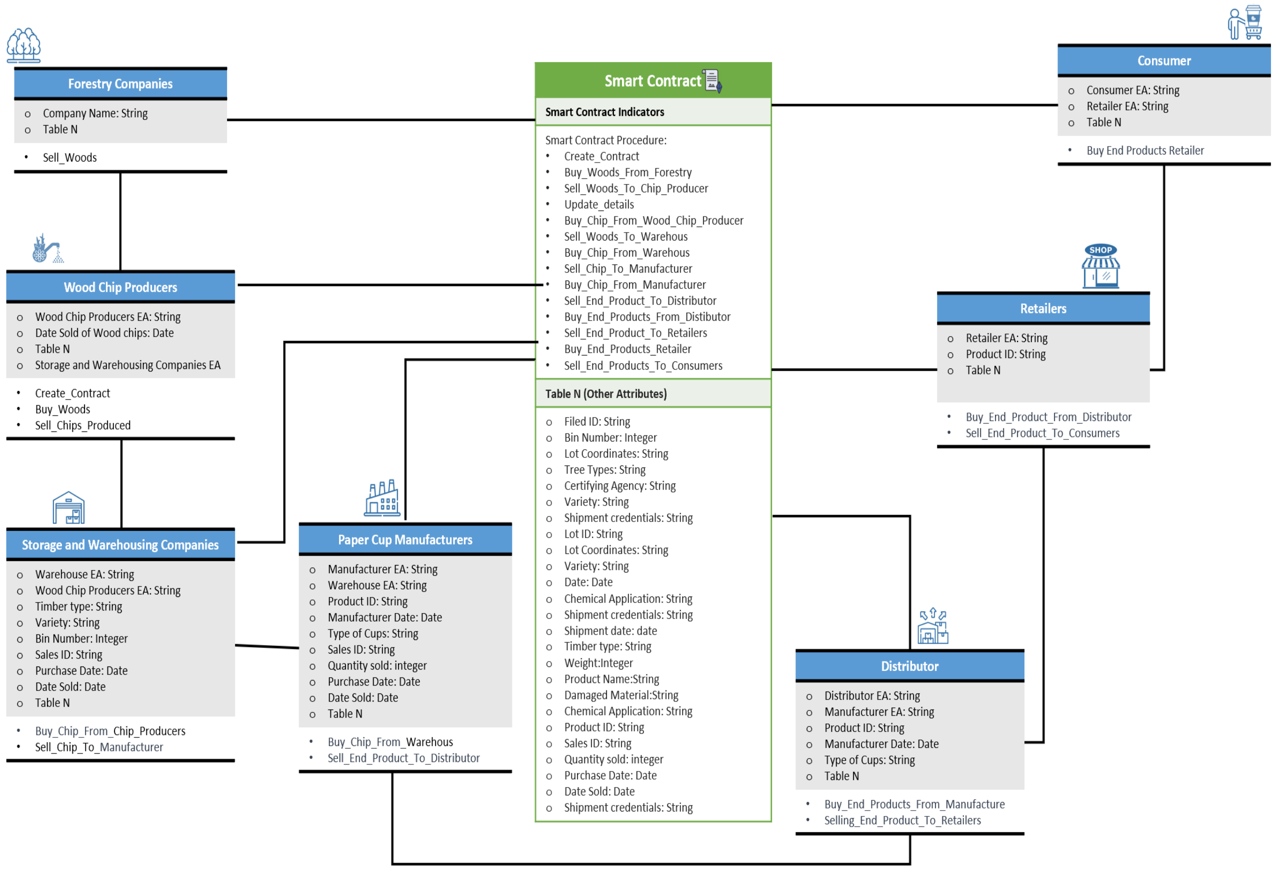

Figure 3-Interconnection between Stakeholders and smart contract diagram on Ethereum Platform

The entity-relationship diagram in Figure 3 illustrates the attributes, functions, and relationships between the participating entities and the smart contract, which rely on metadata and relations for successful smart contract implementation. In the context of blockchain and IPFS, all images, data, and records are digitally signed and attributed to a specific actor. For instance, when a Wood Chip Producer uploads MPEG files, they become the recognized owner of those files, assuming responsibility for any inaccuracies or fraudulent content. Smart contracts on the blockchain can be programmed to automatically enforce penalties if the farmer engages in dishonest behavior [9]. Alternatively, cameras with built-in capabilities and communication can be installed in the fields to capture and directly transmit images to the blockchain for recording and storage. These hardware cameras can be securely designed to prevent hacking or tampering, ensuring that the uploaded images can be audited, trusted, and open to dispute or verification by any participant or stakeholder on the blockchain [21]. Each participant in the system possesses an Ethereum address (EA) and interacts with the smart contract by invoking specific functions. Figure 4 illustrates the sequence of events in a scenario where a Wood Chips Producer creates a smart contract. After an offline agreement between the Forestry Company and the Wood Chips Producer, the Wood Chips Producer purchases seeds from the Forestry Company, triggering the invocation of the

WoodsRequestedByWood-ChipProducer event, which is accessible to all active participants (i.e., the Wood Chip Producer and the Forestry Company). The Forestry company executes the sellWoods() function, providing attributes such as the Forestry Company Ethereum Address (Wood Company EA), Ethereum Address of Wood Chip Producer (Wood Chip Producer EA), Quantity, LotAttributes, and more. The Forestry Company updates tree growth details at regular intervals on the file system using IPFS, saving the tree image in IPFS and storing the IPFS hash in the smart contract. This process continues until the harvesting stage, with crop growth images recorded periodically. As illustrated in Figure 4, the updateGrowthImage() function is responsible for capturing and documenting the growth of trees. Whenever an image is uploaded to the InterPlanetary File System (IPFS), its hash value is recorded in the smart contract, and subsequently, the TreeGrowthImageUpdated event is disseminated to all currently engaged entities. Upon the completion of the crop harvesting process, a contractual arrangement is established between the Forestry Company and the Warehouse for the purpose of storage. The Forestry Company obtains information regarding the levels of moisture, humidity, weight, and duration of storage within the Warehouse. Subsequently, upon reaching a mutual understanding, the company proceeds to sell the Chips for storage within said Warehouse. Figure 4 illustrates the implementation of the buyWood() function by the Warehouse and the sellToEleva-tor() function by the Forestry Company.

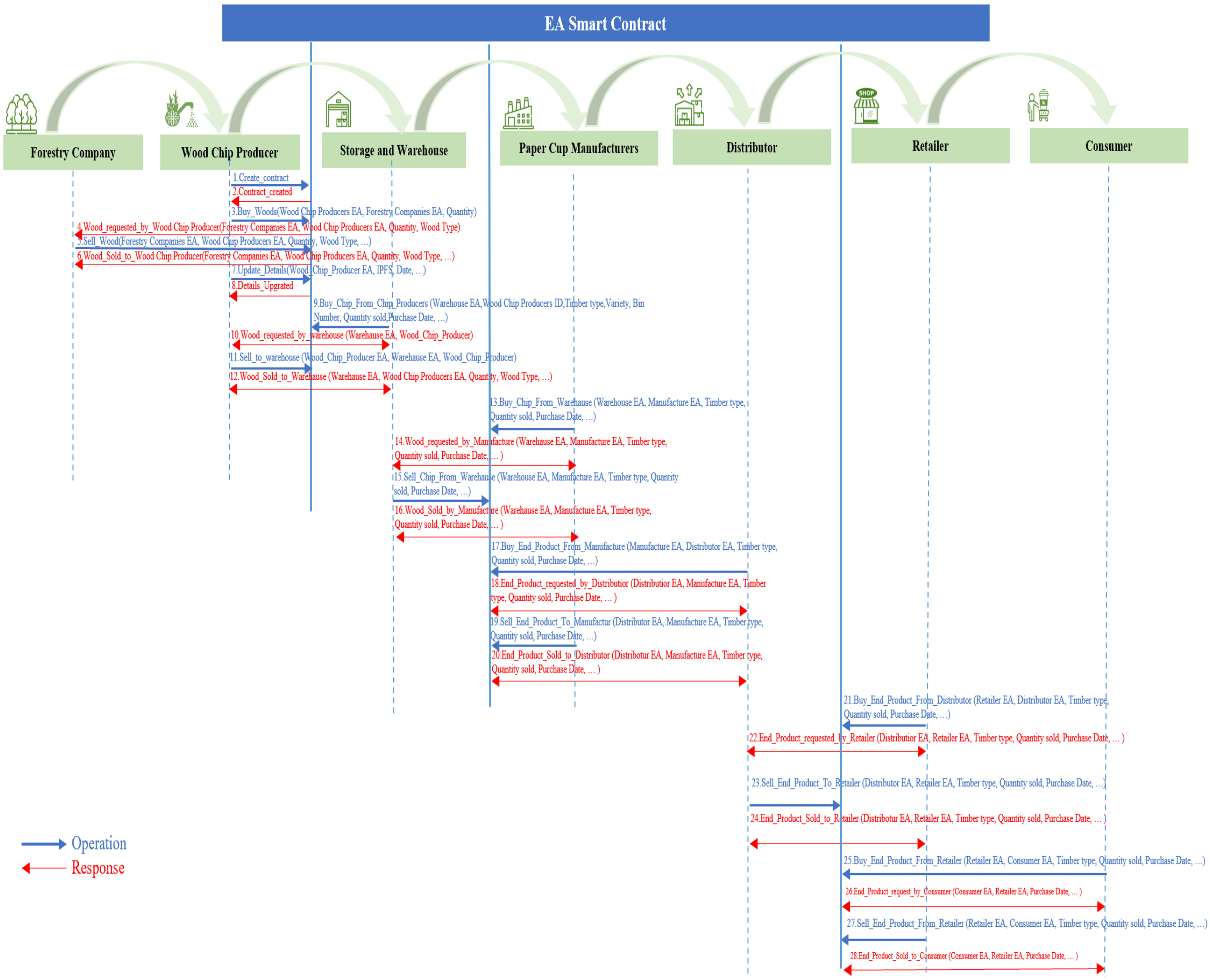

Figure 4-Progression architecture of interconnection between Stakeholders and smart contract diagram in the case

Accordingly, the message sequence diagram depicting the process of the grain processor purchasing grain from the Warehause. The buyTimber() function is executed by the processor, passing parameters such as the Ethereum addresses of the requesting grain processor (Processor EA) and the Timber Warehouse (Warehouse EA), Quantity, and DateOfPurchase. This triggers the TimberRequestedByWarehause event, prompting the Warehause to execute the sellWoodToProcessor() function. The WoodSoldToWarehause event is broadcasted across the network, sharing details such as the buyer and seller Ethereum addresses, Quantity, and DateOfSales. Subsequently, the distributor entity expresses its interest in purchasing finished products from the processor. Correspondingly, the buyProductFromManufacturer() function is executed by the distributor. Typically, the distributor serves as a warehouse that buys, stores, and ships products in large quantities to wholesalers or retailers. The ProductRequestedByDistributor event is triggered, prompting the processor to sell the Cups to the distributor. The forestry company then executes the sellProductToDistributor() function, providing parameters such as the Ethereum addresses of the timbers, distributor, quantity sold, and date of sales. The ProductSoldToDistributor event is activated, notifying the actively involved entities (i.e., Manufacturer and Distributor) at that specific point in time.

Moreover, Figure 4 illustrates the message sequence diagram demonstrating the collaboration between the distributor, retailer, and the consumer through the smart contract. The distributor engages with interested retailers to sell goods, while the retailers request limited quantities of goods from the distributor. Accordingly, the retailer executes the buyProductFromDistributor() function, triggering the ProductRequestedByRetailer event. The distributor responds by executing the sellProductToRetailer() function, and the ProductSoldToRetailer event informs all participants about the cups' sale. The end consumers then purchases the product from the local retailer by executing the buyProductFromRetailer() function, triggering the EndProductRequestedByConsumers event through the smart contract. Finally, the retailer sells the product to the end consumers by executing the sellEndProduct() function, and the smart contract broadcasts the sale with the EndProductSold event.

The use of our proposed blockchain-based solution with smart contracts in the paper-based coffee cups supply chain offers traceability advantages, providing verifiable and unalterable information to all stakeholders without relying on a central authority. Starting from wood transactions between the forestry company and the Wood Chip producer, the entire volume of timbers produce sold between subsequent entities is logged and can be verified. Transactions, such as the sale of chips, cannot be modified or tampered with, ensuring transparency and preventing the mixing of woods with different quality criteria. The Wood chips producer's periodic uploading of images via IPFS creates a digital record that validates the agreed-upon conditions and facilitates continuous monitoring of storage growth. Traceable identifiers per lot and IoT-enabled containers equipped with sensors, cameras, GPS locators, and communication capabilities further ensure continuous monitoring of quality compliance and provide real-time notifications on product conditions. With blockchain, this information is tamper-proof and readily accessible to all stakeholders, eliminating the need for intermediaries. Standard identifiers such as global location identifiers or GPS geotagging can be used to add additional attributes, ensuring precise tracking of the product's physical location or stakeholder locations within shipping or storage containers. It is important to acknowledge that in the supply chain, there is a possibility of stakeholders engaging in fraudulent activities or recording false data. However, the blockchain system accurately records such fraudulent data with validated attribution to the originating stakeholder. If, at a later stage, the data is identified as incorrect, all participants and judges can confidently attribute the data to the specific actor or stakeholder involved. The blockchain can effectively detect and expose fraud in this manner. To address and mitigate such fraudulent activities, smart contracts can be programmed to include additional functions that invalidate shipments or the entire supply chain process. Penalties can be imposed on the fraudulent stakeholders, or alternative corrective actions can be taken. These corrective actions generate new data and actions that are linked to the fraudulent data, ensuring precise traceability and auditability that is both accurate and indisputable.

4. Current Algorithm for interaction between each stakeholder in the Smart Contract Network

The following part comprehensively explains the algorithms that develop the operational principles of the proposed blockchain-based procedure. The first stage entails the Wood chip producer launching the setup of a smart contract and reaching a consensus on the purchasing conditions with a registered forestry company. Algorithm (I) in Figure 5 outlines the process of wood sale, which includes verifying the Wood chips producer's registration, payment of the wood price, and updating the contract and participant states accordingly.

I) Forestry Companies sell Wood to Wood Chip Producer

Input:

- "W" as the list of registered Wood Chip Producer
- Ethereumaddress (EA) of Wood Chip Producer
- Ethereumaddress (EA) of Forestry Companies
- Quantity
- Wood_Type
- Wood_Brand
- Wood_Price

1. Contractstate is Created
2. State of the Wood Chip Producer is Wood_request
3. Forestry Companies state is ready
4. Restrict access to only W belongs to Wood Chip Producer
5. If Wood Chip Producer = registered and Wood_Price = Paid, then :
6. Contract state changes to Wood_Request_Submitted
7. Change state of Wood Chip Producer to wait_for_Wood
8. Forestry company state Agree_to_sell
9. Create a notification message stating sale of Woods
10. End
11. Else
12. Revert contract state and show an error.
13. End

II) Manufacture buy Wood to Warehouse

Input:

-"M" is the list of the registered Manufacturerer
-Ethereumaddress (EA) of Manufacture
-Ethereumaddress (EA) of Warehause
-Quantity
-Chip_Price
-Date _purchased

1. Contractstate is Buy_From_Warehause
2. State of the Wood Chip Producer is Wood_request
3. Timber_Wood state is Chips_bought_From_Chip_Producer
4. Restrict access to only M belongs to Manufacturerer
5. If Wood Chip Producer = agreed and Wood_Price = Paid, then :
6. Contract state changes to Wood_Request_Submitted
7. Change state of Wood Chip Producer to wait_for_Wood
8. Chip_Producer_company state Agree_to_sell
9. Create a notification message stating sale of chip to requesting Manufacture
10. End
11. Else
12. Contract state changes to Wood_Request_failed.
13. State of Manufacturer is request_failed.
14. Chip_Producer_company state is cancel_request_of_Processor
15. Create a notification message stating request failure
16. End
17. Else
18. Revert contract state and show an error.
19. End

Figure 5-Current Algorithm for interaction between each stakeholder in the Smart Contract Network from Forestry Company to Warehouse

Algorithm (II) in Figure 5 describes the process of selling woods from the Warehause to the grain Manufacturer. Important factors such as moisture content, bin number, date of purchase, and shipment date are considered. The contract state transitions to BuyFromWarehause, and conditions regarding the registration of the grain processor and payment are checked. If the conditions are met, the contract and participant states are updated, and all active entities are notified of the Chip sale.

Otherwise, the contract and participant states revert to their initial state, and the transaction is terminated.

The next stage involves the Cups processor selling the finished product to distributors. Algorithm (III) in Figure 6 explains the system state and participant roles involved in the purchase of products by retailers from distributors. Parameters such as date of product manufacture, quantity sold, and date of purchase are important considerations. The contract restricts access to registered retailers and verifies the acceptance of the sale agreement and completion of product payment. Successful transactions result in state updates and notifications, while failure scenarios trigger corresponding state changes and notifications to participants.

III) Distributor sell End_Product to Retailer

Input:
- "R" as the list of registered Retailers
- Ethereumaddress (EA) of Distributor,
- Ethereumaddress (EA) of Retailers,
- Quantity Sold
- Wood_Type
- Wood_Brand
- Wood_Price
- Date_Manufactured
- Date_Purchased

1. Contractstate is Coffee_Cups_Sold_to_Distributors
2. Distributors State is Coffee_Cups_received_from_Manufacturer
3. Retailer state is Ready_to_Purchase
4. Restrict access to only R belongs to Retailers
5. If Sale is agreed and Product_payment= successful, then :
6. Contract state changes to Sale_Request_Agreed_Success
7. Change state of Distributors to Producr_sold_to_Retailer.
8. Retailer state Cups_Delivered_Successful
9. Create a notification message stating Success_trade
10. End
11. Else
12. Contract state changes to Sale_Request_failed.
13. State of Distributors is request_failed.
14. Retailer state is cancel_request_of_Processor
15. Create a notification message stating request failure
16. End
17. Else
18. Revert contract state and show an error.
19. End

IV) Consumers buy End_Product from Retailer

Input:
- "C" as the list of registered Consumers
- Ethereumaddress (EA) of Retailers,
- Ethereumaddress (EA) of Consumers,
- Quantity Sold
- Product_ID
- Sales_ID
- Date_Purchased

1. Contractstate is Coffee_Cups_Sold_to_Distributors
2. Retailer State is Coffee_Cups_received_from_Manufacturer
3. Consumers state is Ready_to_Buy
4. Restrict access to only C belongs to Consumers
5. If Sale is agreed and Product_payment= successful, then :
6. Contract state changes to Sale_Request_Agreed_Success to concumers
7. Change state of Retailers to Producr_sold_to_consumers.
8. Consumer state Cups_purchased_Successful
9. Create a notification message stating Success_purchase
10. End
11. Else
12. Contract state changes to Sale_Request_failed.
13. State of retailers is request_failed.
14. Consumer state is cancel_purchase_of_Processor
15. Create a notification message stating request failure
16. End
17. Else
18. Revert contract state and show an error.
19. End

Figure 6-Current Algorithm for interaction between each stakeholder in the Smart Contract Network from Distributors to Consumers

Finally, Algorithm (IV) in Figure 6 describes the algorithm for consumers purchases from retailers. The consumers, as the final entity in the product processing and tracking model, initiates the purchase process. The contract verifies consumers access, checks important parameters for tracking the product, and updates the contract and participant states accordingly. Successful payments result in state changes and notifications, while incorrect payments lead to failure states and corresponding notifications to participants.

5. Conclusion

In this article, we have put forth a proposal for a solution and a versatile framework that utilizes the Ethereum blockchain and smart contracts to facilitate the traceability, tracking, and business transactions the supply chain of paper-based coffee cups with the help of applying blockchain technology.

Our aim is to eliminate intermediaries and the central point of processing. We have provided comprehensive information regarding the system's architecture, design, entity-relation diagram, interactions, sequence diagrams, and implementation algorithms. Our solution demonstrates its applicability to trace and track the paper-based cups supply chain, but it is important to note that the presented aspects and details can be adapted to offer trusted and de-centralized traceability for any Wood or food produce. It is worth mentioning that blockchain technology still encounters significant challenges in terms of scalability, governance, identity registration, privacy, standards, and regulations. As part of our future work, we intend to address some of these key challenges and develop corresponding solutions. Furthermore, our proposed solution will incorporate automated payment mechanisms and incorporate proof of delivery. This involves the utilization of cryptocurrency and smart contracts to automate and centralize the payment process for all parties involved, following the successful completion of the physical delivery of crops and products.

Acknowledgments

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