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RESEARCH ARTICLE

Role of Blockchain Technology in Supplychain Management

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ABSTRACT Today, the primary issues for both physical and online retailers are fake and stolen goods. The likelihood that this product is fake is unknown to consumers. They lack a clear method to check the product's integrity. This not only jeopardizes consumer trust but also imposes significant financial ramifications on both buyers and sellers. Therefore, we suggest a method in which we incorporate blockchain technology to confirm the product's integrity. Central to our proposition is the integration of Non-Fungible Tokens (NFTs) as unique digital identifiers, combined with the dual security layers of holographic labels and RFID tags. This system operates on a private blockchain, ensuring enhanced scalability and transaction efficiency. Furthermore, the mechanism incorporates a collateral system initiated upon order placement, incentivizing honesty and timely delivery among participants. In the event of discrepancies, a robust dispute resolution system, underpinned by a voting mechanism, ensures fairness and trustworthiness. Our experimental implementation demonstrates the system's effectiveness in reducing costs and enhancing transparency in supply chain management. The results highlight the potential of blockchain technology in revolutionizing supply chain management, offering a compelling alternative to traditional systems with reduced costs and increased security and transparency.

INDEX TERMS Blockchain, product circulation, non-fungible tokens (NFTs), supply chain management, holographic labels, RFID tags, private blockchain, collateral system, incentive mechanism, dispute resolution, voting mechanism, counterfeit goods, transparency, authenticity, retail landscape.

I. INTRODUCTION

The evolution of the retail sector has been nothing short of transformative. From bustling marketplaces to sophisticated e-commerce platforms, the way we buy and sell has undergone significant shifts. However, with these advancements come challenges that threaten the very fabric of trade: counterfeit and stolen goods. These challenges are not just limited to tangible storefronts but have permeated the digital realm, casting a shadow of doubt over the authenticity of products and the credibility of sellers.

Counterfeit products not only lead to financial losses for consumers but also tarnish the reputation of genuine brands and manufacturers. For the consumer, the inability to distinguish between genuine and counterfeit products poses a significant risk, both in terms of monetary value and, in some cases, health and safety. For brands, the proliferation of counterfeit goods erodes brand value, trust, and loyalty. The digital age, while offering unparalleled convenience, has inadvertently provided a fertile ground for counterfeiters to thrive, leveraging the anonymity and vastness of the internet.

In the face of these challenges, there is a pressing need for a system that can ensure product authenticity from the point of manufacture to the end consumer. Traditional methods, while effective to some extent, often fall short in the face of sophisticated counterfeiting techniques. This calls for a solution that is not only robust but also adaptable to the ever-evolving landscape of retail.

Enter blockchain technology. Originally conceptualized to support the digital currency Bitcoin, blockchain has

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emerged as a versatile tool with applications far beyond cryptocurrency. Its decentralized nature, coupled with its ability to provide a transparent and immutable record of transactions, makes it an ideal candidate to address the challenges of counterfeit and stolen goods in the retail sector [12], [13], [14], [15].

This research paper delves into the intricacies of a proposed blockchain-based product circulation system, designed to revolutionize the traditional supply chain dynamics. By harnessing the unparalleled security and transparency features of blockchain technology, we aim to establish a system that ensures product authenticity, traceability, and accountability at every juncture of the supply chain. In the subsequent sections, we will explore the proposed mechanism in detail, highlighting its components, benefits, and potential to reshape the future of retail.

Our research introduces the Supply Chain Consensus (SCC) Algorithm, tailored specifically for supply chain dynamics. This algorithm emphasizes node classification based on stake and trust, aiming for a balanced validation process. Additionally, we've explored the use of Non-Fungible Tokens (NFTs) for digital twinning in supply chains, offering a method for product authentication. Our system also suggests a periodic reconciliation process, aiming to maintain data integrity across nodes. To encourage positive participation, we've designed an incentive mechanism that balances rewards and penalties based on node behaviour.

This paper is structured as follows: Section II delves into the relevant research literature. Section III outlines the traditional product circulation system, while Section IV introduces our blockchain-based approach. The core components of our proposal are detailed in Section V. Section VI provides a comprehensive discussion, and we wrap up with conclusions in Section VII.

II. RELATED WORK

The integration of blockchain technology with supply chain management has been extensively researched, with various methodologies and frameworks proposed to address specific challenges and enhance the efficiency and transparency of supply chains. This section reviews some of the pivotal works in this domain:

Islam et al. [1] conducted a comprehensive survey on the integration of blockchain technology with heterogeneous networks, emphasizing its potential in enhancing cybersecurity. They highlighted the challenges of data integrity, scalability, and significant computing complexity. Our methodology addresses these challenges by introducing efficient consensus mechanisms and a private blockchain structure, ensuring faster transactions and controlled participation.

Tian, F. et al. explored the potential of integrating RFID and blockchain technologies to establish a traceability system for the agri-food supply chain in China. Recognizing the pressing need for food safety and authenticity, especially in the Chinese context, the research proposed a robust solution that leverages the strengths of both technologies. By doing so, it addresses significant concerns related to food safety, offering a transparent and tamper-proof mechanism to track and verify every step of the supply chain. While the study provides valuable insights into the application of blockchain in the agri-food sector, our methodology further builds upon this foundation by introducing additional layers of security and efficiency, ensuring a more comprehensive and versatile approach to supply chain management [2].

Sheriff et al. [3] proposed a secure blockchain-based framework for food supply chain management using a hybrid IDEA algorithm. Their approach focuses on ensuring the authenticity and traceability of food items throughout the supply chain. While their method offers enhanced security, it primarily targets the food industry, and its adaptability to other sectors remains unexplored. In contrast, our proposed system offers a more versatile solution, adaptable to various industries, ensuring both product authenticity and efficient supply chain management.

Gulen et al. [4] reviewed the application of blockchain technology in the agricultural food supply chain, specifically focusing on Turkey. They emphasized the transformative potential of blockchain in ensuring the traceability and authenticity of agricultural products. While their study provides valuable insights into the agricultural sector of Turkey, our proposed system is designed for a broader range of applications, ensuring a global perspective on supply chain management.

Saberi et al. [5] explored the relationship between blockchain technology and sustainable supply chain management. They highlighted the potential of blockchain in enhancing transparency and traceability in supply chains. However, their study primarily focused on the sustainability aspect and might not delve deep into the security concerns and real-time tracking. In contrast, our proposed system integrates advanced security mechanisms and real-time tracking, ensuring a more comprehensive solution for supply chain management.

Tajima [6] explored the strategic value of RFID in supply chain management. Their research emphasized the transformative potential of integrating RFID technology into the supply chain, highlighting its ability to enhance real-time tracking, reduce errors, and improve overall efficiency. However, one of the challenges they pointed out was the initial cost of implementing RFID systems and the need for standardization across the supply chain. In comparison, our proposed system integrates RFID technology with other security measures like holographic labels, ensuring a multi-layered approach to product authentication and tracking. This not only addresses the challenge of product counterfeiting but also enhances the overall efficiency and reliability of the supply chain.

Hasan and Salah [7] proposed a blockchain-based solution for the proof of delivery of physical assets. Their approach focuses on ensuring the delivery of items between a seller and a buyer using a chain of contracts. The system is designed to adapt to the number of courier services required, with each contract pointing to the next in the chain. The main contract, termed "Proof of Delivery (PoD)," initiates the chain, while the "Buyer Transporter (BT)" contract signifies the end. If multiple transporters are involved, intermediary "Courier Service (CS)" contracts are created. While this structure undeniably champions transparency and traceability as items traverse the chain of contracts, it presents certain challenges. The sophisticated arrangement of contracts, despite its transparent nature, can become increasingly complex, particularly when multiple transporters are integrated into the system. Such complexity might lead to elevated transactional costs and introduce potential delays. Moreover, as the number of contracts proliferates due to the addition of transporters, there arises a scalability concern, which could adversely impact the speed of the verification process. The inherent rigidity of the system, characterized by its strict dependence on the PoD for initiating the chain and the BT for its termination, may not be versatile enough to cater to the varied nuances of different supply chain models.

Toyoda et al. [8] delved into the challenges posed by traditional RFID technology in ensuring product authenticity, especially during the post-supply chain phase. Their research introduced the Product Ownership Management System (POMS), a novel approach that integrates blockchain technology to bolster the security and traceability of products with RFID tags. By harnessing the decentralized nature of blockchain, POMS ensures that only genuine products with verifiable ownership can be sold to end consumers. This system's practical implementation on the Ethereum platform further demonstrated its feasibility and cost-effectiveness. While Toyoda et al.'s approach offers a robust mechanism for ensuring product authenticity post-supply chain, our proposed system introduces enhanced scalability features and a multi-layered security structure, addressing broader challenges in the supply chain management domain.

The aforementioned studies provide a comprehensive overview of the various methodologies and frameworks proposed in the realm of blockchain integration with supply chain management. Each research offers unique insights and solutions to specific challenges in the domain. Our proposed system, while building upon these foundational works, introduces innovative features and mechanisms that address a broader spectrum of challenges, ensuring a holistic, efficient, and transparent supply chain management system.

III. TRADITIONAL PRODUCT CIRCULATION SYSTEM

In the conventional product circulation system, the journey of a product from its origin (manufacturer or producer) to the end consumer is facilitated through a series of intermediaries, including wholesalers, distributors, retailers, and sometimes even agents. The manufacturer produces the item and then sells it to a wholesaler or distributor. This distributor, in turn, might sell the product to another intermediary or directly to a retailer. The retailer then offers the product to the end consumer. Throughout this chain, the product's information, such as its origin, batch number, manufacturing date, and other relevant details, is typically recorded on paper or in centralized databases. These records are prone to errors, tampering, or even loss. Verification of product authenticity and traceability in such a system relies heavily on these records and the trustworthiness of the intermediaries. Disputes, if any, are resolved through traditional legal channels, which can be time-consuming and costly. The lack of a unified, transparent, and tamper-proof system often leads to challenges like counterfeiting, product adulteration, and inefficiencies in the supply chain.

With this backdrop, the introduction of a blockchain-based product circulation system can be presented as a transformative solution that addresses the inherent challenges of the traditional system, offering enhanced transparency, security, and efficiency.

IV. PROPOSED BLOCKCHAIN-BASED PRODUCT CIRCULATION SYSTEM

In this section, we introduce our innovative blockchain-based supply chain management system. Central to this system are four pivotal participants: the seller, buyer, transporter, and arbitrator. The seller, often synonymous with the manufacturer, is the originator of the product. The buyer represents the end consumer or entity intending to acquire the product from the seller. The transporter, a crucial link in this chain, shoulders the responsibility of ensuring the product's seamless and safe transit from the seller to the buyer. Lastly, the arbitrator, an impartial entity, steps in to mediate and resolve any disputes that might arise between the involved parties, ensuring fairness and adherence to agreed terms. This diagram 1 provides a high-level overview of the product's journey from production to purchase.

A. PRODUCT CREATION & DIGITAL TWINNING

In the initial phase of the product's lifecycle, the manufacturer undertakes the process of crafting or producing the item. This product, once created, is then equipped with a dual-layered security feature. An RFID tag, known for its capability to store electronic information, is embedded onto the product. Over this RFID tag, a unique holographic label is placed, adding an additional layer of visual security. This combination not only ensures the product's authenticity but also makes counterfeiting considerably challenging. Parallelly, in the digital realm, a Non-Fungible Token (NFT) is minted for this product.

1) NFT MINTING PROCESS

- Smart Contract Deployment: A smart contract, which is a self-executing contract with the terms of the agreement directly written into code, is deployed on the blockchain. This contract governs the creation and management of the NFT.
- Data Embedding: The product's digital twin data is embedded into the NFT. This is achieved by encoding the data into the smart contract or linking it to the NFT as metadata.

- Minting: The NFT is then minted or created on the blockchain. Minting is the process of recording the NFT onto the blockchain, making it a unique and tamper-proof digital asset. This process is typically initiated by the manufacturer or an authorized entity.

This NFT acts as the product's digital counterpart or "digital twin." It encapsulates vital data about the product, such as its origin, manufacturing date, and other pertinent details. The creation of this NFT ensures that every physical product has a corresponding digital identity, which can be used for verification, tracking, and establishing provenance in subsequent stages of the product's journey.

2) DATA STORED IN RFID TAG

- Unique Product ID: A unique identifier for the product, which can be used to fetch more detailed information from a database or blockchain.
- Batch or Lot Number: Useful for products manufactured in batches. It can help in identifying the manufacturing batch, which can be crucial in case of recalls or quality checks.
- Manufacturing Date: The date when the product was manufactured.
- Expiration Date: Relevant for perishable goods or products with a limited shelf life.
- Product Type or Category: A brief identifier or code representing the type or category of the product.
- Manufacturer ID: An identifier for the manufacturer or the brand.
- Quick Access URL or QR Code: A link to a website or platform where more detailed information about the product can be accessed.
- NFT Reference: If the product has an associated NFT, a reference ID or link to that NFT can be stored on the RFID. This doesn't mean storing the entire NFT on the RFID but rather a pointer or reference to it.

B. BLOCKCHAIN ENTRY & VERIFICATION

Once the product is ready and its digital twin, the NFT, is minted, the next crucial step is to record its essential details on a private blockchain. This blockchain, designed for controlled participation and faster transactions, becomes the immutable ledger for the product's journey. Key product data, such as its unique identification number, manufacturing details, and other specifications, are securely logged onto this blockchain. Alongside the product's data, the unique ID and metadata of the associated NFT are also stored. This process ensures that the physical product and its digital representation are intrinsically linked, providing a seamless integration of the tangible and digital realms. The private blockchain, with its inherent security features, guarantees that this data remains tamper-proof and can be accessed and verified by authorized participants at any stage of the product's circulation.

1) STORING RFID INFORMATION IN NFT

By integrating RFID data with Non-Fungible Tokens (NFTs), a seamless bridge is established between a product's physical presence and its digital representation, significantly enhancing traceability. This integration is pivotal in meticulously tracing a product's journey throughout the supply chain. Furthermore, embedding RFID data within the NFT introduces an added layer of security. Any potential tampering or discrepancies with the RFID tag can be swiftly detected by cross-referencing the data with its corresponding NFT. NFTs inherently possess the capability to house a rich set of metadata. By assimilating RFID details, a more expansive and detailed digital overview of the product is achieved, encapsulating its origin, transit history, and other pertinent attributes. For individuals seeking to verify a product's authenticity, the process is streamlined: a simple scan of the RFID provides access to the associated NFT, which in turn offers a comprehensive history and detailed specifications of the product. Bolstering this system's integrity is the immutable nature of blockchain technology. Once the RFID data finds its place within an NFT, it is safeguarded against any alterations or tampering, cementing its trustworthiness and reliability.

Algorithm 1 Payment Release and Incentive Mechanism

Input: Product ID, buyer, transporter, seller, NFT ownership, collateral amount, delivery status, incentive criteria
Output: Payment status, Incentive

```
if NFT ownership of Product ID = buyer then
    Release collateral amount to seller and transporter.
    Transfer payment from buyer to seller.
    Update NFT ownership to buyer.
    if delivery status meets incentive criteria then
        Award incentive to transporter.
        Return "Incentive Awarded"
    else
        Return "No Incentive Awarded"
    end if
    Return "Payment Successful"
else
    Hold collateral amount in smart contract.
    Initiate dispute resolution mechanism.
    Return "Payment Pending"
end if
```

C. PRODUCT LISTING FOR SALE & NFT DISPLAY

With the product's essential details and its digital twin securely recorded on the blockchain, it is now primed for introduction to the market. The product is listed for sale on a designated platform or marketplace, making it available to potential buyers. This listing is not just a mere catalog entry; it is enriched with the product's associated NFT. The NFT, displayed prominently alongside the product, serves as a badge of authenticity and provenance. It provides potential buyers with a comprehensive digital overview of the product, showcasing its origin, manufacturing details, and other relevant metadata. This integration of the NFT with the

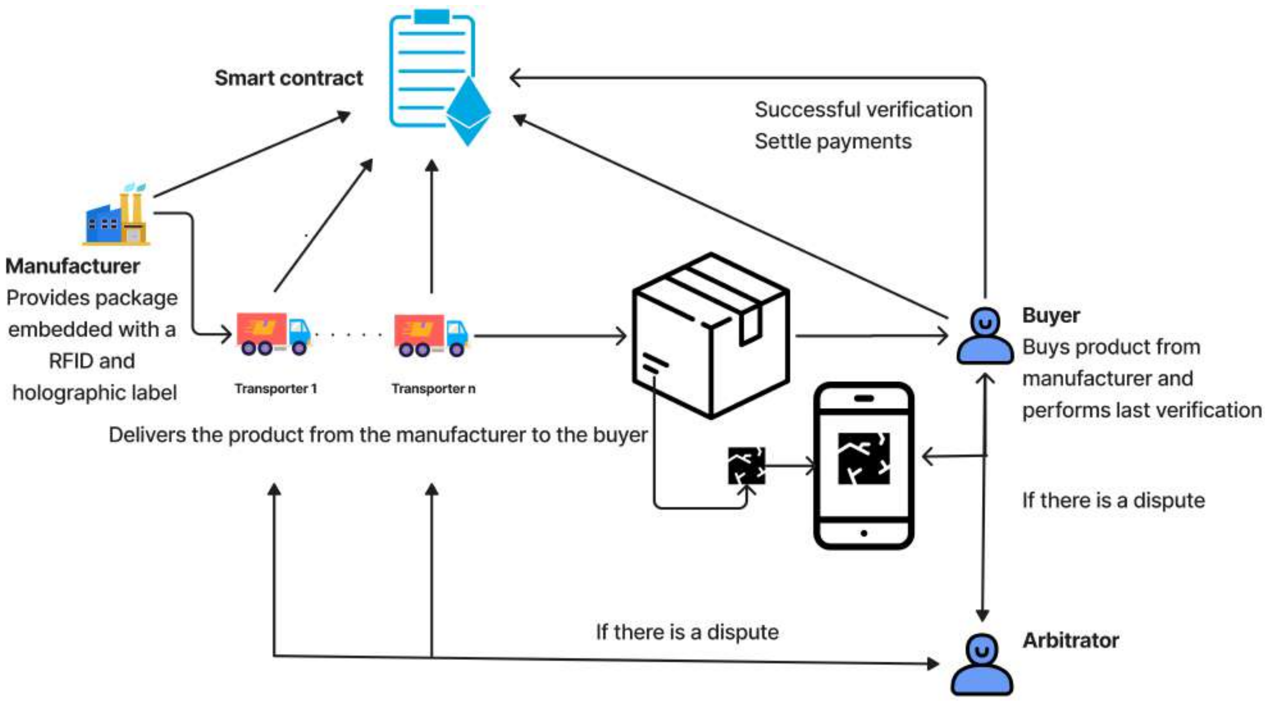

FIGURE 1. Proposed blockchain-based product circulation system.

product listing not only elevates the buyer's confidence in the product's legitimacy but also emphasizes the product's unique identity in the vast marketplace. In essence, the NFT becomes both a certificate of authenticity and a digital storyteller for the product, ensuring transparency and trustworthiness.

D. ORDER PLACEMENT & COLLATERAL SYSTEM INITIATION

As potential buyers navigate the marketplace, they have the opportunity to delve into the details provided by the NFTs, ensuring they are making informed purchasing decisions. Once a buyer decides to purchase a product, they place an order, signalling the commencement of the transaction process. With the order in place, the collateral system is immediately initiated. This system is designed to safeguard the interests of all parties involved in the product's transit. The involved parties, such as transporters and intermediaries, are required to deposit a predetermined amount as collateral into a smart contract. This collateral acts as a financial guarantee, ensuring that each party will diligently fulfil their responsibilities throughout the product's journey. The smart contract holds onto this collateral, marking the NFT's ownership as "Pending Transfer." This status remains until the product safely reaches the buyer and undergoes successful verification. By intertwining the order placement with the collateral system, the process ensures a layer of financial security and commitment, fostering trust and accountability in the subsequent stages of the product's transit.

E. PRODUCT DISPATCH & TRANSIT

With the order placed and the collateral system activated, the product's journey from the manufacturer to the buyer begins. The manufacturer, ensuring the product is well-prepared and packaged, initiates the dispatch process. As the product embarks on its journey through the supply chain, each transition and movement is meticulously recorded on the blockchain. This is achieved through periodic scans of the embedded RFID tags and visual inspections of the holographic labels, confirming the product's authenticity at every checkpoint. Additionally, the associated NFT's metadata is verified at each stage, further strengthening the product's traceability. Transporters and intermediaries play a pivotal role in this phase, ensuring the product's safe and timely transit. Their performance is closely monitored, and they are incentivized for successful verifications and prompt deliveries. Conversely, any discrepancies, delays, or negligence can lead to penalties, ensuring that all parties remain committed to the product's safe delivery. This phase, underpinned by blockchain's transparency and the dual-layered security of RFID and holographic labels, ensures that the product's journey is both traceable and trustworthy.

F. BUYER TRACKING & VERIFICATION

As the product progresses through its journey, the buyer is not left in the dark. Leveraging the power of the private blockchain, the buyer is granted real-time access to track the product's movement and status. This transparency ensures that the buyer remains informed about the product's

Algorithm 2 Dispute Resolution and Voting Mechanism

Input: Dispute details, list of stakeholders, arbitrator candidates

Output: Resolution outcome

Dispute details include the nature of the dispute, involved parties, and evidence.

List of stakeholders are the entities involved in the supply chain.

Arbitrator candidates are the potential entities to mediate the dispute.

if dispute arises **then**
  Initiate voting mechanism.
  for each stakeholder in list of stakeholders **do**
    Stakeholder votes for preferred arbitrator candidate.
  end for
  Arbitrator ← candidate with majority votes.
  if Arbitrator is neutral and trusted by majority **then**
    Arbitrator reviews dispute details.
    Arbitrator accesses blockchain and NFT for evidence.
    Arbitrator reaches a decision.
    Execute decision and resolve dispute.
    Return "Dispute Resolved"
  else
    Return "Dispute Resolution Failed"
  end if
else
  Continue normal transaction process.
end if

whereabouts, expected delivery timelines, and any potential delays or issues [11]. Upon the product's arrival at its destination, the buyer plays a crucial role in the verification process. They are tasked with cross-referencing the product's physical attributes, such as the RFID tag and holographic label, with the digital details stored in the associated NFT's metadata. This comprehensive verification process ensures that the product received matches its digital representation, confirming its authenticity and integrity. If the product aligns with its blockchain records and NFT details, the verification is deemed successful, paving the way for the subsequent stages of payment and ownership transfer.

G. PAYMENT RELEASE & INCENTIVE MECHANISM

Upon the successful verification of the product by the buyer, the transaction enters its financial culmination phase. The smart contract, which has been holding onto the collateral deposited by the involved parties, initiates the payment process. Transporters and intermediaries, who have played their part in ensuring the product's safe and timely delivery, receive their due payment. In addition to their standard fees, they may also be awarded additional incentives for exceptional service, timely deliveries, or any other predefined criteria that they have met or exceeded. These incentives serve as a motivation for all parties to maintain high standards of service in future transactions. Conversely, if there were any discrepancies or issues during transit, penalties could be imposed, ensuring accountability. The buyer's payment for the product is also processed, and the ownership of the NFT is officially transferred from the manufacturer or seller to the buyer, marking the completion of the product's journey. The collateral system, having served its purpose, releases the deposited amounts back to the respective parties, ensuring that all financial commitments are settled transparently and efficiently. The algorithm 1 outlines the financial culmination phase of a product's transaction upon its successful verification by the buyer.

Algorithm 3 Supply Chain Consensus Algorithm

Initialization:
Define Primary Nodes (PNs) and Secondary Nodes (SNs)
Set supermajority threshold (e.g., 2/3 of PNs)
procedure Transaction Batching
  SN groups multiple transactions into a batch
  Propose batch to PNs for validation
end procedure
procedure Batch Proposal
  SN creates batch
  SN proposes batch to a subset of PNs for validation
end procedure
procedure Validation Process
  Randomly select subset of PNs for validation
  for each PN in subset **do**
    Validate batch against records and NFTs
    Vote on batch validity
  end for
end procedure
procedure Batch Commitment
  if supermajority of PNs validate the batch **then**
    Commit batch to blockchain
  else
    Flag batch for review or discard
  end if
end procedure
procedure Rewards and Penalties
  if batch is committed **then**
    Reward SN for successful batch
    Reward PNs for validation
  else
    Penalize malicious nodes
  end if
end procedure
procedure Periodic Reconciliation
  All nodes cross-reference records
  if discrepancies found **then**
    Flag and resolve via majority consensus
  end if
end procedure

H. DISPUTE RESOLUTION & VOTING MECHANISM

In the intricate web of supply chain transactions, disputes can occasionally arise, be it due to product discrepancies, delivery issues, or other unforeseen challenges. To address such situations, a robust dispute resolution mechanism is integrated into the system. Should a dispute arise, a neutral arbitrator or a panel is selected to mediate and resolve the issue. The selection of this arbitrator or panel isn't arbitrary; it's driven by a transparent voting mechanism involving key stakeholders in the supply chain. This ensures that the chosen entity has the confidence and trust of the majority. The immutable nature of the blockchain and the comprehensive history stored in the NFT play pivotal roles during dispute resolution. They provide an unalterable record of the product's journey, aiding in fact-checking and evidence presentation. Once the arbitrator or panel reaches a decision, it's executed, ensuring fairness and adherence to the agreed-upon terms. This mechanism not only resolves disputes efficiently but also reinforces trust and accountability among all parties involved in the transaction.

The algorithm 2 is designed to address and resolve any disputes that may arise during supply chain transactions. When a dispute is detected, the system initiates a transparent voting mechanism. Each stakeholder involved in the supply chain is given the opportunity to vote for their preferred arbitrator from a list of candidates. The candidate who receives the majority of votes is selected as the arbitrator.

The chosen arbitrator is then tasked with reviewing the details of the dispute. To ensure a fair and informed decision, the arbitrator accesses the blockchain and the associated NFT to gather evidence and verify claims. This step leverages the immutable nature of the blockchain and the comprehensive history stored in the NFT, providing an unalterable record of the product's journey.

Once the arbitrator has thoroughly reviewed the evidence and claims, they reach a decision on how to best resolve the dispute. This decision is then executed, ensuring that the resolution is fair and adheres to the agreed-upon terms. The algorithm ensures that disputes are addressed efficiently, reinforcing trust and accountability among all parties involved in the transaction.

I. BATCHING TRANSACTIONS & CONSENSUS MECHANISM

To further enhance the scalability and efficiency of the blockchain system, especially in scenarios where numerous products are being transacted simultaneously, the system employs a batching technique. Instead of recording each individual transaction as a separate entry on the blockchain, multiple transactions are grouped together and recorded as a single batched entry. This approach significantly reduces the load on the blockchain, ensuring faster processing times and optimized resource utilization. However, batching doesn't compromise the integrity or security of the data. Each batched transaction is still subject to rigorous verification through the consensus mechanism. This mechanism, tailored for the private blockchain environment, ensures that only validated and agreed-upon transactions are added to the blockchain. By combining the efficiency of batching with the robustness of the consensus mechanism, the system ensures that even as transaction volumes grow, the blockchain remains agile, secure, and trustworthy.

Algorithm 4 Product Authenticity Verification Using RFID and NFT

Input: Product ID, RFID data, NFT metadata, current owner
Output: Authenticity status

```
Retrieve the NFT associated with the given Product ID.
if NFT exists then
    if RFIDdata = NFTmetadata then
        if currentowner = NFTowner then
            Return "Product is Authentic"
        else
            Return "Ownership Mismatch"
        end if
    else
        Return "Product Data Mismatch"
    end if
else
    Return "Product Not Registered"
end if
```

V. KEY COMPONENTS OF THE PROPOSED SYSTEM

A. SUPPLY CHAIN CONSENSUS (SCC) ALGORITHM

The SCC algorithm 3 is designed with the unique requirements of a supply chain in mind. By classifying nodes based on their stake and trust level, it ensures that only the most trusted entities have a significant say in the validation process. However, by requiring a super majority, it also ensures that no single entity or a small group can dominate the decision-making process. Batching transactions and involving only a subset of nodes in validation make the process efficient and cost-effective. The rewards and penalties system ensures all nodes act in the best interest of the network. Lastly, periodic reconciliation acts as a safety net, ensuring any discrepancies or errors that might have slipped through are caught and corrected. This makes SCC a robust, efficient, and tailored consensus algorithm for a supply chain-based private blockchain.

1) NODE CLASSIFICATION

In the proposed consensus algorithm, nodes are distinctly classified based on their stake and trust within the supply chain system.

- Primary Nodes (PNs): These nodes are central to the SCC algorithm. They are typically stakeholders with significant investment and interest in the supply chain, such as manufacturers, major distributors, or logistics companies. PNs have elevated privileges in terms of

Algorithm 5 Post Supply Chain Management for NFT-Based Product Sale

Input: Product details, NFT details, buyer details
Output: Sale status, NFT ownership transfer status
Product details include product ID, price, and description.
NFT details include NFT ID, current owner, and metadata.

if shopkeeper wants to sell product **then**
  Display product details and associated NFT on marketplace.
  if buyer shows interest **then**
    Buyer verifies product authenticity using NFT metadata.
    if product is genuine **then**
      Buyer proceeds with payment.
      if payment is successful **then**
        Transfer product to buyer.
        Initiate NFT ownership transfer.
        Update NFT details with new owner.
        Return "Sale Successful and NFT Transferred"
      else
        Return "Payment Failed"
      end if
    else
      Return "Product Verification Failed"
    end if
  else
    Continue displaying product on marketplace.
  end if
else
  Continue normal shop operations.
end if

decision-making and validation processes due to their higher stake and trust level within the network.

- Secondary Nodes (SNs): These nodes play a supportive role in the supply chain. They include entities like smaller distributors, retailers, or logistics service providers. SNs are responsible for updating product details as they move through the supply chain but have a comparatively lower stake than PNs.

2) TRANSACTION BATCHING

Transaction batching is a technique employed to enhance the efficiency and scalability of the blockchain system. Instead of processing and recording each transaction individually, multiple transactions are aggregated into a single cohesive batch. Once formed, this batch is then proposed for addition to the blockchain. By consolidating transactions in this manner, the system can significantly reduce the overhead associated with individual transaction validations, leading to faster processing times and optimized resource utilization. This approach not only streamlines the transaction recording process but also ensures that the blockchain remains agile, even as transaction volumes surge.

3) BATCH PROPOSAL

The batch proposal process is a pivotal step in ensuring the integrity and accuracy of product details updated by Secondary Nodes (SNs). Whenever an SN makes changes or updates to product details, instead of immediately recording these changes, it aggregates them into a consolidated batch. Once this batch is formed, it doesn't get directly added to the blockchain. Instead, the SN proposes this batch to a predefined set of Primary Nodes (PNs) for validation. These PNs, being trusted entities with a higher stake in the system, are responsible for scrutinizing the batch's contents, ensuring its authenticity, and verifying that the updates align with the system's protocols. Only upon receiving validation from the PNs does the batch get approved for addition to the blockchain. This layered approach of batch proposal and validation by PNs ensures that the blockchain maintains its integrity, accuracy, and trustworthiness at all times.

4) VALIDATION PROCESS

The validation process in the Supply Chain Consensus (SCC) Algorithm is a crucial component that ensures the integrity and authenticity of transactions within the blockchain-based supply chain management system. This process involves a series of steps to select and utilize Primary Nodes (PNs) for the validation of transaction batches.

- Node Pool Creation: The first step involves creating a pool of eligible Primary Nodes (PNs). This pool comprises all PNs that are active and meet certain criteria, such as reliability, historical accuracy in validation, and compliance with network protocols. These criteria ensure that only trustworthy and capable nodes participate in the validation process.
- Randomization Mechanism: To select a subset of PNs from the pool, a randomization mechanism is employed. This mechanism is based on cryptographic techniques, such as random number generators, which use blockchain data (hash of the latest block) as a seed. This approach ensures that the selection process is fair, unbiased, and unpredictable.
- Ensuring Unpredictability: The randomization process is designed to be tamper-proof and opaque, preventing any prediction or manipulation of which PNs will be selected. The actual selection is only revealed at the time of validation, maintaining the integrity of the process.
- Dynamic Subset Size: The number of PNs chosen for each validation task can vary. Factors influencing this include the total number of PNs available, the complexity of the batch, and the network's current workload. This dynamic sizing ensures efficiency without compromising the thoroughness of the validation.
- Rotation and Diversity: The system ensures regular rotation of PNs and equal opportunity for all nodes in

the pool to participate over time. This rotation promotes diversity in the validation process, bringing different perspectives and reducing the risk of bias.
- Transparency in Selection: Once a subset of PNs is selected, their identities are announced on the blockchain. This transparency allows other network participants to know which nodes are responsible for validating a specific batch, thereby maintaining openness in the process.
- Validation Procedure: The selected PNs then proceed to validate the batch. They cross-reference the batch's data against existing records and associated NFTs, verifying the data's integrity and authenticity. This step is crucial in ensuring that only accurate and legitimate information is recorded on the blockchain.

5) BATCH COMMITMENT

The commitment of a batch to the blockchain is a decisive step, ensuring that only validated and agreed-upon transactions become a permanent part of the ledger. For a batch to be committed, it must receive approval from a supermajority of the selected Primary Nodes (PNs). Typically, this supermajority might be set at a threshold like 2/3 of the PNs, ensuring a broad consensus. If the batch successfully garners the requisite number of affirmative votes, it is then officially appended to the blockchain, making its contents immutable and publicly verifiable. However, if the batch fails to achieve this supermajority consensus, it doesn't fade into oblivion. Instead, it's flagged for a detailed review. This review process allows stakeholders to identify any discrepancies or errors in the batch. If the issues are rectifiable, the batch can be corrected and then resubmitted for validation. On the other hand, if the batch is determined to be malicious or fundamentally flawed, it is discarded, ensuring that the integrity of the blockchain remains uncompromised. This commitment process, with its checks and balances, ensures that the blockchain remains a trustworthy and accurate record of all valid transactions.

6) REWARDS AND PENALTIES

The incentive mechanism within the Supply Chain Consensus (SCC) Algorithm plays a crucial role in motivating and regulating the behaviour of nodes in the blockchain network. This mechanism is intricately designed to encourage active participation, maintain data integrity, and deter any malicious activities.

- Reward Structure for Secondary Nodes (SNs): SNs are incentivized for each successfully proposed batch that is committed to the blockchain. The reward amount considers factors like the complexity of the batch, data volume, and submission timeliness. This structure motivates SNs to actively participate and ensure the accuracy of their data submissions.
- Incentives for Primary Nodes (PNs): PNs receive rewards for their role in the validation process, which includes reviewing, cross-referencing, and voting on batches proposed by SNs. The reward amount is based on their engagement level and validation accuracy, encouraging PNs to diligently perform validations and ensure only legitimate transactions are recorded.
- Penalty Mechanism: The system imposes penalties for submitting incorrect, incomplete, or malicious data. Penalties range from reward forfeiture for minor infractions to severe consequences like suspension or expulsion for serious violations. This mechanism deters dishonest or negligent behaviour, maintaining network integrity.
- Performance-Based Incentives: Nodes demonstrating high performance and reliability may receive additional incentives or bonuses, such as increased rewards or batch processing priority. This encourages nodes to maintain high operational standards and contribute positively to the network.
- Transparency in Incentive Distribution: The distribution of rewards and penalties is transparent and recorded on the blockchain, ensuring fairness and allowing network participants to audit the incentive mechanism. This transparency builds trust among nodes and stakeholders.
- Dynamic Incentive Adjustment: The incentive structure can be adjusted based on network conditions and transaction volumes. This ensures the mechanism remains effective and relevant as the network evolves.
- Feedback Loop for Improvement: The system includes a feedback loop for nodes to provide input on the incentive mechanism. This feedback is used for continuous improvements, ensuring the mechanism aligns with network goals and participant needs.

By integrating these aspects, the SCC algorithm ensures active and honest participation from all nodes, enhancing the efficiency, reliability, and integrity of the blockchain-based supply chain management system.

7) PERIODIC RECONCILIATION

To further ensure data integrity, the system undergoes periodic reconciliation. During this, all nodes cross-reference their records. Any discrepancies are flagged and resolved through a majority consensus.

B. ENSURING PRODUCT AUTHENTICITY THROUGH RFID AND NFT INTEGRATION

The algorithm 4 provides a method to verify the authenticity of products in the circulation system. In the traditional product circulation system, counterfeiting remains a significant challenge. Sellers can replicate products, artwork, or music, and sell these counterfeits without facing immediate consequences. However, by integrating RFID technology with NFTs, we can introduce a robust mechanism to combat this issue. The algorithm

1) RFID AND NFT INTEGRATION FOR AUTHENTICITY VERIFICATION

Each product is embedded with an RFID tag, which contains unique information about the product. This RFID

TABLE 1. Comparison between existing system and proposed product circulation system.

Parameter	Existing System	Proposed System
Traceability	Limited to traditional tracking methods	Enhanced with blockchain, ensuring full traceability
Security	Basic security measures	Multi-layered security with RFID tags, NFTs, and holographic labels
Transparency	Limited transparency in product journey	Full transparency with blockchain records
Cost Efficiency	Higher costs due to inefficiencies	Reduced costs with efficient consensus and batching
Scalability	Limited scalability	Enhanced scalability with batched transactions
Dispute Resolution	Manual resolution methods	Automated and transparent resolution with voting mechanism
Public Acceptance	Relies on traditional trust models	Gamification and incentives for increased public acceptance
Consensus Mechanism	Not applicable or basic consensus	Customized consensus tailored for supply chain

tag serves as a physical identifier, making it challenging for counterfeiters to replicate due to its unique electronic signature [9], [10]. Parallelly, an NFT, representing the product's digital twin, is minted on the blockchain. This NFT contains metadata about the product, including its origin, manufacturing details, and the unique information from the RFID tag. The combination of RFID and NFT ensures a dual-layered verification system, where the physical product can be matched with its digital representation.

2) OWNERSHIP VERIFICATION THROUGH NFTS

NFTs inherently indicate the current owner of the product. When a buyer is interested in purchasing a product, they can verify its authenticity by scanning the RFID tag and cross-referencing it with the associated NFT on the blockchain. If the NFT's metadata matches the RFID's data and the NFT indicates that the shop owner is the current possessor, it confirms that the shop owner has a genuine product. This process ensures that only genuine products, with a verifiable chain of ownership, are sold to consumers.

3) OWNERSHIP TRANSFER MECHANISM

Upon a successful sale, the ownership of the NFT can be transferred from the seller (shop owner) to the buyer. This transfer is recorded on the blockchain, ensuring an immutable record of the transaction. The new owner can then use the NFT for any future verifications or sales, ensuring a continuous chain of authenticated ownership. This mechanism not only deters counterfeit sales but also provides a transparent record for buyers, ensuring they always receive genuine products.

By integrating RFID tags with NFTs, this system offers a comprehensive solution to the challenge of counterfeiting, ensuring product authenticity, traceability, and a transparent chain of ownership.

C. POST SUPPLY CHAIN MANAGEMENT FOR NFT-BASED PRODUCT SALE

The algorithm 5 is designed to facilitate the sale of a product along with its associated NFT in a marketplace. When a shopkeeper or product owner decides to sell a product, the product details, along with its associated NFT, are displayed on the marketplace.

Potential buyers can view the product and its NFT details. The NFT serves as a digital certificate of authenticity for the product. If a buyer is interested in purchasing the product, they can use the metadata stored in the NFT to verify the product's authenticity, ensuring that they are purchasing a genuine item.

Once the buyer verifies the product's authenticity and decides to proceed with the purchase, they make the payment. If the payment is successful, the product is transferred to the buyer. Simultaneously, the ownership of the NFT is transferred from the shopkeeper (or current owner) to the buyer, reflecting the change in product ownership. The NFT's details are updated to indicate the new owner.

This algorithm ensures a seamless and transparent sale process, leveraging the power of NFTs to guarantee product authenticity and provide a digital record of product ownership. The integration of NFTs in the post-supply chain management enhances trust and confidence in the buying process, ensuring that buyers receive genuine products and have a verifiable digital record of their purchase.

VI. DISCUSSION

A. FEATURES OF THE PROPOSED SYSTEM

The proposed blockchain-based product circulation system introduces a suite of innovative features for enhanced supply chain management. Central participants include the seller, buyer, transporter, and arbitrator. A standout feature is "Product Digital Twinning," where each product is paired with a Non-Fungible Token (NFT), ensuring a seamless blend of physical and digital identities. Products are secured with RFID tags and unique holographic labels, deterring counterfeiting [9]. These products, when listed for sale, are enriched with their NFTs, serving as authenticity badges. The system leverages a private blockchain for recording product details, ensuring swift transactions and data integrity. A collateral system safeguards transit parties' interests, while a real-time tracking feature keeps buyers informed. Disputes are addressed through a robust resolution mechanism, backed

TABLE 2. Cost analysis considering distance in miles, gas units, and cost reductions.

Distance (miles)	Number of Transporters	Traditional System Cost per Product (USD)	Blockchain-based System Cost per Product (USD)	Blockchain Gas Cost (Gas Units)	Cost Reduction (%)
50-100	1	1.70	1.36	50,000	20%
100-250	2	2.68	2.14	60,000	20.15%
250-500	3	3.82	3.06	70,000	19.9%
500-750	4	5.15	4.12	80,000	20%
750-1000	5	6.50	5.20	90,000	20%

by a transparent voting process. The system's scalability is ensured through batching techniques and an efficient consensus mechanism. In the post-supply phase, the system facilitates product sales alongside their NFTs, emphasizing traceability and verifiable ownership. The table 1 provides a comparative analysis between the traditional (existing) system and the newly proposed product circulation system.

B. USER INTERFACE AND EXPERIENCE

In the proposed blockchain-based product circulation system, the focus on user interaction is paramount, ensuring that each stakeholder–buyers, sellers, transporters, and arbitrators–engages with a platform that is intuitive, efficient, and secure. The system's interface is meticulously designed to cater to the specific needs and activities of each user group, providing a seamless and user-friendly experience.

Buyers are greeted with a streamlined and informative browsing experience. Product listings are detailed and enriched with corresponding NFTs and digital twin information, allowing buyers to verify the authenticity of products effortlessly. The interface simplifies the verification process, presenting NFT details such as provenance, manufacturing data, and the product's supply chain journey comprehensively. The purchase process is designed for convenience, requiring minimal input from the buyer while providing real-time updates on product transit status and delivery timelines.

Sellers benefit from a user-friendly dashboard designed for efficient product listing and inventory management. The system simplifies the integration of physical products with their digital counterparts, guiding sellers through the NFT minting process to ensure accurate data representation. Moreover, sellers have access to robust analytics and reporting tools, enabling them to monitor sales trends, track product transit, and stay informed about the status of their products throughout the supply chain.

Transporters interact with a specialized logistics management interface, equipped with features tailored to their operational needs. This includes route optimization, transit status updates, and tools for verifying product authenticity, such as RFID tag scanning capabilities. The system keeps transporters informed and motivated by providing real-time notifications about incentives for timely and successful deliveries, alongside alerts for any discrepancies or issues that require immediate attention.

Arbitrators are provided with a comprehensive dashboard that centralizes dispute cases, streamlines the presentation of evidence, and supports an efficient voting and decision-making process. The interface is crafted to ensure clarity and structure in dispute resolution, making all necessary information and tools readily accessible to facilitate fair and prompt outcomes.

By prioritizing user-centric design, the system ensures that each stakeholder engages with a platform that not only meets their specific needs but also enhances the overall efficiency and transparency of the product circulation process. This approach is instrumental in fostering trust, encouraging system adoption, and ultimately driving the success of the blockchain-based product circulation system.

C. COST-BENEFIT ANALYSIS

In the realm of supply chain management, the adoption of a blockchain-based system represents a significant shift from traditional practices. This section provides a comprehensive cost-benefit analysis, highlighting the financial implications and the return on investment (ROI) for organizations considering this technological leap.

The initial investment in a blockchain-based system includes the development and deployment of smart contracts, integration of RFID and NFT technologies, and the establishment of the necessary infrastructure for a private or public blockchain. In contrast, traditional systems incur costs related to setting up centralized databases and implementing security measures against counterfeiting and fraud.

On the operational front, the blockchain system entails ongoing expenses such as transaction fees (notably gas costs in blockchain parlance), maintenance of the blockchain infrastructure, and periodic updates and security audits. Traditional systems, meanwhile, face recurring costs in data management, storage, and regular compliance checks.

The benefits of transitioning to a blockchain-based system are manifold. Organizations can expect increased efficiency and speed in transaction processing, thanks to the elimination of intermediaries and the automation of various processes. The enhanced security framework significantly reduces the risk of counterfeit products, bolstering the integrity of the supply chain. The transparency inherent in blockchain systems fosters trust among stakeholders, with real-time tracking and immutable records enhancing the dispute resolution process. Moreover, adherence to regulatory requirements is streamlined, and the brand's reputation is fortified through a demonstrable commitment to authenticity and quality [21], [22].

D. CONSTRAINTS

The proposed blockchain-based product circulation system, while innovative, requires significant technical expertise due to its intricate integration of blockchain, RFID, and holographic labels. This complexity not only demands specialized skills for implementation and maintenance but also incurs substantial initial setup costs, encompassing technological infrastructure, system design, and development. Moreover, as with any novel system, gaining public acceptance and trust is paramount. Stakeholders, especially end consumers, need to be convinced of the system's benefits, requiring transparent communication and potentially educational campaigns. Additionally, while the system has been designed for scalability, there remain concerns about its performance as transaction volumes surge, potentially leading to bottlenecks in processing speed and system responsiveness. These challenges highlight the need for meticulous planning and resource allocation for successful adoption [19].

E. PRACTICAL IMPLICATIONS AND USE CASES

The proposed blockchain-based product circulation system, integrating RFID with NFTs, offers a wide range of practical applications across various industries, demonstrating its potential versatility and effectiveness.

In the pharmaceutical industry, this system can be pivotal in combating counterfeit medications. By assigning unique NFTs linked to RFID tags on medication packages, it's possible to trace each product from production to patient. This approach not only reduces the risk of counterfeit drugs entering the supply chain but also enhances the efficiency of medication recalls. Implementing this system could initially face resistance from distributors due to its complexity, but this can be mitigated through comprehensive training and detailed documentation.

In the automotive sector, where counterfeit parts are a significant concern, the system can be utilized to improve traceability and reduce the prevalence of counterfeit parts. Each car part equipped with an RFID tag and linked to an NFT on the blockchain would allow manufacturers to track the part's journey through the supply chain. Integrating this system with existing supply chain infrastructures might pose a challenge, but it can be addressed through the development of custom APIs and interfaces for seamless integration with legacy systems.

For luxury goods and the art world, the system can serve as a powerful tool to authenticate products and artworks. Luxury brands can use it to curtail the circulation of counterfeits, thereby bolstering customer confidence. Artists and galleries can leverage the system to verify the authenticity of artworks, enhancing their value and reinforcing buyer trust. The challenge here lies in familiarizing stakeholders with the technology, which can be overcome through targeted educational initiatives and user-friendly interfaces.

In the agriculture sector, particularly for organic farmers, the system can provide transparent histories of produce. Consumers would be able to easily verify the organic origin and handling of the produce, increasing trust in organic labels.

These potential applications highlight the adaptability and effectiveness of the proposed system in addressing industry-specific challenges. While initial resistance and integration complexities are expected, they can be effectively managed through tailored solutions and proactive stakeholder engagement. The successful implementation of this system could revolutionize supply chain management, ensuring product authenticity, and enhancing transparency in global trade [16], [17], [20], [21], [22].

F. RESULTS

In our research, we conducted an experimental implementation of a blockchain-based product circulation system to validate its efficiency over traditional methods. The system was built using a combination of advanced blockchain technologies and programming tools, focusing on automating key supply chain processes and ensuring scalability and efficiency.

The core of our system is an ERC-721 smart contract, utilized for creating Non-Fungible Tokens (NFTs) for each product. These NFTs serve as digital twins, encapsulating essential product data and ensuring authenticity and traceability. The smart contract was developed using Solidity and deployed using Remix IDE, a powerful tool for Ethereum smart contract development.

To simulate real-world transaction processing, we integrated the system with MetaMask, a widely-used Ethereum wallet, and conducted tests on Polygon's Mumbai testnet, which has an average transaction time of 2-3 seconds. This approach allowed us to execute and monitor smart contract functions without incurring real-world costs.

The backend of our system, developed with Node.js and Express.js, interacted with the Ethereum blockchain through the ethers.js library. This setup was crucial for executing smart contract functions and handling various supply chain processes, including the collateral mechanism, incentive system, and dispute resolution.

A key feature of our system was transaction batching, implemented at the backend to test scalability. By grouping multiple transactions, we significantly reduced the load on the blockchain, leading to faster processing times and lower costs.

We meticulously recorded transaction times and costs under various scenarios, such as different numbers of transporters and distances. These metrics were crucial in demonstrating the system's efficiency. For example, in scenarios with increased transporters and longer distances, our blockchain-based system consistently showed reduced costs and faster transaction times compared to traditional systems.

The automation of supply chain processes, powered by the Ethereum blockchain and smart contracts, resulted in a highly efficient system. The ERC-721 smart contract for NFT creation played a pivotal role in ensuring product authenticity and streamlining the supply chain operations.

The table 2 showcases the cost analysis considering varying distances and the corresponding number of transporters involved. As the distance increases, the number of transporters also rises, leading to a proportional increase in costs for both systems. However, the blockchain-based system consistently offers a reduced cost per product compared to the traditional system. This cost efficiency can be attributed to the inherent advantages of blockchain, such as reduced need for intermediaries, transparent and tamper-proof records, and efficient consensus mechanisms.

VII. CONCLUSION

The integration of blockchain technology into the realm of product circulation and supply chain management heralds a transformative shift from traditional methodologies. Conventional systems, while functional, often grapple with vulnerabilities such as susceptibility to fraud, errors in property registration, and challenges in tracking and verification. Blockchain, with its inherent properties of immutability, transparency, and heightened security, offers a formidable solution to these challenges. While certain contemporary tracking tools might boast advanced security features, the decentralized nature of blockchain amplifies this security manifold, making it exceedingly challenging for malicious entities to compromise the system.

Furthermore, the essence of assets in the supply chain remains predominantly physical. As we endeavour to transpose these assets onto the blockchain, it becomes imperative to meticulously design the nexus between digital tokens and their corresponding physical entities. This ensures not just the security of these assets, but also their accurate representation and verification on the blockchain.

REFERENCES

[1] M. S. Islam, M. A. Rahman, M. A. B. Ameedeen, H. Ajra, Z. B. Ismail, and J. M. Zain, "Blockchain-enabled cybersecurity provision for scalable heterogeneous network: A comprehensive survey," *Comput. Model. Eng. Sci.*, vol. 138, no. 1, pp. 43–123, Jan. 2024, doi: 10.32604/cmes.2023.028687.

[2] F. Tian, "An agri-food supply chain traceability system for China based on RFID & blockchain technology," in *Proc. 13th Int. Conf. Service Syst. Service Manage. (ICSSSM)*, Jun. 2016, pp. 1–6 doi: 10.1109/ICSSSM.2016.7538424.

[3] M. M. Sheriff and A. D. John, "A secure blockchain based food supply chain management framework using hybrid IDEA algorithm," *Int. J. Syst. Syst. Eng.*, vol. 15, no. 5, Jan. 2025, doi: 10.1504/ijsse.2025.10059358.

[4] K. G. Gulen and A. Karaagac, "Agricultural food supply chain with blockchain technology: A review on Turkey," *J. Global Strategic Manage.*, pp. 13–28, Jan. 2024, doi: 10.20460/jgsm.2023.314.

[5] S. Saberi, M. Kouhizadeh, J. Sarkis, and L. Shen, "Blockchain technology and its relationships to sustainable supply chain management," *Int. J. Prod. Res.*, vol. 57, no. 7, pp. 2117–2135, Apr. 2019, doi: 10.1080/00207543.2018.1533261.

[6] M. Tajima, "Strategic value of RFID in supply chain management," *J. Purchasing Supply Manage.*, vol. 13, no. 4, pp. 261–273, Dec. 2007, doi: 10.1016/j.pursup.2007.11.001.

[7] H. R. Hasan and K. Salah, "Blockchain-based proof of delivery of physical assets with single and multiple transporters," *IEEE Access*, vol. 6, pp. 46781–46793, 2018, doi: 10.1109/ACCESS.2018.2866512.

[8] K. Toyoda, P. T. Mathiopoulos, I. Sasase, and T. Ohtsuki, "A novel blockchain-based product ownership management system (POMS) for anti-counterfeits in the post supply chain," *IEEE Access*, vol. 5, pp. 17465–17477, 2017, doi: 10.1109/ACCESS.2017.2720760.

[9] K. Michael and L. McCathie, "The pros and cons of RFID in supply chain management," in *Proc. Int. Conf. Mobile Bus. (ICMB)*, Sydney, NSW, Australia, Jul. 2005, pp. 623–629 doi: 10.1109/ICMB.2005.103.

[10] B. Unhelkar, S. Joshi, M. Sharma, S. Prakash, A. K. Mani, and M. Prasad, "Enhancing supply chain performance using RFID technology and decision support systems in the Industry 4.0—A systematic literature review," *Int. J. Inf. Manage. Data Insights*, vol. 2, no. 2, Nov. 2022, Art. no. 100084, doi: 10.1016/j.jjimei.2022.100084.

[11] D. Koutras, V. Malamas, P. Kotzanikolaou, and T. Dasaklis, "A risk assessment methodology for supply chain tracking services," in *Proc. Int. Conf. Cyber Manage. Eng. (CyMaEn)*, Bangkok, Thailand, Jan. 2023, pp. 555–559, doi: 10.1109/CyMaEn57228.2023.10051006.

[12] D. Geethanjali, R. Priya, and R. Bhavani, "Smart contract document authentication for digital clothing design specification based on blockchain and QR code," in *Proc. Int. Conf. Innov. Comput., Intell. Commun. Smart Electr. Syst. (ICSES)*, Chennai, India, Jul. 2022, pp. 1–9 doi: 10.1109/ICSES55317.2022.9914106.

[13] S. Johny and C. Priyadharsini, "Investigations on the implementation of blockchain technology in supplychain network," in *Proc. 7th Int. Conf. Adv. Comput. Commun. Syst. (ICACCS)*, vol. 1, Coimbatore, India, Mar. 2021, pp. 1–6, doi: 10.1109/ICACCS51430.2021.9441820.

[14] J. Mehta, D. Mehta, J. Jain, and S. Dholay, "Asset tracking system using blockchain," in *Proc. Asian Conf. Innov. Technol. (ASIANCON)*, Pune, India, Aug. 2021, pp. 1–7, doi: 10.1109/ASIANCON51346.2021.9544543.

[15] R. Verma and N. Dhanda, "Application of supply chain management in blockchain and IoT—A generic use case," in *Proc. 13th Int. Conf. Cloud Comput., Data Sci. Eng. (Confluence)*, Noida, India, Jan. 2023, pp. 405–410, doi: 10.1109/Confluence56041.2023.10048815.

[16] I. R. Barron and G. Sharma, "Toward CanvasChain: A block chain and craquelure hash based system for authenticating and tracking fine art paintings," in *Proc. Int. Symp. Electron. Imag., Media Watermarking, Secur., Forensics*, 2020, p. 399 doi: 10.2352/ISSN.2470-1173.2020.4.MWSF-399.

[17] M. Naz, F. A. Al-Zahrani, R. Khalid, N. Javaid, A. M. Qamar, M. K. Afzal, and M. Shafiq, "A secure data sharing platform using blockchain and interplanetary file system," *Sustainability*, vol. 11, no. 24, p. 7054, Dec. 2019, doi: 10.3390/su11247054.

[18] R. Kumar and R. Tripathi, "Traceability of counterfeit medicine supply chain through blockchain," in *Proc. 11th Int. Conf. Commun. Syst. Netw. (COMSNETS)*, Bengaluru, India, Jan. 2019, pp. 568–570 doi: 10.1109/COMSNETS.2019.8711418.

[19] D. M. Lambert and M. C. Cooper, "Issues in supply chain management," *Ind. Marketing Manage.*, vol. 29, no. 1, pp. 65–83, Jan. 2000, doi: 10.1016/s0019-8501(99)00113-3.

[20] T. Hepp, P. Wortner, A. Schönhals, and B. Gipp, "Securing physical assets on the blockchain: Linking a novel object identification concept with distributed ledgers," in *Proc. 1st Workshop Cryptocurrencies Blockchains Distrib. Syst.*, Jun. 2018, pp. 60–65, doi: 10.1145/3211933.3211944.

[21] M. M. Queiroz, R. Telles, and S. H. Bonilla, "Blockchain and supply chain management integration: A systematic review of the literature," *Supply Chain Manag., Int. J.*, vol. 25, no. 2, pp. 241–254, Aug. 2019.

[22] P. Gangwani, A. Perez-Pons, S. Joshi, H. Upadhyay, and L. Lagos, "Integration of data science and IoT with blockchain for Industry 4.0," in *Blockchain and its Applications in Industry 4.0*. Singapore: Springer, 2023, pp. 139–177.

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