

Revolutionizing Healthcare Supply Chains with a Blockchain Framework for NFT-Based Product Certification and Inventory Management

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Abstract—The proposed framework leverages Non-Fungible Tokens (NFTs) to revolutionize supply chain management by ensuring product authenticity. Each product document stored in a repository is minted as an NFT. The NFT is a digital twin of the product's certification, containing metadata for tracking its origin, authenticity, and key details. When a buyer verifies the product's authenticity, the NFT is burned as a final step, ensuring that the product cannot be re-certified without a new issuance. This framework creates a transparent, tamper-proof, and decentralized system to enhance trust and accountability in the supply chain. By integrating the Ethereum-based PureChain network and smart contracts, this solution benefits from high availability, immutability, and the ability to automate key processes. The system verified and retrieved the base URI of a designated product identity (ID) whose NFT was stored in a GitHub repository. A vulnerability check of the smart contract codes with `solidcheck.io` shows that the smart contracts are 84% secured with no serious security threats, as all considerations were made in the contract code design.

Index Terms—PureChain, NFT, Verification, Smart Contract, Digital Twin and Inventory Management.

I. INTRODUCTION

Supply Chain Management (SCM) involves coordinating goods, services, information, and finances from suppliers to consumers, covering the entire product or service lifecycle, from raw material acquisition to post-sale services. The healthcare supply chain applies SCM principles to surgical, medical, pharmaceutical goods, medical devices, and laboratory and clinical equipment, supporting practitioners like physicians, nurses, and veterinarians [1], [2]. Traditional supply chains lacked advanced technology, leading to shortcomings in traceability, transparency, reliability, cost efficiency, integrity, and sustainability due to insufficient tracking capabilities [3].

The absence of traceability and transparency raises questions regarding the security and uniqueness of healthcare products, which now increases the incidence of substandard fabrication and counterfeiting in the healthcare sector. It's interesting to note that a new era of data security across several industries has been ushered in by the rise of blockchain as a technology trend [4]. Blockchain technology can be used to exchange and securely preserve sensitive medical data. To

guard against record tampering, the architects of a recently proposed medical information management system decided to put a cryptographic hash of the record on the blockchain [5] [6]. Nakamoto, in 2008, defined the blockchain as a network of interconnected, cryptographically protected records that are highly resistant to change [7]. This technology facilitates the decentralized storage of data by users. Blockchain, a distributed immutable ledger technology, was established as the supporting architecture for cryptocurrencies. It comprises a series of blocks linked to one other by a hash, a type of cryptographic signature [8].

This paper presents a framework for NFT-based product certification and inventory management in the healthcare supply chain, leveraging blockchain's decentralization to enhance trust, traceability, and security. The design includes two smart contracts: an ERC721 contract for minting NFTs on Ethereum, which also returns the current block timestamp for security and verification, and a second contract for inventory management, product verification, supply control, and access management. Role-based access control enables authorized addresses to mint NFTs and perform specific functions. The system addresses overstocking and understocking in the healthcare industry, ensuring cost efficiency and accurate record-keeping. Deployment utilized the Ethereum-based PureChain network, selected for its zero transaction costs and smart auto-mining capabilities [9].

The contribution of this work includes the following:

- 1) Providing Non-Fungible Tokens NFTs as a digital certificate for product authentication and certification.
- 2) Provide a smart system that automates inventory management in the healthcare supply chain.
- 3) Provide a trusted decentralized system to enhance traceability, immutability, and security in the healthcare supply chain.

The rest of the paper is organized as follows: Section II discusses some related works, section III provides a detailed methodology of the proposed design, section IV discusses the results, and section V states the conclusion and future work.

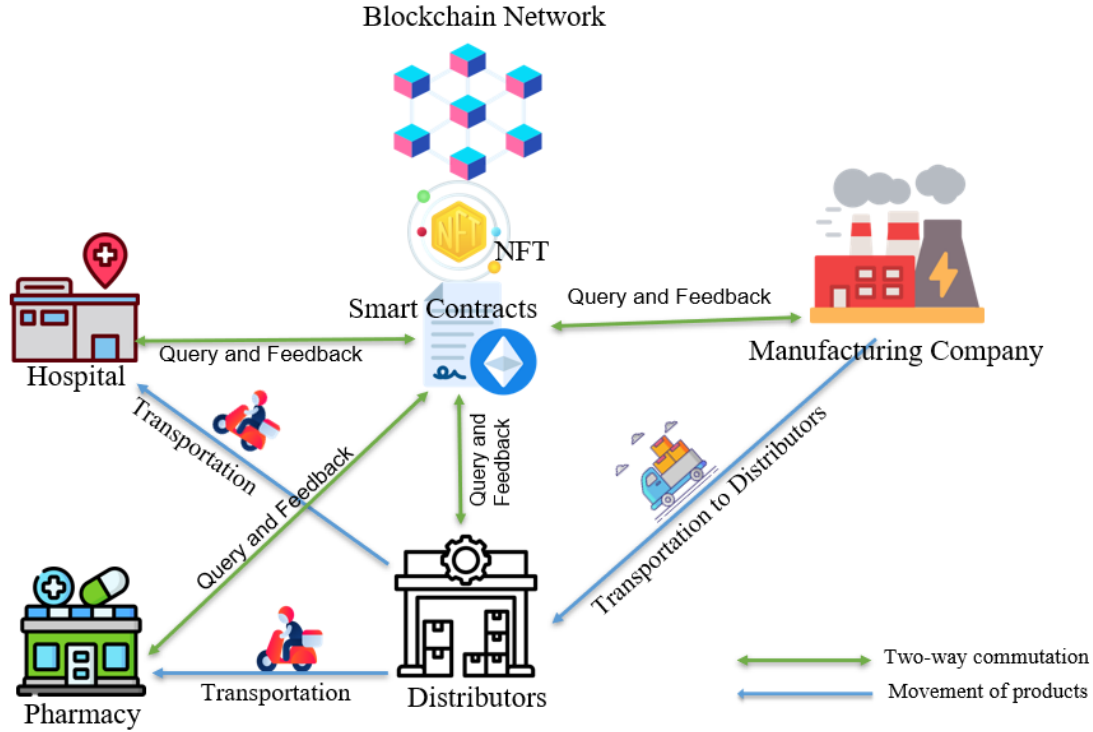


Fig. 1. The Proposed System Model for the Blockchain NFT-based Product Certification and Inventory Management in Healthcare Supply Chain.

II. RELATED WORKS

This section reviewed some papers that employed blockchain in various healthcare supply chains. To automate the forward supply chain of COVID-19 medical equipment and maintain safe and transparent information exchange among waste management stakeholders, the authors [10] propose a decentralized blockchain-based system. The solution securely handles data on trash disposal and the supply chain by merging decentralized interplanetary file system (IPFS) storage with the Ethereum blockchain management system. They also create algorithms that set guidelines for managing COVID-19 waste and specify sanctions for non-compliance, encouraging traceability and reliability throughout the process. The use of blockchain technology in conjunction with information hiding techniques to improve data privacy and security of the PPE supply chain during the COVID-19 pandemic was explored by Elazaoui A. et al. in their work titled Blockchain-Based Distributed Information Hiding Framework for Data Privacy Preserving in Medical Supply Chain Systems [11].

The authors of Musamih et al. proposed a decentralized off-chain storage solution and smart contract-based Ethereum blockchain technology for effective product tracing in the healthcare supply chain. The smart contract gives all parties access to a safe, unchangeable history of transactions, ensures the provenance of data, and does away with the need for middlemen [12]. [13] proposed a general framework to automate procedures and information sharing utilizing Ethereum smart contracts and decentralized storage systems. Additionally, it

provides specific algorithms that capture the interactions between supply chain participants.

The papers above discussed traceability, decentralization, data privacy, and security; we provided all these characteristics in our system and included the ERC721 token protocol that mints NFTs unique to individual products in the supply chain. This protocol added more security and trust to our system. We also included an automated inventory management system for cost management to cut wastage due to excess stock.

III. SYSTEM METHODOLOGY

The proposed system model Fig. 1 shows the design architecture and the connections between stakeholders in a healthcare supply chain. The green arrows represent the two-way communication between smart contracts and stakeholders, while the blue arrows represent the movement of products from the producers to the hospitals or pharmacies. The system is designed to guarantee trust among the healthcare supply chain stakeholders. Two smart contracts were designed with solidity on Remix IDE for Web3 development and deployed on the PureChain network; one is responsible for minting the NFTs linked to the product document, which serves as a digital twin to the product's document; it also registers the product's details such as product name, manufacturing date, expiring date, batch number, and certification ID. The second smart contract manages product inventory and grants permission to accept or reject product supply. Fig. 2 (A) illustrates the process of product registration to the smart contract, minting, verification, and accept or reject, while

(B) represents inventory management, including stock count, reordering, or rejecting orders. The manufacturing company is responsible for registering the product and minting the NFT for the product certificate. The product data is then stored in an off-chain storage system (IPFS or GitHub, in our case). The Content identifier (CID) is then stored in the Purechain network. The product is delivered to the verifier (buyer) and can be verified using the CID generated for the particular product by the IPFS. In contrast, the NFT associated with the product certificate burns out after product confirmation. The first contract, the ERC721, was called into the inventory management smart contract. Below are detailed explanations of the two smart contract codes and their functions.

A. NFT Token Contract

The manufacturer uploads the product document to a repository such as IPFS or GitHub. The document's hash and product details are passed to the *mintNFT* function, creating an NFT. It is designed with an ERC721 (non-fungible token) protocol with additional functionalities like access control, token freezing, and vote management. OpenZeppelin libraries were Incorporated, adding standard and extendable functionalities for security and efficiency. The following is a detailed breakdown of the smart contract as illustrated in Algorithm 1, including components and functionalities:

1) Inherited Libraries and Contracts:

- ERC721 (from OpenZeppelin): Provides the standard implementation of the ERC721 non-fungible token (NFT), enabling minting, transferring, and ownership of unique tokens.
- ERC721 Burnable: Extends ERC721 to allow token burning, effectively removing a token from circulation.
- Access Control: Adds role-based access control functionality, allowing the assignment of roles that govern permissions for specific functions in the contract.

2) Contract-Specific Functions:

- MINTER ROLE: This function grants permission to mint new tokens.
- FREEZER ROLE: This function freezes tokens and prevents their transfer.
- DEFAULT ADMIN ROLE: This is the admin role with control over granting and revoking other roles.
- Product Details Struct: Stores information associated with a token, including product name, batch number, manufacturing date, expiring date, and certification ID.
- Mappings: Each product detail is mapped with its token identity.
- frozen Tokens: Tracks whether a token is "frozen" (i.e., cannot be transferred).
- default Admin: Receives DEFAULT ADMIN ROLE and FREEZER ROLE permissions.
- minter: Is granted the MINTER ROLE to allow minting of new tokens.

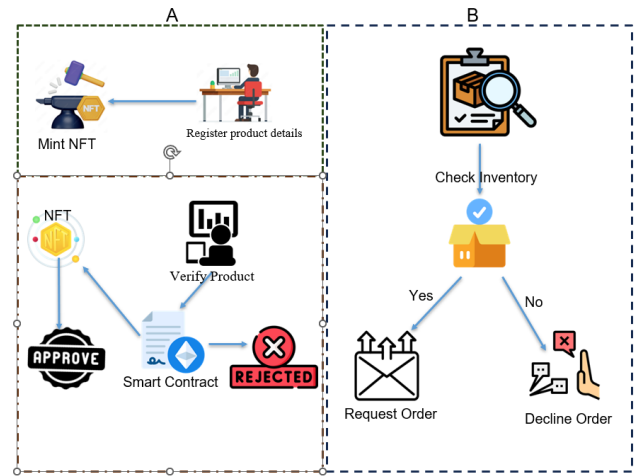


Fig. 2. Illustration of smart contract actions: Part A showing registration, NFT minting, and product verification. Part B shows Inventory management.

Algorithm 1 Token Minting and Management

Require: Initialize Token Minting

Setup: Roles (DEFAULT ADMIN, MINTER, FREEZER).

Base URI: Return <https://shorturl.at/mLSui>.

Mint Token:

Require: Input: *to*, *tokenId*, product details.

if Caller has MINTER ROLE **then**

Mint token to *to*, store details in *productDetails[tokenId]*.

end if

Token Existence:

Require: Input: *tokenId*.

Return *true* if token exists, else *false*.

Clock Functions:

Return *block.timestamp* or "mode=timestamp".

=0

- Constructor: The constructor sets the initial values and grants specific roles, initializes the contract with the ERC721 token name and symbol and initializes the EIP-712 domain for off-chain signatures.

- baseURI: Overrides the base URI function from ERC721. It defines the base URI that points to the project's GitHub repository for token metadata. eg `baseURI "https://github.com/Gozie01/HealthcareCert.git"`.

- MintNFT: Mints a new token to a specific address with an associated *tokenId*. Also record the Product Details (e.g., product name, batch number) for the token. Can only be executed by accounts with the MINTER ROLE.

- verify And Retrieve Token: Verifies that the provided product details match the stored details for a specific token. If all details match, it returns the base URI and 'true'; otherwise, it returns an empty string and 'false.'

- Uses 'keccak256' hashing for string comparison to ensure accurate matching.

- 8) token exists: Internal function to check if a token exists by querying its owner using ownerOf. Returns 'true' if the token exists; otherwise, 'false.'
- 9) freeze Token: Freezes a specific token, preventing its transfer. This can only be executed by accounts with the FREEZER ROLE. The token must exist to be frozen.
- 10) is Frozen(): Checks if a token is frozen. Requires the token to exist before checking its frozen status.
- 11) update(): Updates the internal state for governance votes (from ERC721 Votes), invoked when tokens are transferred or ownership changes.

B. Inventory Manager Contract

The NFT smart contract was imported in this smart contract; see Algorithm 2. The key features of this smart contract include the following:

- 1) Add Products: Admin can add new products with specified minimum and maximum thresholds.
- 2) Update Quantity: Admin can update the quantity of a product. If the amount exceeds the maximum threshold, it will revert.
- 3) Place Order: Admin can place orders for products. If the order drops the quantity below the minimum threshold, it triggers a reorder.
- 4) Reject Order: Admin can reject an order if the verification does not match or when there is enough at the store.
- 5) Event Emission: For better tracking, events are emitted for reorders, order rejections, and payment processing.

Algorithm 2 Inventory Management

Require: Initialize Inventory Manager

Role Setup: Grant DEFAULT ADMIN and MANAGER roles to msg.sender.

Add Product:

Require: Input: name, minThreshold, maxThreshold.

Require: msg.sender is ADMIN/MANAGER.

if name is non-empty and minThreshold > 0 < maxThreshold **then**

 Generate productId, ensure product doesn't exist.

 Initialize products[productId] and map name to productId.

 Emit ProductAdded.

end if

Get Product Details:

Require: Input: name. Output: Product.

Require: msg.sender is ADMIN/MANAGER.

 Retrieve productId and return products[productId] if it exists.
 =0

addresses with the token ID can verify the product's authenticity. The NFT minting is designed to increase after minting a particular product to ensure continuity. Buyers retrieve the NFT metadata and verify its authenticity using the verify function; if successful, the smart contract executes the burnNFT function. Once the NFT is burned, the product is marked as verified, and its document cannot be reused or altered. For testing the proposed framework, a certificate was designed and stored in a GitHub repository with this link "<https://GitHub.com/Gozie01/HealthcareCert.git/>" to test the system, and the GitHub address was used to mint the NFT for the certificate. The code for the design can be accessed through this GitHub link: <https://github.com/Gozie01/HealthcareSupplyChain.sol.git>.

IV. RESULTS

The proposed system was designed with solidity on Remix IDE and was deployed to the PureChain network. Fig. 3 displays the user interface, with all the input and view functions. Only the default admin address, which doubled as the default minter, could mint and manage the contract and assign roles to others as msg.sender. The second contract managed inventory, such as supply acceptance, rejection, and reordering. The NFT associated with the product certificate burnt out immediately after the receiver updated his record, and the token ID could not return the token address.

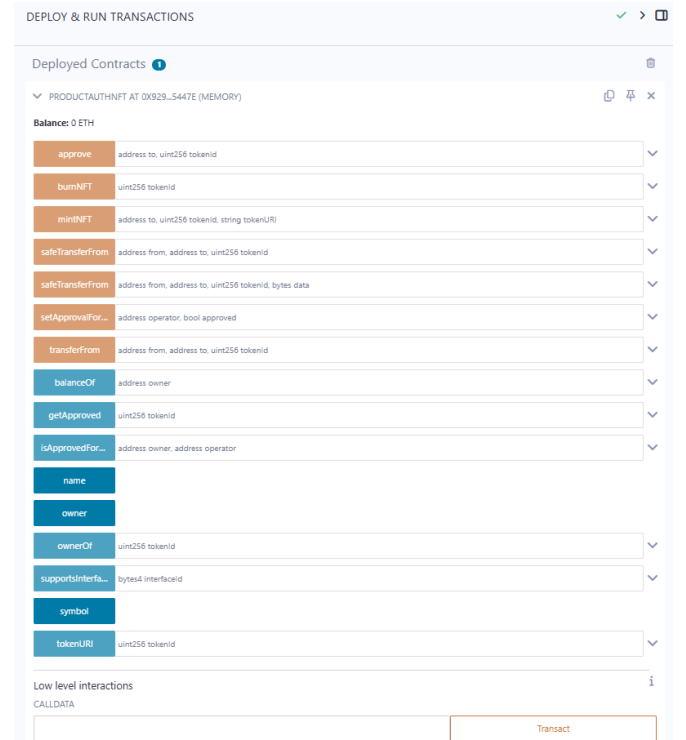


Fig. 3. The Smart Contract Interface showing both view and input functions.

The *HEALTHLogistics* contract implements the PureChain-based product certification system that uses NFTs to represent individual healthcare products. Key functionalities include:

The system is designed for healthcare logistic management that uses an ERC721 token to mint an NFT for a particular health product document. The NFT is a digital twin of the product document that contains all the product details and is stored in secured storage such that only the

Minting Product NFTs only authorized minters mints NFTs, embedding detailed product information such as name, batch number, manufacturing date, expiration date, and certification ID. **Product Verification** token holders or third parties can verify the accuracy of the stored product details. The token can be "frozen" if discrepancies are found to prevent further transfers. **Secure Transfer Mechanism** The contract prevents frozen tokens from being transferred, ensuring only valid tokens can circulate in the system. The **InventoryManager** contract is designed to manage inventory efficiently with robust access controls and rate-limited operations. Key functionalities include: **Product Management** admins can add, remove, and update products with specific thresholds (minimum and maximum). **Order Handling** The system supports order placement and rejection, ensuring that inventory levels remain within predefined thresholds. **Access Control** Role-based permissions (DEFAULTADMINROLE and MANAGERROLE) ensure only authorized users can execute critical functions.

The smart contract code was scanned for vulnerabilities using solidcheck.io Fig. 4 shows that the result is 84% secured with no critical threat found. A reentrancy guard was activated to prevent any reentrancy attack, and the contract was made pausable in the case of emergencies. All transactions are timestamped to improve the security.



Fig. 4. The Smart Contract code Vulnerability scan with Solidcheck.io.

V. CONCLUSIONS

A system for enhancing the healthcare supply chain was developed to address trust and security challenges faced by stakeholders. The system ensures transparency and traceability while preventing fraud by utilizing NFTs as digital certificates for product verification. The **HEALTHLogistics** contract facilitates secure product representation and verification, while the **InventoryManager** contract automates inventory control, resolving issues like overstocking, understocking, and product shortages. Together, these contracts integrate stakeholders into a unified, decentralized network, achieving tracking, traceability, and trust, thereby enhancing the reliability and efficiency of healthcare supply chain management. This framework can potentially revolutionize supply chain management by ensuring authenticity, reducing fraud, and fostering stakeholder trust.

Future work will include the integration of Internet of Things (IoT) devices to track the location and condition of products while in transit, as well as real-time updates for all healthcare stakeholders. Artificial intelligence systems would also help to analyze and predict demand and supply

patterns based on the available information. It will also detect tempering, intrusion, and attacks.

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