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IMPLEMENTING BLOCKCHAIN FOR DRUG TRACEABILITY IN HEALTHCARE SUPPLY CHAINS: A SECURE AND TRANSPARENT SOLUTION

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ABSTRACT: Global supply networks connect numerous organizations and locations to support lifesaving medical operations. Information generated by complex systems may be inaccurate, obscure, and unreliable. Problems in the supply chain result in the widespread availability of harmful and expensive counterfeit drugs. Several investigations are currently underway to learn the logistics of getting life-saving medications to those who need them. Tracking pharmaceutical items throughout their supply chains is essential for preventing the production of counterfeit medicines and ensuring the safety of patients. Most healthcare supply chains rely on centralized track-and-trace systems, which compromise patient privacy, transparency, and credibility. Monitoring the healthcare supply chain is simplified by Ethereum's smart contracts and off-chain storage autonomy. All participants in a smart contract are able to verify the origin of data thanks to the immutable ledger of transactions, which eliminates the need for intermediaries. Investigating the logic behind the answers and how the system works. We test, evaluate, and examine the cost and security of the system to provide a more transparent medicine supply chain.

KEYWORDS:Blockchain,drugcounterfeiting,traceability,healthcare,supplychain,trust,security.

1. INTRODUCTION

Pharmaceutical companies, medical device manufacturers, hospitals, clinics, and patients themselves are all part of the intricate healthcare supply chain. The lack of information, the centralization of power, and the presence of competing interests make it difficult to oversee the supply chain in this network. Issues like the recent COVID-19 outbreak can be traced back to the healthcare system's intricacies, which allow for the introduction of counterfeit medications. Fake medications are often manufactured or labeled to seem like the real thing on purpose. These drugs may be contaminated, outdated, have insufficient or incorrect amounts of intended active pharmaceutical ingredients (API), include contaminants, or have been used for purposes other than those intended. Some counterfeit drugs are poorly made or have flawed formulations.

About 30 percent of medicines in developing nations are counterfeit, according to the Health Research Funding Organization. According to a new report by the WHO, counterfeit medicines are a leading cause of death in developing nations, especially among youngsters. Fake drugs are dangerous to people and expensive for the pharmaceutical industry. The counterfeit drug trade in the United States is quite costly. Figure 1 depicts a typical distribution process for pharmaceuticals. Manufacturers of FDA-approved medications rely on API suppliers. Drugs are packaged by the thousands every day by pharmaceutical manufacturers and repackagers. The primary distributor sources and ships various lots to pharmacies in response to fluctuating demand, while secondary distributors handle bulk shipments. Distributors and third-party logistics providers like FedEx and UPS utilize their own trucks to transport pharmaceuticals to their respective destinations.

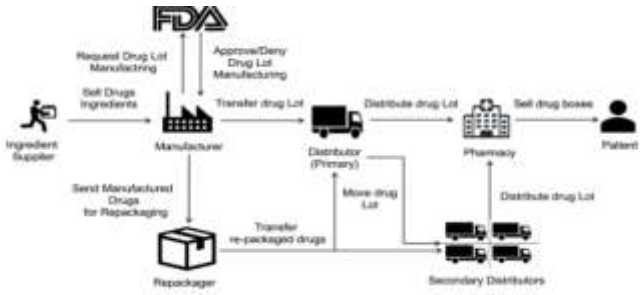

FIGURE1. Drug supply chains takeholders and their relationships.

Due to the intricate nature of the healthcare supply chain, counterfeit medications are often used. Because of the difficulty of obtaining medications, they might avoid distribution. Strong control, regulation, and tracking are required to reduce the prevalence of counterfeit medical supplies in the healthcare supply chain.

The effort of making it feasible to monitor and validate the origin and movement of pharmaceuticals is actively supported and supervised by nations around the world. Have a peek at the USA for example. Electronic and digital tracking is required by the Drug Supply Chain Security Act so that pharmaceutical firms can monitor the flow of prescription medications across the United States. Since 2008, China has mandated that all parties involved in the distribution of pharmaceuticals must keep records of the products' movements between storage facilities. Proof of ownership and authenticity of the store has been provided.

Each node in the blockchain contains the genesis block as well as any additional blocks that are linked to the longest chain, much like a linked list. In the realms of the Internet of Things (IoT), electronic government (eGov), and electronic document management (EDM), numerous helpful apps have been developed in recent years. A distributed blockchain database and hash-based cryptographic proof are employed.

This article describes preliminary efforts to implement blockchain technology into the pharmaceutical supply chain in an effort to increase transparency. Blocks make the modifications to the ledger, working from the oldest transaction to the most recent one. Because pharmaceutical supply chains are so intricate, we recommend implementing end-to-end drug traceability with the use of blockchains. Our medicine supply chain also includes the Food and medicine Administration, the retailer, the manufacturer, the wholesaler, the retailer's pharmacy, and the end user. Only suppliers, manufacturers, and wholesalers exist in other models. Pharmacists are considered to be on the fringe of the pharmaceutical supply chain. The slash character () is seen here.

It's obvious that there's a close relationship between our customers, on-chain assets, smart contracts, and distributed file storage. Since we weren't referring to the relationships between stakeholders, we had to come up with our own language to describe them. Due to the rapid nature of SMS communication and the ongoing monitoring of smart contracts, there is no lag time. DApp users will be notified of any changes in title thanks to the smart contracts associated with individual drug lots. Proof of drug receipt is required in smart contracts between manufacturers, distributors, and suppliers [20]. Inaccurate, sluggish, and irreversible records. When all was said and done, we looked at the method's total cost and how safe its supply chain was.

2. RELATEDWORK

While we are working on other issues, eliminating the manufacturing and circulation of counterfeit medicines and medical supplies is our top priority. We differentiated between blockchain-based and conventional approaches.

TRADITIONAL EFFORTS FOR DRUG TRACEABILITY

Obtaining complete data about anything by tracking its official identification across its entire lifespan. Resources are defined as anything in a supply chain that can be identified and located at any given time. TRU (Transaction Reporting Unit) tracking is the process of keeping a record of all the transactions that have taken place. The TRU (Temperature Recording Unit) must have multiple identifiers for supply chain visibility. Understanding the identities, relationships, and characteristics of TRUs is made possible by means

of such traceability systems. In the past, information about items was gathered with the help of barcodes, RFID IDs, wireless sensor networks (WSNs), and electronic product codes (EPCs). At each stage of the supply chain, the GS1 tag data is used to determine who is in possession of what. By using a mobile app with integrated GDSN technology, patients can verify the authenticity of a product. Using this system, consumers can verify their claims of ownership. Healthcare providers and pharmacists employ barcode scanning to ensure only high-quality supplies make it to their shelves.

BLOCKCHAIN-BASED SOLUTIONS FOR DRUG TRACEABILITY

Because of the lack of transparency in the traditional centralized techniques, the central authority can make changes to data without notifying the appropriate parties. The blockchain's immutability and transaction recording capabilities are only two of its numerous advantages. Blockchain technology is used in the business world since it cannot be altered. We have doubts regarding the source and transparency. Supply chain information at a high level is typically well-organized and simple to locate. The names of suppliers, the locations of production facilities, and the product components are all factors to consider when developing a supply chain strategy. Traceability requires the identification of the correct component, the establishment of transparent rules for communicating with peers, the collection and creation of accurate data, the storage of that data on a platform, and its subsequent dissemination. For precise information, familiarity with the pipeline is essential. Blockchain cryptography is at the heart of a new decentralized, auditable system for monitoring drug distribution. Mettler said they will implement blockchain-based solutions in the medical field, however they provided no proof or specifics. Kurki suggested that the pharmaceutical industry could gain from incorporating blockchain technology into their operations. Only broad ideas were broken down. An anti-counterfeiting solution built on Ethereum was demonstrated by Muniandy and Ong Tze Ern. When smart contracts are poorly reviewed or implemented, they are useless.

The drug ledgers maintained by Huang's group ensure the integrity of the system by recording authorized and confidential traceability data for all parties involved. The entire drug supply chain's transactions are recorded. To merge, split, or otherwise manipulate medical files, UTXO data larger than 16 bits is required. The convenience of the UTXO data structure in terms of design, storage requirements, and space use was recently investigated.

His given name is Faisal. It was proposed that Hyperledger be used to monitor the distribution chain of medications. The authors demonstrated that they could enhance data transmission rate, response time, and resource efficiency while working in a constrained network setting. The ad focused largely on blockchain scalability, an often-discussed topic. To ensure the integrity of the main blockchain's transactions and hashed data, Hulse Apple resorted to a second blockchain. Because each object has its own record in the blockchain, it's difficult to make changes to private keys.

3.BLOCKCHAIN-BASED DRUG TRACE ABILITY SYSTEM FOR PHARMACEUTICAL SUPPLY CHAINS

Because of the lack of transparency in the traditional centralized techniques, the central authority can make changes to data without notifying the appropriate parties. The blockchain's immutability and transaction recording capabilities are only two of its numerous advantages.

Feedback on how to view and maintain track of information was not as precise or clear as it could have been. Data is typically readily available and readily apparent at the top of the supply chain. In order to properly map supply chains, you must have access to essential information such as supplier names, facility locations, product components, and more. Careful selection of a component, establishment of communication

standards with partners, collection and creation of trustworthy data, storage of said data on a platform, and dissemination of said data are all necessary steps toward achieving traceability. You'll need supply chain management expertise to obtain detailed data.

Drug ledgers, according to Huang and others, improve processes by providing public and private information to all parties involved. The entire drug supply chain's transactions are recorded. In order to sort, rearrange, and retrieve drug trade records, additional UTXO data is required. A recent investigation examined the storage requirements, programming complexity, and cost of the UTXO data format's state space.

His given name is Faisal. Hyperledger was proposed as a tool for monitoring drug distribution chains. Their network isn't very large, and their technology hasn't been field-tested, but they've managed to increase throughput, decrease latency, and maximize resource use anyhow. The advertising largely focused on blockchain scaling, which is a trending subject in the industry. To ensure the integrity of the main blockchain's transactions and hashed data, Hulse Apple resorted to a second blockchain. Since every item has its own blockchain record, private keys cannot be altered. This unclear and unreliable plan ensures the security of the supply chain.

Investigating the potential of distributed ledger technology in the distribution of healthcare products. Technology companies Cisco, IBM, Accenture, Intel, Bloomberg, and Block investigate the origins of arsenic and its path into the human body. A distributed ledger can ensure compliance with the DSCSA and other industry regulations. Farma Trust tracked the distribution of pharmaceuticals using Ethereum, Hyperledger, and Quorum. The ability to enforce rules and restrict the sequence in which transactions can occur is one of quorum's many advantages. Bulk pharmaceutical packaging is the final stage of production..

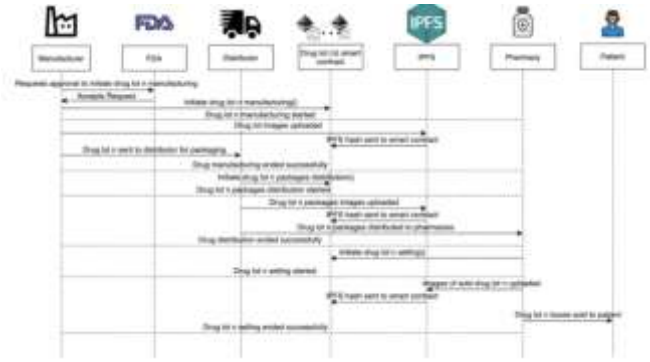

FIGURE3.

A smart contract's components and their interplay are visualized in a sequence diagram.

Distribution:

An illustration of the interconnected nature of smart contracts. Distributors will upload an image of the packed pharmaceutical Lot to IPFS, a decentralized file store system, whenever the Lot is ready for shipment. After that, IPFS will assign a hash to the smart contract. At this point, the containers containing the batches of drugs are delivered to the pharmacies.

Sale/Consumption

Customer contacts with pharmacies are depicted in the diagram's final section. Lot boxes will be sold by the pharmacy, and the suppliers will be informed. When a photograph of the medicine package is uploaded to IPFS, the smart contract is hashed. Deal is finalized after patient receives Lot pack.

COMPARISON OF PROPOSED SOLUTION WITH EXISTING SOLUTIONS

In this section, we'll have a look at some alternatives to the proposed system for a transparent pharmaceutical drug supply chain. As can be shown in Table 1, no single entity can exert control over the data in a decentralized system. An additional vital component of

TABLE1. Compariso nbetween ourproposed solution and then on-blockchainsolutions.

	Smart-Track	Data-Matrix Tracking System	NFC	Proposed Solution
Decentralized	No	No	No	Yes
Resilience	No	No	No	Yes
Integrity	No	No	No	Yes
Tracking and Tracing	Yes	Yes	Yes	Yes
Security	No	No	No	Yes
Transparency	No	No	No	Yes

Because there are fewer potential failure points in a decentralized system, our infrastructure is more robust. Blockchain's immutability guarantees the integrity of the data it stores. Evidence of any

kind can be found in a journal. Unstructured data is secure since it is difficult to alter. Supply chains rely heavily on open communication between participants. All users of our system have unrestricted, secure access to audited transactions. Track and trace is included by default with every Table 1 choice, and some even contain additional functions like

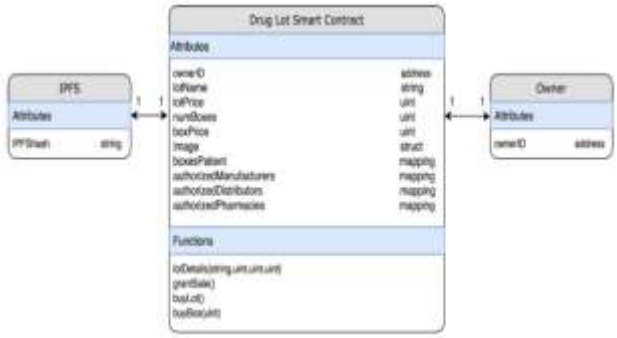

TABLE2. Comparison between ourproposed solution and other blockchain-basedsolutions.

	Our Solution	Huang et al [34]	Faisal et al [32]
Blockchain Platform	Ethereum	Bitcoin	Hyperledger-Fabric
Mode of Operation	Public Permissioned	Public Permissioned	Private Permissioned
Currency	Ether	BTC	None
Off-Chain Data Storage	Yes	No	No
Programmable Module	Smart Contract	None	Docker Container

Hyperledger Fabric is a blockchain infrastructure platform. Our system makes use of public permissions, while Hyperledger Fabric relies on private ones. We employ Ethereum's native currency, Ether, in our operations.

4.IMPLEMENTATION OF PROPOSED TRACE ABILITY SYSTEM

The solution is constructed with Ethereum. Since Ethereum is a public database, anyone can access it. As a web-based application, Remix IDE facilitates the development of smart contracts by providing the opportunity to test and debug Solidity code. Anyone can view the entire code1.

IMPLEMENTATIONDETAILS

The manufacturer will use the smart contract to kick off the supply chain-wide pharmaceutical Lot event. Even newcomers to the network will be able to monitor the status of any given pharmaceutical lot because to the ledger's ongoing recording of events. Images uploaded to an IPFS Lot can be viewed by the team. The creator will let buyers know when The Lot is ready to be packaged and sold. Information about a lot's owner can be found in the lot's sales record. To keep things as straightforward as possible, the medical Lot smart contract does not require FDA approval prior to implementation.

Organizational relationships in smart contracts are depicted in Figure 4. Figure 4 depicts the owner being located with the use of smart contracts on the Ethereum network. Smart contracts for drug lots instead display locations as addresses to protect the privacy of individual owners. The transfer of ownership of Medicine Lots is recorded in the blockchain. Each drug's name, price, image, and package may be viewed in detail on smart contracts. Three entity mappings have been approved so far.

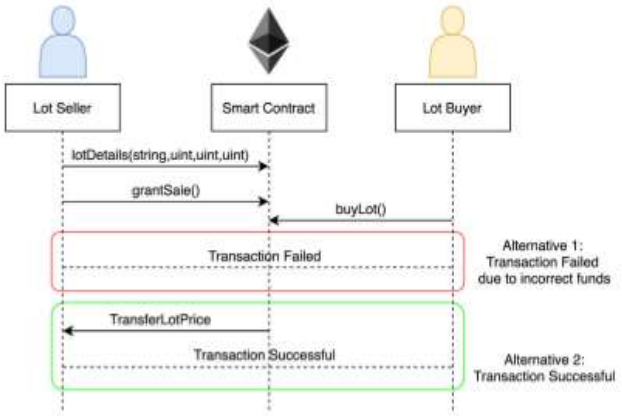

FIGURE5. Functioncalls and events for two different cenarios for Lotsale.

Drug transit and business deals were agreed upon. Smart contracts regulate the manufacturing and exchange of parcels. Name, price, number, and cost are all necessary components of batch data. IPFS allows manufacturers to transmit photos and get their corresponding hashes. Since each Lot only transmits a single image, there is a one-to-one relationship between intelligent contracts and IPFS.

negotiating the purchase of a home with the seller. A well-oiled supply chain integrates pharmacy, transportation, and manufacturing. The figure's series diagram depicts both of these cases. The seller stores the chain hash, data about the item, and maybe an IPFS image. The public is informed via Grant Sale when land is up for grabs. Many consumers buy something with the intention of having two of it. The purchaser must

have sufficient funds, and the developer of the function must be unaware of the Ethereum address associated with the Lot. There are currently two options available. It is possible that the sale of the Lot will fall through if the buyer is unable to make the required payment. Money is given to the buyer as payment for the lot. When comparing the numbers 5 and 6, the differences are negligible at best. A lot of people buy cases of Lot. Medication delivery lines between pharmacies and patients typically handle this. To fulfill BuyBox payments, shops accept them.

FIGURE6. Functioncallsandeventsfortwodifferentscenariosforlotboxessale.

In two distinct lot box sales situations, there are function calls and events that take place.

There are two possible outcomes. It is against the law to make a transaction for more money than the cost of the packaging. If the shipment is satisfactory, the seller is rewarded with the full box price. The purchased quantity will be reflected in an adjusted number of containers for both parties.

To demonstrate the functionality of our intelligent controller, we shall describe in depth the processes that underpin our approach. Approval is required from both the seller and the buyer.

Algorithm 1 Creating a Lot in Smart Contract

Input: lotName, lotPrice, numBoxes, boxPrice, IPFShash, Caller, OwnerID
Output: An event declaring that the Lot has been manufactured
An event declaring that the image of the Lot has been uploaded
Data:
lotName: is the name of the Lot
lotPrice: is the specified price of the Lot
numBoxes: is the total number of boxes within a Lot
boxPrice: is the price of each box within a Lot
IPFShash: is the IPFS hash of the Lot image
ownerID: is the Ethereum address of the owner of the Lot
initialization;
if *Caller == ownerID* **then**
  Update *lotName*
  Update *lotPrice*
  Update *numBoxes*
  Update *boxPrice*
  Add *IPFShash*
  Emit an event declaring that the Lot has been manufactured
  Emit an event declaring that the Lot image has been uploaded to the IPFS server
else
  Revert contract state and show an error.

Algorithm 2 Granting Lot Sale

Output: An event declaring that the Lot is for sale
initialization;
if *Caller == ownerID* **then**
  Emit an event stating that the Lot is up for sale
else
  Revert contract state and show an error.

Harmony of thought. You can trust the seller to promptly deliver your purchased Lot. • Obtaining Lot Boxes, Algorithm 4 is nearly identical to Algorithm 3, with a few key distinctions. The quantity of Lot boxes, however, must be supplied by the buyer before proceeding to Step 3. The cost per customer transfer must reflect the total quantity of boxes being moved. When invoked, this method modifies the connection between the buyer's address and the package purchase.

TRACEABILITY ANALYSIS OF THE PROPOSED SOLUTION

This section explains Lot's drug potency validation. Every medicine Lot

Algorithm 3 Buying Lot

Input: ownerID, Buyer, Seller, Transferred Amount, lotPrice
Output: An event declaring that the Lot has been sold
Data: *ownerID*: The Ethereum address of the current Lot owner
Buyer: The Ethereum Address of the buyer
Seller: The Ethereum Address of the Seller
Transferred Amount: The amount transferred to the function
lotPrice: The price of the Lot
initialization;
if *Buyer* $\neq$ *Seller* $\wedge$ *TransferredAmount* $=$ *lotPrice* **then**
  Transfer the price of the Lot to the seller
  Update ownerID by replacing the seller Ethereum address to the buyer Ethereum Address
  Emit an event declaring that the Lot has been sold
else
  Revert contract state and show an error.

Intelligent contracts created per transaction start and record ledger events. Use separate Ethereum addresses for all transactions involving illegal drugs. Copies of the Ethereum address for each

drug are difficult to manufacture and prone to errors. Smartphones have the capability of decoding QR codes. Smartphones can read two-dimensional QR codes with as many as 4,000 characters. It is possible to create scannable QR codes using Ethereum addresses. Patients can access the medications they require with the help of QR codes. Figure 7 illustrates how effective a medicine is from a pharmacological standpoint. D App may scan the drug's QR code, and web3j can connect to an on-premises or cloud-based Ethereum node. The D App uses Infura's JSON-RPC to convert QR codes to Ethereum addresses. The duplicate Ethereum node record streamlines the customer onboarding procedure. The Lotto smart contract's Ethereum address is used by the Ethereum node gateway as a transaction counter. You may trace the Lot's provenance by displaying the smart contract's Ethereum address and the name of the associated event. This immutable blockchain employs event filtration to verify the authenticity of pharmaceuticals. The first cryptocurrency-powered pharmacy has gone on sale.

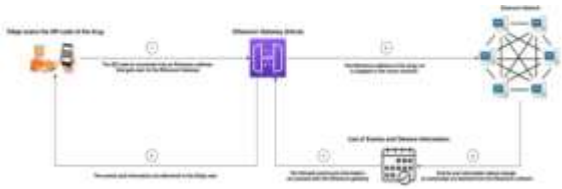

FIGURE7. Applicationusecaseoftheproposedblockchain-basedsolution.

Algorithm 4 Buying Lot Boxes

Input: ownerID, Buyer, Seller, Transferred Amount, boxPrice, numBoxes, numBoxesToBuy, Transferred Amount, boxesPatient
Output: An event declaring that the Lot boxes have been sold
Data: *ownerID*: The Ethereum address of the current Lot owner
Buyer: The Ethereum Address of the buyer
Seller: The Ethereum Address of the Seller
Transferred Amount: The amount transferred to the function
boxPrice: The price of the Lot box
numBoxes: The total number of boxes in the Lot
numBoxesToBuy: The number of boxes the buyer wants to buy
boxesPatient: Maps the number of boxes bought to the buyer address
initialization;
if *Buyer* $\neq$ *Seller* $\wedge$ *TransferredAmount* $=$ *numBoxesToBuy*boxPrice* **then**
  Transfer the price of the boxes to the seller
  Update ownerID by replacing the seller Ethereum address to the buyer Ethereum address
  Update numBoxes owned by the seller by decreasing the sold amount from it
  Update boxesPatient by assigning the purchased amount to the buyer address
else
  Revert contract state and show an error.

Data sharing on the Ethereum network is seen in Figure 7. Each node in the network stores an immutable copy of the ledger to ensure the integrity of the data at all times. This case study demonstrates the efficacy of our drug-tracking technology in the pharmaceutical supply chain. Infura will track transactions and changes in Ethereum ownership, and the DApp will display this data. To process Ethereum jobs, the system employs Web3j, JSON-RPC, and Infura.

5.TESTING AND VALIDATION

In order to verify Ethereum smart contracts, developers can use the web-based Remix IDE. Three participants' Ethereum addresses are listed in Table 3.


```
"from": "0x5e72914535f202659083db3a02c984188fa26e9f",
"topic": "0x44c99ce1ec0af6519400dc5641e20fd507c596f90096ffe116181619d7ab1a25",
"event": "lotManufactured",
"args": {
        "0": "0xCA35b7d915458EF540aDe6068dFe2F44E8fa733c",
        "manufacturer": "0xCA35b7d915458EF540aDe6068dFe2F44E8fa733c",
        "length": 1
```


FIGURE 8. Successful execution of lotDetails Function.


```
"from": "0x5e72914535f202659083db3a02c984188fa26e9f",
"topic": "0x15a51b79663b36aa87b7e256eddbad58070b43d374c4294e41b9e76ad43a4c04",
"event": "lotSale",
"args": {
        "0": "Aspirine",
        "1": "200",
        "2": "1000000000000000000",
        "3": "1000000000000000000",
        "_lotName": "Aspirine",
        "_numBoxes": "200",
        "_lotPrice": "1000000000000000000",
        "_boxPrice": "1000000000000000000",
        "length": 4
```


FIGURE 9. Successful execution of grantSale Function.


```
"from": "0x5e72914535f202659083db3a02c984188fa26e9f",
"topic": "0xeb373dc4c684e4ae6135618e7fc15d654b409d8071dc8126b4a5d18ac86590db",
"event": "lotSold",
"args": {
        "0": "0x14723A09ACff6D2A60DcdF7aA4AFf308FDDC160C",
        "newownerID": "0x14723A09ACff6D2A60DcdF7aA4AFf308FDDC160C",
        "length": 1
```


FIGURE 10. Successful execution of buyLot Function.


```
"from": "0x5e72914535f202659083db3a02c984188fa26e9f",
"topic": "0x82c28ddbad097bd1003a55cdb6788f38fbe3033fa91c813a8a00652716c0d45b",
"event": "boxesSold",
"args": {
        "0": "50",
        "1": "0x14723A09ACff6D2A60DcdF7aA4AFf308FDDC160C",
        "_soldBoxes": "50",
        "newownerID": "0x14723A09ACff6D2A60DcdF7aA4AFf308FDDC160C",
        "length": 2
```


FIGURE 11. Successful execution of buyBox Function.

- Each and every box. Figure 8 displays the final product, including saved data and some working samples of the software.
- Notifying the public that the newly formed Lot is for sale is a crucial part of the Permit Sale function. Successfully calling a method is seen in Figure 9.

- To obtain the Lot from Player1, this approach employs Player2 (whose Ethereum address is listed in Table 3). Figure 8 depicts User1 transferring 1Ether, while Figure 10 shows the function correctly executing.

6.CONCLUSION

We investigated the need for regulations to prevent the distribution of potentially lethal counterfeit medications in the pharmaceutical industry's supply chains. We built and tested a blockchain-based tracking system for the distribution of pharmaceuticals. To create immutable records of the supply chain and to automatically record occurrences for all parties involved, our method employs cryptography, blockchain technology, and Ethereum smart contracts. Our usage of energy-efficient smart contracts was particularly lauded. Our system effectively protects transaction data from fraud even when dealing with several parties, as is the case in the pharmaceutical industry.

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