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Blockchain-based Soybean Traceability in Agricultural Supply Chain

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ABSTRACT The globalized production and distribution of agricultural produce bring a renewed focus on the safety, quality and validation of several important criteria in agriculture and food supply chains. The growing number of issues related to food safety and contamination risks has established an immense need for effective traceability solution that act as an essential quality management tool ensuring adequate safety of products in the agricultural supply chain. Blockchain is a disruptive technology that can provide an innovative solution for product traceability in agriculture and food supply chains. Today's agricultural supply chains are complex ecosystem involving several stakeholders making it cumbersome to validate several important criteria such as country of origin, stages in crop development, conformance to quality standards and monitor yields. In this paper, we propose an approach that leverages the Ethereum blockchain and smart contracts efficiently perform business transactions for soybean tracking and traceability across the agricultural supply chain. Our proposed solution eliminates the need for a trusted centralized authority, intermediaries and provides transactions records, enhancing efficiency and safety with high integrity, reliability, and security. The proposed solution focuses on the utilization of smart contracts to govern and control all interactions and transactions among all the participants involved within the supply chain ecosystem. All transactions are recorded and stored in the blockchain's immutable ledger with links to a decentralized file system (IPFS), and thus providing to all a high level of transparency and traceability into the supply chain ecosystem in a secure, trusted, reliable, and efficient manner.

INDEX TERMS Blockchain, Ethereum, Smart contracts, Traceability, Soybean, Agricultural Supply Chain, Food Safety

I. INTRODUCTION

MONITORING the development of agricultural products and efficient logistics management in food and agricultural supply chain is critical to ensure product safety. The growing concerns about food safety and contamination risks have renewed the focus for enhanced traceability across the supply chain [1, 2]. In addition agricultural products being traded across several countries require precise tracking and conformance to country specific regulations [3, 4]. Traceability of products in agricultural supply chain requires collection, communication and management of critical information by precisely identifying the origin, various information exchange in the supply chain. The dynamic nature of information in the agricultural/food supply chain where products are produced, processed and sent via several intermediaries makes it difficult to track and trace. Product contamination and its implications to public health strongly emphasize traceability as necessary policy tool towards monitoring food quality and safety [5]. Dabbene and Gay [6] argue the use of precise data collection via information communication tools such as bar-codes and RFID enables data acquisition and better traceability in agricultural and food supply chains. The current practice of traceability in agriculture supply chain largely suffers from data fragmentation and centralized controls which proves vulnerable to both data modification and management. In the event of contamination identifying the source and swiftly isolating the product from supply chain requires close coordination among multiple stakeholders in agricultural supply chain. Individual stages in food supply chains often have good traceability but exchange of information between stages proves to be difficult and time consuming [7].

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Recent technology developments through the application of blockchain technology can provide a meaningful and practical solution ensuring traceability of agricultural produce and eliminates the need for a trusted centralized authority [8]. Blockchain technology has gained immense popularity among supply chain and logistics community due transparency and immutability of transactions, enhances trust among participating stakeholders. Due to its tamperproof, trusted, secure and traceable nature, blockchain can be deployed effectively in the agriculture and food supply chain management. The overall structure and functioning of food supply chain is vast and complex involving multiple stakeholders ranging from farmers, manufacturers, processors, and consumers [9]. Food and agricultural supply chain is getting a lot of attention from the research community due to problematic long supply chain, from raw materials to the end consumer makes it extremely hard and time-consuming in tracking back the origin of a product. Hence, there is a need to create a secure framework for tracking details about the origin, farming methods adopted, and safety of the food product throughout the supply chain cycle without a third party or centralized control. Few other major issues to be solved in the supply chain cycle includes provenance, protocol regulations across multiple distributors, processors and retailers [9].

The blockchain is basically an immutable and decentralized, shared public ledger of transactions which allows participants to keep track of transactions without central recordkeeping [10–12]. Blockchain is a shared distributed ledger composed of add-on blocks that include details of all transactions data, execution outcomes and is traceable [13, 14]. Each block is hashed and linked to the next block, making it a secure chain of immutable and tamper-proof records [14]. The adoption and implementation of blockchain technology can also ensure payment security to sellers while sharing important criteria about the origin, certification of organic or non GMO, crop yields, and alert potential contamination risk among others. Ethereum is a programmable blockchain platform that has the ability to govern business logic including interactions, sequence of events, and access control to enforce the required workflow and execute agreed-on business logic among supply chain participants. The Ethereum Virtual Machine (EVM) is the runtime environment for Ethereum computations on which the user programs are executed. A smart contract is a protocol that is intended to digitally verify and carry out credible transactions that are traceable and irreversible, without third party intervention [15].

The overarching objective of this paper is to demonstrate how blockchain and Ethereum smart contracts can efficiently trace and track and enable seemless integration of business transactions and workflows in the agricultural supply chain. We propose, implement, and analyze a blockchain-framework to provide traceability and visibility in the soybean supply chains. Figure 1 illustrates the existing product flows in soybean supply chain identifying the actors and their corresponding function in the supply chain. The process flow shown in Figure 1 is being adopted from previous studies on modeling traceability framework [16, 17] for bulk grain supply chains. The primary contribution of this paper can be summarized as follows:

- We present a blockchain-based solution and framework for traceability and visibility in the soybean supply chain using Ethereum smart contracts.
- We discuss and highlight key aspects of our blockchain solution in terms of the overall system design and architecture, featuring main interactions among the main participants, with entity relations and sequence diagrams.
- We present, implement, and test smart contract algorithms that govern and ensure the proper interactions among key stakeholders in the soybean supply chain.

The reminder of the paper is organized as follows. Section 2 presents related literature of blockchain applications in food and agricultural supply chain. In Section 3, we discuss the design, system overview, and sequence diagrams for blockchain based approach for soybean traceability. In Section 4, we describe implementation details including algorithms for soybean sale between various participants in the supply chain using smart contracts. Finally, Section 5 concludes the study and outlines briefly research challenges and future work.

II. RELATED WORK

In this section, we review and highlight related work found in the literature on blockchain applications for food and agricultural supply chains. While literature on blockchain applications in banking, finance and insurance industries have been increasing steadily, the literature on food and agriculture is scant and just started to gaining popularity. Tian in [18] propose a food supply chain traceability based on Hazard Analysis and Critical Control Points (HACCP) using blockchain and Internet of Things. Previously, Tian in [19] discussed the advantages and disadvantages of RFID and blockchain for agriculture food supply chain traceability. Caro et al. [20] present AgriBlockIoT a blockchain based traceability solution integrating data from IoT devices along the value chain. They developed a use case for tracking produce from farm to fork and present implementation comparisons through both Ethereum and Hyperledger. Tse et al. [21] discussed at high abstract level how to apply blockchain technology to food supply chain, and compared the blockchain-based solution with tradition solutions. The authors also highlighted key aspects related to security, integrity, and trust. Lin et al. [22] review blockchain concepts for Agri-ICT systems and present a model ICT system for agriculture using blockchain technology.

Tripoli and Schmidhuber [23] discuss the application of distributed ledger technologies (DLT) and smart contracts for increasing efficiency, provide traceability in the agriculture. The authors identify both technical challenges and barriers to the adoption to conclude that DLTs have significant potential in achieving sustainable development goals. Mao et al. [24] present a blockchain based credit evaluation system via smart

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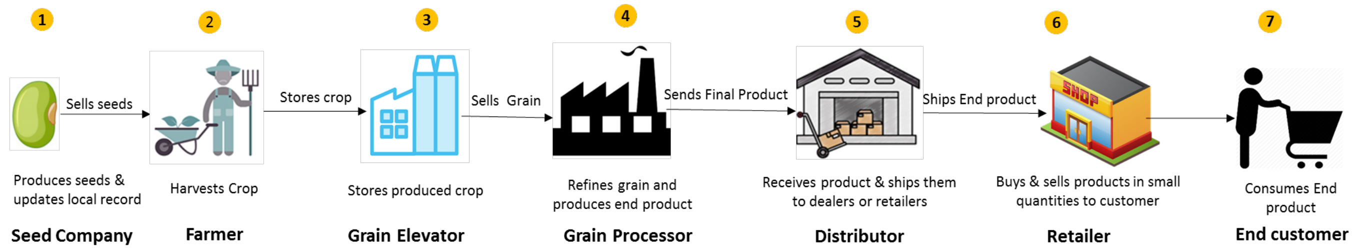

FIGURE 1. Existing product flows in Soybean supply chains

contracts for efficient management in food supply chain. Galves et al. [25] review challenges and potential use of blockchain for assuring traceability and authenticity in the food supply chains. Mao et al. [26] propose a consortium blockchain approach to efficient food trading system. They proposed an optimized improved practical byzantine fault tolerance (iPBFT) algorithm to optimize trading portfolio of buyers in the food supply chain. Further Mao et al. [26] validate their proposed food trading system using consortium blockchain via a case study applied to Shandong province in China. Lucena et al. [27] present an approach for grain quality measurement using blockchain and smart contracts. They present implementation solution for a real life case that resulted in 15% added valuation for genetically modified (GM) free for soy grain exports from grain exporter business in Brazil. Chinaka [28] studied how implementing blockchain based solution can facilitate value transfer by translating farmer's assets such as livestock, farm lands and produce applied to small scale agriculture in Africa. Schneider [29] designed a prototype blockchain system to enhance transparency and automate processes in the agricultural sector. Holmberg and Aquist [30] studied the challenges in implementing a blockchain based traceability solution in the dairy industry. Some recent examples of blockchain pilot implementation in food and agriculture supply chain includes wheat trade facilitated via blockchain technology in Australia through Agridigital using Ethereum. Food Traceability Pilots by Walmart through IBM Hyperledger [31]. Louis Dreyfus, a large commodity trader, successfully completed the first ever blockchain based commodity trade of US soybeans to China's Shangong Bohi Industry [32].

As evident from those related work, there is clearly a growing trend in adopting blockchain technology for enhanced information security, transparency, authentication of various criteria in food and agricultural supply chains. A significant portion of the literature discuss the conceptual application of blockchain in agricultural supply chains falling short of specific implementation framework or approach. Our paper aims to bridge the gap and contribute to the growing literature of blockchain application by showing how blockchain and Ethereum smart contracts can offer an efficient, trusted, secure, and decentralized trace and track solution for soybean supply chains. Our work presents salient features of the proposed system, with adequate details on architecture, meta data, sequence diagrams of interactions and messaging, and algorithms - which are generic enough to be applied to almost all use cases related to agricultural supply chain involving multiple stakeholders.

III. A BLOCKCHAIN-BASED APPROACH FOR SOYBEAN TRACEABILITY

In this section, we describe our proposed solution that utilizes Ethereum blockchain and smart contracts to trace, track, and perform transactions in soybean supply chains. Our solution eliminates the need a trusted centralized authority and provides transactions and records for food supply chain management and safety with high integrity, reliability, and security.

A. GENERAL SYSTEM OVERVIEW

The Ethereum smart contracts has the potential to transform safety of agricultural and food products into an integrated smart system that guarantees the quality of product delivered to the end customer. Our proposed framework and solution will focus on the usage of smart contracts executed autonomously on the public Ethereum blockchain platform. The execution of the smart contract functions and code will be carried out by the thousands of mining nodes that are globally distributed, and the execution outcome is agreed by all of the mining nodes. It is worth noting that mining nodes are what make up the blockchain network. A mining node can be any computing machine that collects, validates, and executes transactions. The nodes also store data and outcome of these transactions in a ledger that is replicated and synchronized by all mining nodes. In a way a mining node has the same exact replica of all other mining nodes. In blockchain, smart contracts will receive transactions in form of function calls, and will also trigger events to enable the participating entities to continuously monitor, track and get suitable alerts when violations occur. Thereby, it eventually helps in restoring the conditions to the optimal and responding to the violations that occur within the food value chain. Our solution focuses on soybean supply chain to be particular in this case. Figure 2 illustrates a general overview of the system architecture of the proposed food supply chain management solution. As shown in the figure, the main participating entities include the Seed Company, the farmer, Grain Elevator, Grain Processor, Distributor, Retailer, the end Customer and the blockchain that has the EVM executing the smart contract. Furthermore, in blockchain, every actor or participant has to have an Ethereum account, with a unique Ethereum Address (EA) which uniquely identifies the actor. The Ethereum account basically consists of the EA with public and private keys which are used to cryptographically and digitally sign and validate the integrity of the data within each transaction, and associate each transaction with a specific EA or account.

B. SYSTEM DESIGN

Each participating entity has a role, association, and interactions with the smart contract. There are seven participating entities and their role are summarized as follows:

- ***Seed Company:***
  Seed Company is the entity that produces a huge variety of seeds identified by EAN-UCC global standard identifiers per lot of the product sold to specific farmer. The seed company acts as a strong ally in food security efforts, as it facilitates farmers' access to planting materials in the form of seed, fertilizers and other nutrients that support agricultural production.
- ***Farmer:***
  Farmer buys seeds from the seed company with traceable standard identifiers of the batch of seeds and the company involved in the sale transaction, cultivates crops and creates the smart contract. The farmer also takes the liability for regularly monitoring and recording the growth details of the crops and saving it on the decentralized file system as images or MPEG files. A popular decentralized file system can be IPFS (Inter Planetary File System), which is peer-to-peer file system in which the content of the file is stored by multiple peers or nodes, which stores the file content with high integrity and resiliency [33]. The hash of the file content is only stored within the smart contract.
- ***Grain Elevator:***
  It is an agrarian facility that stores grain. The Grain Elevator operator determines the grade, quality of the grain and purchases the grain from the farmer. Some important factors to be considered while storing the grain are - temperature, moisture, and duration of storage [16].
- ***Grain Processor:***
  The grain processor buys grains from the elevator, refines the grain, analyses the grain for moisture, eliminates foreign material, and converts the untreated grain into the final product without the need for any further treatment or processing.
- ***Distributor:***
  A distributor is generally a warehouse that purchases final products from the processor. It is an entity which is involved in the process of food product distribution to the general population.
- ***Retailer:***
  Retailer buys finished goods from the distributor usually in batches with traceable identifiers and sells to consumers in small quantities. For example, the retailer may buy in bulk and sell in lower unit of measure to the customer. The standard identifiers preserves a hierarchical relationship enabling tractability.
- ***Customer:***
  The customer is the end user who purchases and consumes the product from the retailer.

To ensure secure tracking of the produce using Ethereum smart contracts and to get all the participants involved in the entire process, and as shown in Figure 2, the seed company produces the soybean seeds and saves the details of seed germination, chemical composition, viability, quality, and dormancy. The soybean seeds sold by the seed company are identified using standardized identifiers such as serialized Global Trade Identification Numbers (GTIN) or equivalent which contains the specific company prefix. The use of standard identifiers enables digital connectivity and tracking potential of both the products and transaction related processes among the participating entities in the agricultural produce supply chain. The farmer buys the seeds from the seed company and carries out the farming. The details of the crop growth are recorded by the farmer at timely intervals in the decentralized file system through IPFS. The crop growth images are time stamped and the IPFS hash of the file is stored in the smart contract. The farmer stores the grain in the elevator after checking relevant factors such as temperature, moisture and time, that causes changes in grains during storage, as heat and humidity lead to quality deterioration resulting in production loss [17, 34]. The grain is then, purchased by the processor which involves refining, analyzing the quality of grain, eliminating moisture and finally preparing the finished product. The distributor buys the finished product from the processor in order to ship the products to potential buyers. The distributor becomes the grain processors' direct point of contact for prospective buyers of food products as they stack up large quantities of products [35]. After this point distributor sells the products/goods to the retailer. Generally, a retailer buys small quantities of an item from a distributor or a wholesaler and sells products directly to customers. Figure 3 shows the entity-relationship diagram that illustrates the smart contract attributes and functions and the relationship between the participating entities and the smart contract. Such metadata and relations are key to implement smart contracts.

In blockchain and IPFS, all images, data, and records are digitally signed and attributed to a certain actor. This means that the actor for uploading images, in this case the farmer uploading MPEG files, is the undisputed owner of such action and is responsible for inaccurate or fraudulent images or MPEG files. Blockchain via smart contracts can be programmed in an automated way to impose penalties on the farmer if acts dishonestly. Another option, is to install the cameras in the field with capabilities and communication, to automatically take images and send them to the blockchain

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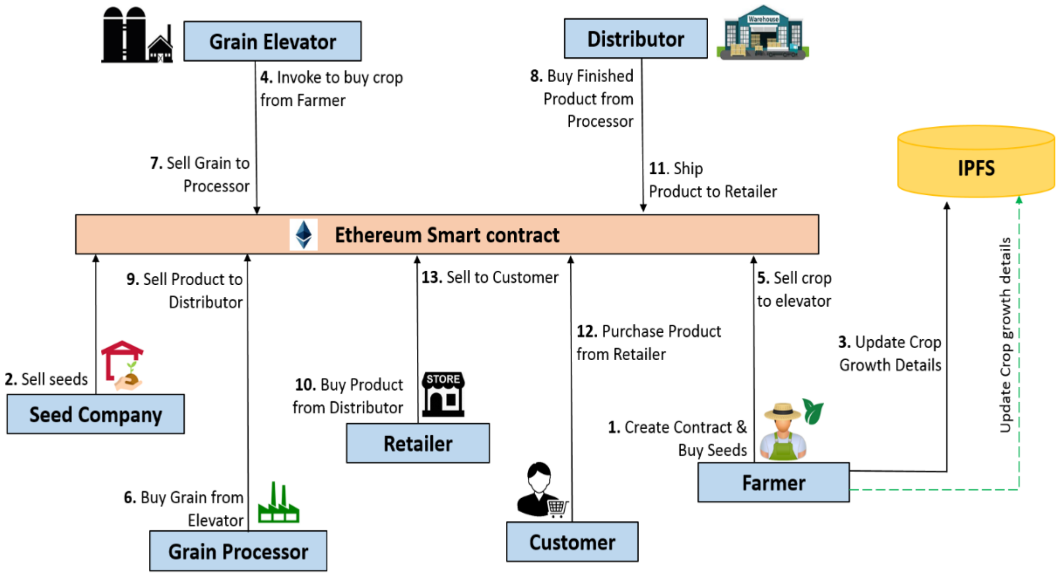

FIGURE 2. A system overview for automating the Soybean traceability using Ethereum Smart Contracts.

to be recorded and stored. Such hardware cameras can be built and provided to farmers to install, and can be designed in a way that cannot be hacked or tampered with, and therefore their uploaded images can be audited, trusted and their content can be disputed or refuted by any participant or stakeholder on the blockchain.

C. SEQUENCE DIAGRAMS

Each of the participating entities has an Ethereum address (EA) and participates by invoking functions within the smart contract. Figure 4 outlines the sequence flow for a scenario where a farmer creates a smart contract. Following the offline agreement between the farmer and the seed company, the farmer buys the seeds from the seed company and an event *SeedsRequestedByFarmer* is invoked and is made available to all active participants (i.e., the farmer and the seed company). The seed company executes the function, *sellSeeds()* that includes the attributes such as the Seed Company Ethereum Address (*Seed Company EA*), Ethereum Address of Farmer (*Farmer EA*), *Quantity, LotAttributes etc.* The crop growth details are updated by the farmer at regular time points onto the file system through IPFS. The farmer saves the image of the crop in the IPFS and stores the IPFS hash in the smart contract. The crop growth updating process continues until the harvesting stage, with the image of the crop being recorded at frequent intervals. As shown in Figure 4, the *updateGrowthImage()* function records the growth of the crop. Each time an image is uploaded in the IPFS, an IPFS hash is stored in the smart contract and event *CropGrowthImageUpdated* is broadcasted among all active entities. Now, when the crop is harvested, there is an offline agreement between the farmer and the grain elevator to store the produced crop. The farmer is given the details about the moisture, humidity, weight of the grain stored in the elevator and the duration of storage in the elevator. The farmer agrees to it and sells the grain to store in the elevator. Figure 4 shows the functions *buyGrain()* and *sellToElevator()* executed by the Grain Elevator and the Farmer respectively.

Figure 5 represents the message sequence diagram in which the grain processor buys grain stored in the elevator. The function *buyGrain()* is executed by the processor by passing parameters such as the Ethereum addresses of both requesting grain processor (*Processor EA*) and that of the Grain Elevator (*Elevator EA*), *Quantity* and *DateOfPurchase*. The event *GrainRequestedByElevator* triggers the associated elevator, which then executes the *sellGrainToProcessor()* function. Event *GrainSoldToElevator* is broadcasted along with the network with the parameters showing the buyer and *seller EA, Quantity and DateOfSales*. The distributor entity then requests to the grain processor in order to buy finished products from the processor. Figure 5 shows *buyProductFromProcessor()* function executed by the interested distributor. The distributor is usually a warehouse that buys stores and ships products in bulk amounts to wholesalers or retailers. Event *ProductRequestedByDistributor* is triggered to invoke the processor to sell the grain to the distributor. The farmer executes the *sellProductToDistributor()* function with the function parameters consisting of the Ethereum addresses of grain processor, distributor, quantity sold and date of sales. The event *ProductSoldToDistributor* is activated to notify the actively interacting entities (i.e., Grain Processor and Distributor) at that particular time point.

Figure 6 shows the message sequence diagram in which distributor, retailer, and the customer collaborate with the smart contract. The distributor interacts with the interested retailers to sell the goods and retailers in turn request for the

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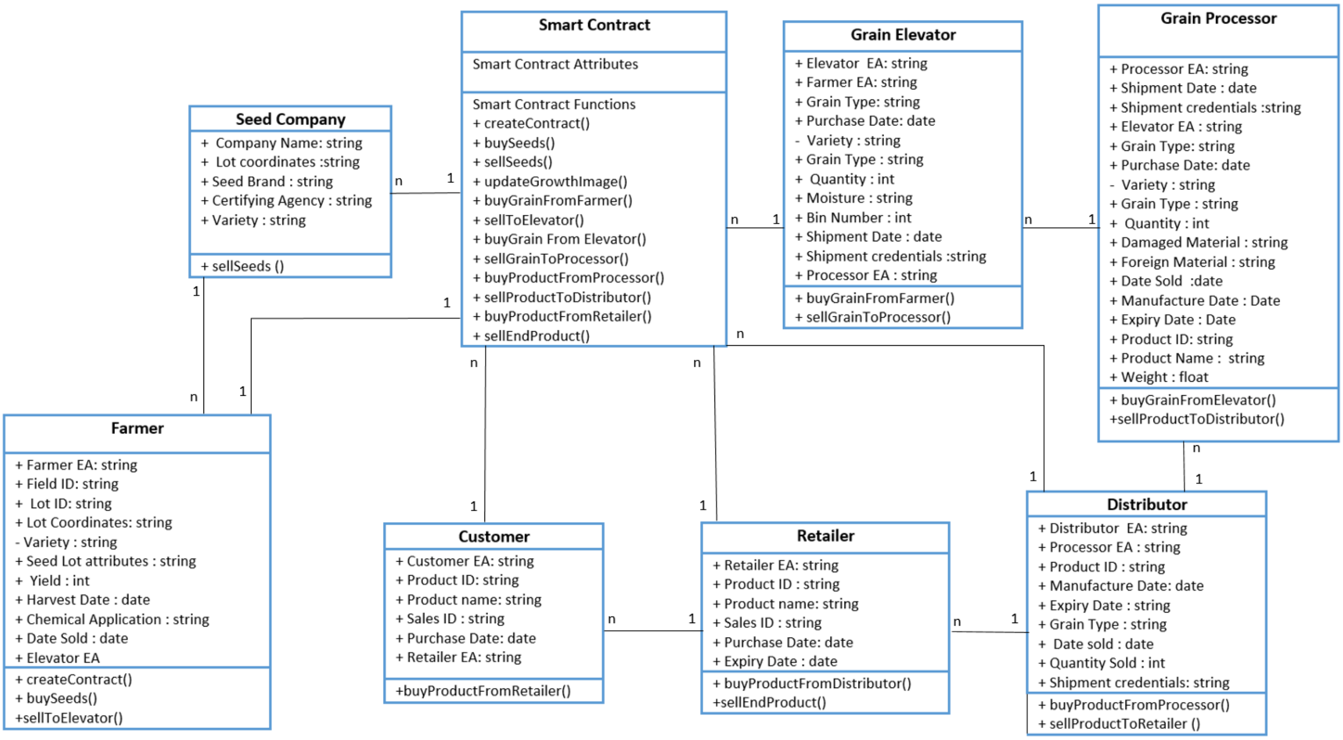

FIGURE 3. Entity relationship diagram

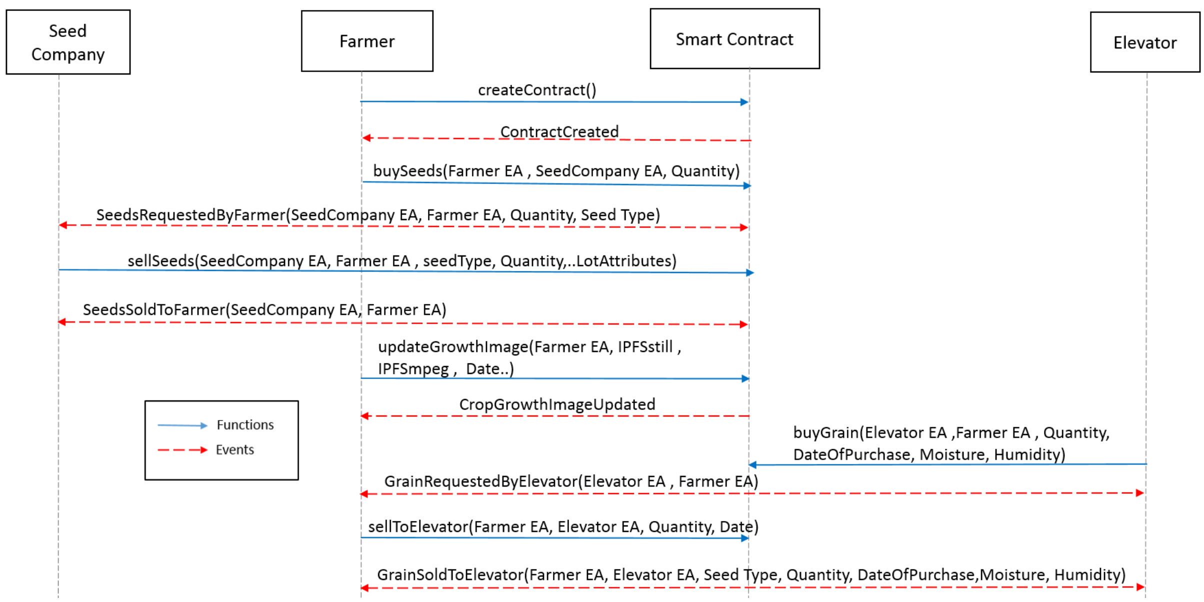

FIGURE 4. Sequence diagram showing the interaction between seed company, farmer, smart contract and elevator

goods from the distributor in limited quantities. As shown in Figure 6, retailer executes *buyProductFromDistributor()* function and the event *ProductRequestedByRetailer* is activated. The distributor executes *sellProductToRetailer()* function and event *ProductSoldToRetailer* notifies all participants about the sale of goods. Now, the end customer buys the product from the local retailer by executing *buyProductFromRetailer()* function, and event *EndProductRequestedByCustomer* is triggered by the smart contract. Finally, the retailer sells the product to end customer by executing *sellEndProduct() function*. The smart contract broadcasts the sale of the product with the *EndProductSold* event.

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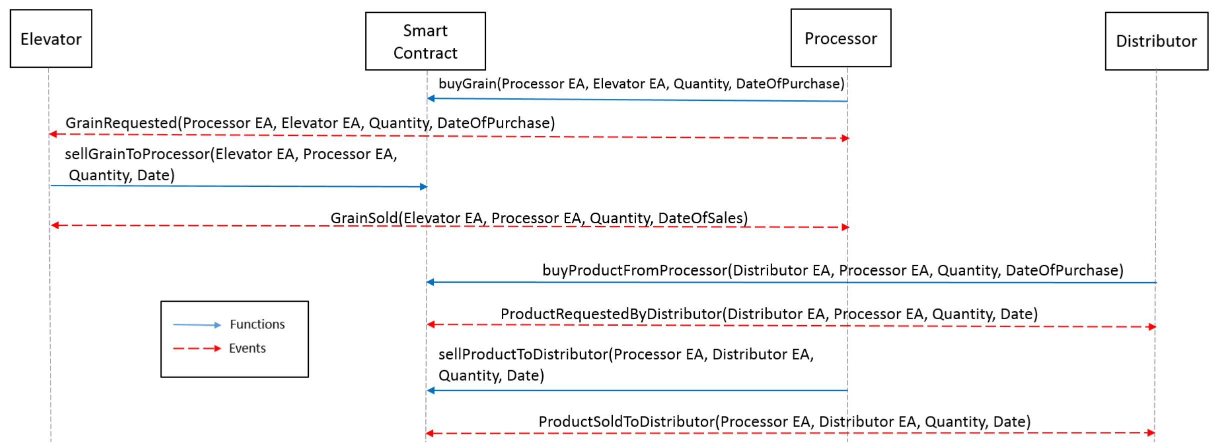

FIGURE 5. Sequence diagram showing interactions between elevator, smart contract, processor, and distributor

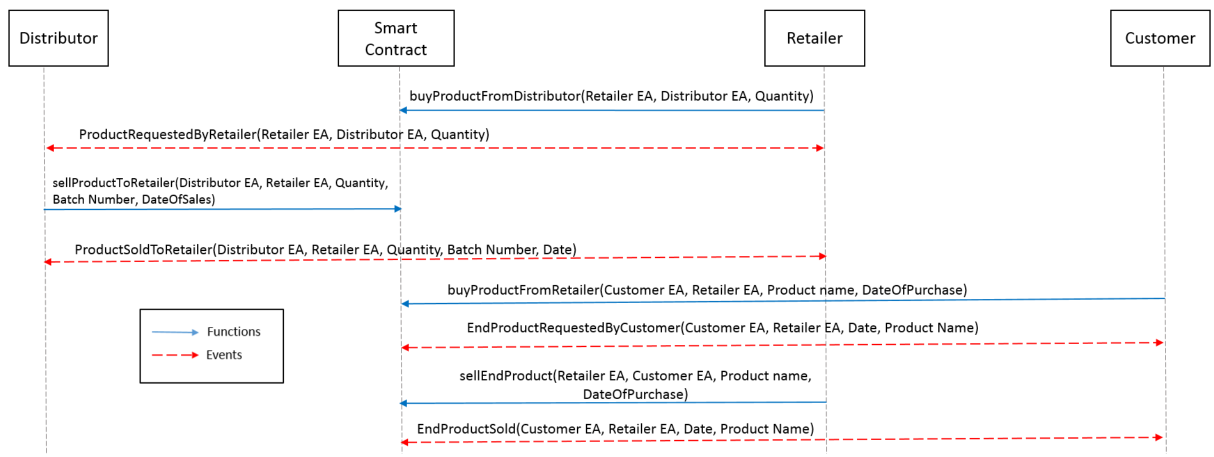

FIGURE 6. Sequence diagram showing interactions among Distributor, Smart contract, Retailer and Customer

D. TRACEABLE FUNCTIONALITY

The advantage of using traceable functionality in soybean supply chain using our proposed blockchain-based solution utilizing smart contracts is the availability of verifiable and non-modifiable information to all stakeholders without a central authority in the supply chain. Beginning with transaction of seeds sold between the seed company and the farmer, to the next echelon the total volume of soybean produce sold between subsequent entities is logged and all transactions can be verified. For example, the volume of grain sold between entities with the agreed conditions cannot be altered or changed. In addition, grains of different quality criteria cannot be mixed together for sale as total volume is known to all stakeholders. The conditions of the agricultural field and crop growth are difficult to monitor while the presented approach wherein the farmer periodically uploads images of the plant and land conditions via IPFS offers a digital record that can be used to validate the conditions agreed upon.

Continuous monitoring for quality compliance is further ensured by the use of traceable identifiers per lot and the ability to trace all corresponding transactions between the stakeholders. The quality of the shipment and conditions can also be monitored using IoT-enabled containers and packages equipped with sensors, cameras, GPS locator, and 4G communication. These sensors can continuously during the shipment process relay and send notifications on the conditions of the crop, product, and shipped items. With blockchain, such information and notification cannot be altered or tampered with and immediately available and accessible by all stakeholders in a trusted and decentralized manner, with no intermediaries. With this, additional attributes can be added to address the traceable precise physical location of the product or stakeholder location by using standard identifiers such as global location identifiers or by geotagging the stakeholder location which can be sent by GPS sensors installed within the shipping or storage containers.

It is worth noting that it is possible that a stakeholder can cheat or can transact and record fraudulent data. In this case, the blockchain does record the data as such with

Algorithm 1: Seed Company sells seeds to Farmer

Input : F is the *list of* registered *farmers*
$Ethereumaddress(EA)$ *of* $farmer$,
$Ethereumaddress(EA)$ *of* $SeedCompany$
$Quantity$, $SeedType$, $SeedBrand$, $SeedPrice$

Contractstate is ***Created***
State of the farmer is ***SeedsRequested***
Seed Company state is ***Ready***
Restrict access to only $f \in F$ i.e., registered Farmers
if *farmer = registered and SeedPrice = paid* **then**
  Contract state changes to *SeedRequestSubmitted*.
  Change State of the farmer to *WaitForSeeds*.
  Seed Company state is *AgreeToSell*
  Create a notification message stating sale of seeds
end
else
  Revert contract state and show an error.
end

validated attribution to the originating of the data (i.e. the true stakeholder). If at a later stage, the data was caught to be incorrect, the judges and all participants can with 100% certainty attribute the data to a particular actor or stakeholder. In this scenario, blockchain can identify fraud. To overcome this type of fraud, blockchain can be programmed through smart contracts to have additional functions to invalidate shipment, or the whole supply chain process, and put some action to impose penalties on fraudulent stakeholders, or take alternative and corrective actions. This will constitute new corrective data and actions that will be generated and linked to the fraudulent data, and thus ensuring accurate and undisputed traceability and auditability.

IV. IMPLEMENTATION FRAMEWORK

In this section, we describe the algorithms that define the working principles of our proposed blockchain-based approach. As discussed earlier, the farmer creates the smart contract. The farmer then agrees to the purchase terms (offline) with one of the registered seed companies. Algorithm 1 describes the process that govern the sale of seeds by the seed company to the farmer. After the initial state of the contract is established, the smart contract checks to confirm that the requesting farmer is already registered and the price of seed is paid. If the scenario is successful, then the state of the contract changes to *SeedRequestSubmitted*, the farmer state changes to *WaitForSeeds* and state of seed company changes to *AgreeToSell*. The contract notifies all the active entities in the chain about the state changes otherwise the state of contract and other active participants reverts to initial state and transaction terminates.

Algorithm 2 describes the process of selling the grain to Grain Processor by Elevator. The elevator stores the purchased crop from farmer and stores it in mass quantities. Most important criteria to consider in this stage are moisture content, bin number, date of purchase and shipment date.

Algorithm 2: Grain Processor buys Grain from Elevator

Input : *'gp' is the list of registered Processors*
$Ethereumaddress(EA) of GrainProcessor$,
$Ethereumaddress(EA)$ *of* $Elevator$
$Quantity$, $DatePurchased$, $GrainPrice$

Contractstate is ***BuyFromElevator***
State of the grain processor is ***GrainRequested***
Grain Elevator state is ***CropBoughtFromFarmer***
Restrict access to only $gp \in GrainProcessor$
if *GrainSale is agreed and GrainPrice = paid* **then**
  Contract state changes to *GrainRequestAgreed*.
  Change State of the grain processor to *WaitForGrainFromElevator*.
  Grain Elevator state is *SellGrainToProcessor*
  Create a notification message stating sale of grain to requesting processor
end
else
  Contract state changes to *GrainRequestFailed*.
  State of grain processor is *RequestFailure*.
  Grain Elevator state is *CancelRequestOfProcessor*
  Create a notification message stating request failure
end
else
  Revert contract state and show an error.
end

At this stage, the contract state is *BuyFromElevator*. The state of the grain processor is *GrainRequested* and the grain elevator state is *CropBoughtFromFarmer*. The contract has to check two conditions as shown in Algorithm 2: (i) if the requesting grain processor is a registered entity and (ii) if the sale of grain is agreed and purchase price is paid. If these two conditions are true or satisfied, the contract state changes to *GrainRequestAgreed*, processor state changes to *WaitForGrainFromElevator*, elevator state changes to *SellGrainToProcessor*, and all the active entities are notified with a message on the sale of grain to the processor. In the other case, if the above mentioned two conditions are not satisfied, contract state changes to *GrainRequestFailed*, processor state changes to *RequestFailure*, elevator state changes to *CancelRequestOfProcessor*.

The grain processor then sells the finished product to the distributors. Next, we elaborate the state of the system and the entities where the retailer buys the product from distributor. Date of product manufacture, Quantity Sold, and Date of Purchase are some of the important parameters to keep a check. The distributors and retailers will be identified with their Ethereum addresses and state of the contract as shown in Algorithm 3. At this stage, the contract state is *ProductSoldToDistributor*, and distributor state is *ProductReceivedFromProcessor*. The state of the retailer is *ReadyToPurchase*. The contract restricts the access to only registered retailers and checks if sale agreement is accepted and product payment is completed. If these conditions are met, the contract executes the transaction where the distributor ships the prod-

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Algorithm 3: Distributor ships product to Retailer

Input : $'r'$ *is the list of registered Retailers* $Ethereumaddress(EA)ofDistributor$, $Ethereumaddress(EA)$ *of* $Retailer$, $DateManufactured$, $QuantitySold$, $DatePurchased$

Contractstate is ***ProductSoldToDistributor***
Distributor state is ***ProductReceivedFromProcessor***
Retailer state is ***ReadyToPurchase***
Restrict access to only $r \in Retailer$
if *Sale = agreed and ProductPayment = successful* **then**
    Contract state changes to *SaleRequestAgreedSuccess*.
    Distributor state changes to *ProductSoldToRetailer*.
    Retailer state is *ProductDeliveredSuccessful*
    Create a 'success' notification message .
end
else
    Contract state changes to *SaleRequestDenied*.
    Distributor state changes to *RequestFailed*.
    Retailer state is *ProductDeliveryFailure*
    Create a request failure notification message.
end
else
    Revert contract state and show an error.
end

Algorithm 4: Customer buys from Retailer

Input : $Ethereumaddress(EA)ofRetailer$, $Ethereumaddress(EA)$ *of* $Customer$, $DatePurchased$, $ProductID$, $SalesID$

Contractstate is ***SaleRequestAgreedSuccess***
Retailer state is ***ProductDeliveredSuccessful***
Customer state is ***ReadyToBuy***
Restrict access to only Customers
if *ProductPayment = successful* **then**
    Contract state changes to *ProductSoldToCustomer*.
    Retailer state is *ProductSaleSuccessful*
    Customer state is *SuccessfulPurchase*
    Create a 'purchase success' notification message.
end
else
    Contract state changes to *SaleOfProductDenied*.
    Retailer state is *ProductSaleFailure*
    Customer state is *FailedPurchase*
    Notify with a 'purchase failure' message.
end
else
    Revert contract state and show an error.
end

uct to the retailer. Here, the state of the contract changes to *SaleRequestAgreedSuccess*, and the distributor state changes to *ProductSoldToRetailer*, and Retailer state changes to *ProductDeliveredSuccessful*. For a successful product delivery done, the contract sends out a notification message stating the successful delivery to the retailer. Else, for a failure scenario, the contract state changes to *SaleRequestDenied*, state of distributor becomes *RequestFailed* and retailer state changes to *ProductDeliveryFailure* and the failure notification message is sent out to all participants.

Finally, we describe the algorithm for purchases made by the customer from the retailer in Algorithm 4. The customer is the final entity in the food processing and tracking model. The customer state is *ReadyToBuy* initially. The state of the contract and retailer are *SaleRequestAgreedSuccess* and *ProductDeliveredSuccessful* respectively. Here, the smart contract restricts access to only Customers to make a purchase from the registered retailers. The important parameters considered to track the product are Customer Ethereum address, Retailer Ethereum address, Date Purchased, Sales ID, Product ID. Upon successful payment of the product price, the state of contract changes to *ProductSoldToCustomer*, retailer state changes to *ProductSaleSuccessful* and customer state changes to *SuccessfulPurchase*. If the payment made is not correct, the state of contract changes to *SaleOfProductDenied*, retailer state changes to *ProductSaleFailure* and customer state changes to FailedPurchase. The contract notifies with an event about the sales failure to everyone in the network.

V. CONCLUSION

In this article, we have proposed a solution and generic framework leveraging Ethereum blockchain and smart contracts to trace, track, and perform business transactions removing intermediaries and central point of processing for soybean traceability across agricultural supply chain. We have presented details and aspects related to the system architecture, design, entity-relation diagram, interactions, sequence diagrams, and implementation algorithms. We showed how our solution can be applied for tracing and tracking soybean supply chain. However, the presented aspects and details are generic enough and can be applied to provide trusted and decentralized traceability to any crop or produce in the agricultural supply chain. To date, blockchain technology still faces key challenges related to scalability, governance, identity registration, privacy, standards, and regulations. As a future work, we plan to look at addressing some of these key challenges and develop solutions addressing them. We also plan to integrate within our proposed solution automated payments and proof of delivery - in which parties are paid using cryptocurrency in an automated and centralized manner by the smart contracts upon successful physical delivery of crops and products. A blockchain-based proof of delivery of physical assets with automated payments in cryptocurrency as well as dispute handling was previously proposed in [36].

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