Improved distribution and food safety for beef processing and management using a blockchain-tracer support framework

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ABSTRACT

Agriculture has since become a major source of livelihood for Nigerians. It also accounts for over 85% of the total food consumed within her borders. The sector has maintained improved productivity and profitability via a concerted effort to address critical issues such as an unorganized regulatory system, lack of food safety data, no standards in agricultural produce, non-adaptation to precision farming, and non-harmony via inventory trace supports. This study proposes blockchain-based trace-support in a continued effort to ensure food quality, consumer safety, and trading of food assets. It uses the radio frequency identification (RFID) sensor to register and track livestocks, farms/farmers, and abattoir processes as well as provisions a databank to trace livestock data. Results show the model adequately perform about 1,101 transactions per seconds with a response time of 0.21 s for queries and 0.28 s for https pages respectively for 2,500 users. Also, it yields a slightly longer time of 0.32 s for queries and 0.38 s for https pages respectively with an increased 5,000 users via the world-state as stored in the blockchain's hyper-fabric ledger. Overall, the framework can directly query and retrieve data without it traversing the whole ledger. This, in turn, improves the efficiency and effectiveness of the traceability system.

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1. INTRODUCTION

The asset market has since become the focal epicenter for financial portfolio diversification and three critical factors that impact human existence include food, clothing, and shelter-mostly with food being a basic need of man-with agriculture playing a dominant role in the asset market [1]–[3]. With agricultural products traded as assets and the inherent challenges in the asset market ranging from volatility to spot and futures prices, optimizing the food value-chain structure becomes critical. As a result, it has become a widely studied phenomenon [4], [5]. We observe that an effective food value supply chain framework must be capable of delivering superior consumer values at a lower cost than the value chain as a whole. It should thus use contracts and portfolios as policies to drive the supply-value chain [5], [6], while also meeting the requirements of stakeholders [7], [8]. Furthermore, supply value-chain managers must be able to consider the interactions of known/unknown parameters, as well as limitations and minor shifts, from which he/she is expected to create a plan that will yield effective and efficient value-chain results [9].

The market has prioritized beef production, processing, and distribution to revolve around packers and producers–who exchange cattle meat and financial portfolios (monies) based on current market value. Herders and farms where such cattle are usually groomed are usually a result of some small family operations or ranch [10]. Whereas, in Nigeria–these farmers often operate as nomads that rear these cattle traveling the length and breadth of the country in search of vegetation that makes possible their capability to feed these cattle [11]. With beef production, that is either for internal consumption, or export (from small farms), it is imperative (though difficult) that adequate data about livestock processed therein be documented via their packaging and distribution chains [12]. Thus, cases may occur where no data exists about livestock slated for consumption. This data shortage and its inability of being shared (without the request of the consumer) has continued to cost beef production sector untold monies, food insecurity, time, safety, and quality assurance from known/unforeseen diseases as well as other forms of shocks present with beef production [13], [14].

Food safety has since become of paramount concern to many citizens (residents in both urban, semi-urban and rural areas) in many countries. Traceability systems are modeled with safety measures ensured during the processing of a commodity to prevent cum mitigate both the consumption of harmful chemicals used in the processing of these food commodities as well as outbreaks and spread propagation of diseases or contagions that are easily communicable to human consumers [15], [16]. Such commodities, if unchecked–can threaten the assets quality and safety. Thus, there must be a recall method as the need arises, if such an asset is deemed unsafe for consumption or does not meet standards [17], [18] to ensure consumer protection from food-borne contagion/disease. Improving production efficiency through reduced production time, costs, and information spread will impact positively the beef value chain [19] as the chain will become a tool to facilitate data exchange, ensure food safety, and improve profitability for the competitive market [20], [21]. Thus, with a plethora of cases in mind to include food vendor ownership, disease control through food safety and quality assurance, increased productivity, asset market opportunities, food stockpiling, and census programmes–the study wishes to address these range of issues through the provision of the food supply value chain tracer system that will effectively and efficiently allow for ease in food distribution and recall (where possible, for defective products) through a sensor-based hyperledger fabric blockchain model.

2. LITERATURE REVIEW

2.1. Livestock traceability support frameworks

Today, the internet with its myriad of interconnected devices–forms a giant component that currently, connects over a 3.5 billion users as of 2019. In addition, this giant network advances a medium to allow shared resources even when it also posits a myriad of challenges and risks that can be explored and exploited [22], [23]. Thus, the internet advances a platform to ease the dissemination of data such as with traceability-based value chain systems [24]. The quicker such data is readily available and shared, the better the production processes will be refined, and the more improved management practices and policies will ensue over time. An increase in the information shared via a traceability system–will proffer reduced production time, reduced cost, and reduced processing incurred via feedback. This, in turn, will translate and aid system robustness, adaptation, greater flexibility, and improved responsiveness to the ever-changing market trends [25].

A typical livestock food supply value chain may include herders, wholesalers/distributors/exporters, retailers, and consumers-with processes such as handling, packaging, transportation, storage, and trading of these products in exchange for contract services, monies, and/or financial portfolios. These processes, along with the necessary stakeholders, form a complex, chaotic, and dynamic structure of processes, the behavior of which influences the overall system's performance [9]. The livestock sector has played and continues to play a critical and pivotal role in ensuring nutritional security and livelihood security for millions of Nigerians. Globally, food safety and security have remained critical, with over 12.2 million Nigerians becoming ill each year as a result of consuming contaminated food or contracting food poisoning [26]. A value chain is frequently advanced as a means of effectively and efficiently managing and tracing/tracking the process of producing livestock-despite their high demand in markets. The food value chain is a series of activities linked together by raw materials (i.e. freshly harvested agricultural yields, products, and processed foods) and their corresponding flow to and fro a demand-supply chain from producers to consumers across organizational boundaries [27]–[29]. Some inherent benefits/goals of traceability in beef processing include [19], [23], [30]–[35]:

- Ownership: with livestock registered and tagged, it is easy for a farmer to prove ownership. This also controls theft and reduces the inconveniences of clearing them for transportation.
- Food quality: tracer system helps track records with safety procedures that assures of methods used for both chemical, microbial, and physical qualities in beef-processing. Retrieved data ensures value-chain

with stakeholders that can implement the required disease control program services as well as evaluate the efficacy of such disease control schemes in livestock rearing.
- Census: absence of registered farmer databank can result in huge manpower (associated cost). But, the availability of such centralized database/databank will both, increase the accuracy of the livestock census as well as ease accessibility efforts of livestock population.
- Effective disease control: tracer systems can ease the detection of causal-agents, and help farms track disease source(s), and if identified–advances procedure(s) to prevent outbreaks to neighboring farms as well as implement/track targeted bio-security measures to yield better results in disease control of an entire farm coverage [36].
- Development: various schemes to boost productivity and promote livestock husbandry via farm support can be implemented with adequate data provided by livestock owners/farms. This, helps to curb arbitrary selection of beneficiaries and ensure the effectiveness of the programme. The provision of a centralized data about farms can help with the efficient formulation of policies and its robust implementation.
- Improved productivity: adequate provision of livestock information can lead to improved selection of breeding-stock–which is performance based. The tracer support system can help provision a mode to aid effective data collection and update of livestock performance. Further analysis overtime, sets the precedence for overall quality of the germplasm through the improved decision for breed-stock, and the improve the sustained practice of their selection therein [37].
- Marketing: tracer system provides farm details and thus, can effectively help manage the processes in livestock databank. Provision of a centralized databank will also effectively help farms better manage all intermediaries and improve the e-marketing practices for the beef industry [38].
- Increase opportunities: developed economies have robust policies to aid a robust implementation of established, stringent livestock tracer system provisioned by legal framework. This has been successfully used with traceback capabilities posied to enhances consumer-trust both on the local and international markets–with a view to increasing the financial portfolios via export services for all stakeholders [39].

2.2. Review of related literature

Livestock production involves a set of related activities that results in a carefully managed, centralized system of livestock products [40]. Traceability seeks to promote all forms of documented, tracer transparency in sustainable agriculture, and traceable beef simply implies meat produced from an identified livestock [41], [42] reared on a registered farm, by a registered farmer or herder, and has all the requisite information about its origin and processing [13]. The birth of tracer-support systems leans on long-standing developments that yields improved food quality and safety management procedures [43], [44] and which–has now emerged as the basis for trade and a new index of quality.

Research by Feng *et al.* [45] integrated the radio frequency identification (RFID) with a barcode printer for their tracer system for a sample value chain, which resulted in a real-time, accurate data acquisition and transmission system with high-yield efficient data tracking capability. Major gaps noticed with the system included: i) its data input mode was inapplicable, ii) data input had inefficient sequence of communication with RFID reader, and iii) system had an overall high cost of implementation. Bezerra *et al.* [26] investigated a tracer system that sought to model goat and sheep meat processing, with quality assurance on meat origin, management practices, and transparency on livestock production units. It resulted in a schematic proposed model were seen to provide a tracer-support for sheep and goat meat.

Research by Bako *et al.* [11], on a food tracer system in Nigeria, investigated the current status with future needs for the poultry value-chain in Nigeria. With the thriving food industry, they sought to provision policy-frameworks towards improving food tracer-system in Nigeria via 3-ways: i) they proposed a realistic, chain visibility model, ii) they sought to validate documents implementing tech innovations, and iii) they emphasized great need for food quality through safety assurance procedures and recall measures–and sough to account for the Nigerian poultry sector roadmap with technological innovations. Stanislawek *et al.* [46] compared the effectiveness cum functions of a tracer support system in selected meat processing plants. With basic internal procedures established, they implemented tracer processes with simulation to enable response in a crisis state. Results unveiled that paper-recording yielded an efficient means for threat source(s) identification with greater chances of performing product traceability in the selected plants. Also, the use of internal markings, documentation flow, staff training, codes, and staff awareness–all proved useful in management of these plants.

2.3. The proposed blockchain support framework

We propose a sensor-based RFID blockchain model–that: i) first, ear-tags livestocks during breeding stage, ii) at maturity, retrieves the information of the ear-tagged livestock for onward processing as the cattle is slaughters and onward processing, and iii) the use of the tracer system to manage stakeholders and user, ranging from farmers, to wholesalers, to retailers, and finally to consumers and user (see [47], [48] for more details). The beef traceability system is a food supply management system with various dynamics, complexity, and functionality as in Figure 1. Figure 1(a) presents a tracer management system scenario [9] with five stakeholders namely: the farm, the processing, a wholesaler, a retailer, and the consumer. Each category consists of members that play same role(s) on the chain management system. The chaincodes represent smart-contracts that runs on the blockchain. Each chain processes the transaction business logic of the support system and uploads the beef production support data of the corresponding chain. Figure 1(b) represents the layered security architectural implementation for the proposed experimental BeProBE blockchain framework.

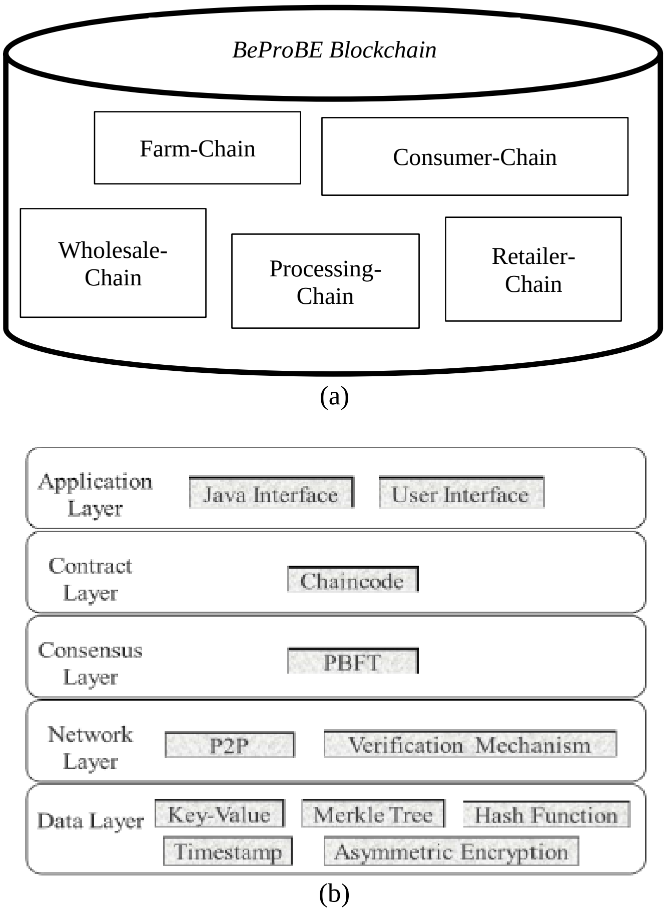

Figure 1. The proposed BeProBE blockchain structure and architecture (a) proposed beef processing blockchain ensemble and (b) the layered architecture of the blockchain

2.4. The BeProBE chaincodes/structure

The framework provides all users with historic data on all beef produced, supplied, bought, and consumed on the chain. As users register, they are granted on the chain–a pair of public/private keys pair to sign each transaction digitally on the chain via our distributed-ledger [49], [50]. The chain uses to validate as well as flag data anomalies on the network system. Algorithm 1 is an algorithm for implementing the BeProBE system.

```
Algorithm 1: The BeProBE SmartSupply Chaincode
INPUT: get Farm_addresses, get Processing_addresses, get Wholesale_addresses, get
process_banks, get_transport_info()
function check (input_address): START
if (input_address == farm_address) then
     return true: else
     Exit
end if: END
function insert_record (new_record: (beefID, beef_processed_batch, process_bank,
id_transaction_transport): START
```

```
if True ←function check (process_bank, id_transaction_transport) then
     return id_transaction_batch ←record_a_transaction (sha256(new_record)): else
     Exit
end if: END
function create_wallet (stakeholder_info): START
if True ←function check (process_bank, id_transaction_transport, input_address) then
     return process_bank_address ← wallet(stakeholder_info): else
     Exit
end if: END
function enable_stakeholder (stakeholder_address, process_bank, beef_info,
stakeholder_type): START
if True ←function check (process_bank_address, id_transaction_transport, input_address)
then
     if (stakeholder_type == known_stakeholder) then
     map_beefID ← put(stakeholder_info, beef_code);
     Process_bank_list ← add(stakeholder_info);
     return true
end if: else
     Exit
end if: END
```

The chain is explained thus [2], [51]–[54]:

- Farm record and validate data of all cattle that were purchased as calves and ear tagged using the sensor-base RFID. Data include the purchase date of the calf, transport, inoculation date, and harvest. The system collates relevant information on the consumption rates across Nigeria. This, serves as validation to help audit the farm process–and issue smart contracts automatically. This data (as an immutable record) helps detect record/value anomalies that occur as outliers in certain thresholds.
- Processing includes all tasks from harvest-to-storage within the processing pool. The smart contracts act as means to aid checks and validate the process inflow/outflow in the chain. All records are banked from the total amount of products received from producers, amount packaged, and amount of product lost at processing.
- Wholesale: processors transfer ownership of the processed product to distributors, directly via the chain. The data is entered via a distributor's app via sensors and smart contracts can automatize the process and create records as anomalies are detected during delivery (e.g., sensor values outside certain thresholds).
- Retail stores detail the received amount of product from distributors and at regular intervals, sensors autonomously store status information of the retail environment. Smart contracts can asynchronously fire to create records if anomalies are detected (e.g., sensor values outside certain thresholds).
- Consuming: retailers store data of sold products on the chain–so that, consumers can transparently verify the entire history and price of any product before purchase is made. The chain also used smart tags to identify each package sent through the chain so that consumers can easily track and retrieve a complete history of the product purchased or otherwise.

3. RESULTS AND DISCUSSION

To evaluate the performance of the proposed BeProBE blockchain-based tracer management model we are poised to use two tests parametrics to evaluate the model's performance namely the throughput by transaction and the application's response time. The throughput by transactions to seeks to determine the model's capacity for the actual transfer rate of data. While, the application or system's response time, which seeks to measure and determine the time interval between a user's request and the feedback to the user.

3.1. Throughput by transaction

We used the Riverbed Modeler 18.0 for test metrics. Throughput is a metric test that essentially determines the system's capacity for the actual transfer rate of data within the system over some time. Here, we measure the number of transactions per second on the proposed blockchain as seen in Figure 2. The number of transactions per second was obtained from the graph above. In tandem with [55]–[57] transactions per second for other blockchains models were found to be less than 30. A feature attributed to their proof of work (PoW) adaptation [58], which is a consensus mechanism that helps each user on the chain to effectively and efficiently, compute the posed task during its mining. The nature of each task requires loads of computational power vis-a-vis processing time. However, our traceability model employs a permissionless chain. Thus, the transaction per second of our experimental framework is about 1,101.

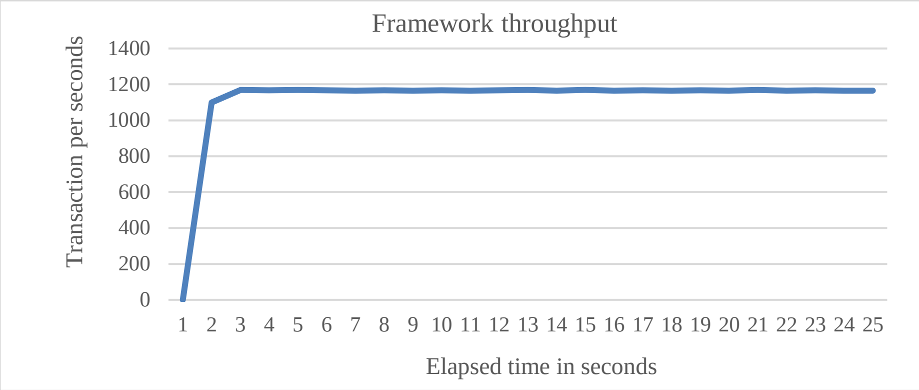

Figure 2. The BeProBE framework throughput

3.2. Application response time

This performance metric seeks to determine the time interval between a user's request and application response time for feedback to the user. We achieve this by measuring the response time from a query on the https page. Querying data means reading such data via the world-state as stored in the blockchain's hyper-fabric ledger [10]. The data are stored as a record, which is a generated key-value pair. Thus, we can query and retrieve data directly as current key-value(s) of a record sought, without it traversing the whole ledger. This, in turn, improves the efficiency and effectiveness of the traceability system. Thus, for the first scenario with a population of 2,500 users, response time was about 0.21 s for queries and 0.28 s for https pages retrieval. While for scenario 2–we experienced a longer response time of about 0.32 s and 0.38 s respectively for both the queries and https pages retrieval.

3.3. Discussion of findings

From Algorithm 2 once beef is harvested at full maturity, it proceeds from the farm to the processing store/bank, where detailed information about the farm and cattle is subjected to processing. Information from the ear-tagged (sensor-based RFID chip) cattle is retrieved and processed via the processing bank to enable for shipment to the various wholesalers. A sample 1 kg tagged beef_1234 is harvested (i.e. state of the transaction) with the batch_1234, and from Farm_Ibusa–implies 1 kg of beef_1234 is harvested with the first batch_1234 from the Farm_Ibusa in December_1. And is subsequently, first processed by the Abattoir_Ibusa.

Algorithm 2: Processing_Bank_Ibusa_Harvested_Rice
```
Harvester = Abattoir_Ibusa
Beef = 1234
Owner = Farm_Ibusa
Harvest Date = 1st December
Current_State = Harvested
```

Thereafter, the beef is taken for processing at the Beef_Abattoir_Asaba as in Algorithm 3. The Algorithm 3 changes from a processing_transaction to a buy_transaction. Thus, note how the same 1 kg amount of beef_1234 changes some of its properties from harvest to processing due to the buy transaction.

Algorithm 3: Abattoir_Asaba_Buys_Harvested_Beef_From_Abattoir_Ibusa
```
Harvester = Abattoir_Ibusa
Beef = 1234
Owner = Beef_Abattoir_Asaba
Harvest Date = 1st December
Value = 3500Naira
Current_State = Processing
```

The owner [abattoir_name] is viewed as the most significant change. While, the current_state_value helps the framework to identify that the beef is now being processed and safely transported across the value chain via its consequent distribution to the wholesalers-retailers-consumers chain. Where again, the state changes to a consume_state transaction to end the beef lifecycle. Mandatorily, records of the consumed beef are still kept on the chain, and the current_state of consumed is noted to aid in tracing and further management. In addition, the value of the owner_property is used by the ledger to control access on the consume_transaction by comparing this owner_property vis-a-vis the identity of each transaction creator via the chaincodes.

4. CONCLUSION

We present a beef traceability model that uses a permissioned chaincode to control nodal queries. In addition, all nodal classes (i.e. farm, processing, and retail) roles were encrypted using SHA256 protocol to secure sensitive data that are uploaded to the chain. The hyper fabric ledger helps to handle all transaction logic, and the resulting model showed a low response time to the query request alongside stable time convergence for the application throughput.

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