# eCattle: A Platform for Traceability and Management of Livestock Transactions using Smart Contracts

DOUBLE-BLIND

*Abstract*—**Livestock farming is vital to the global economy, but faces challenges in traceability, sustainability, and productive efficiency due to a lack of standardization and difficulties in data sharing. With the increasing demand for transparency, blockchain technology emerges as a solution, standing out for its decentralization, immutability, and transparency. This study explores the application of blockchain in livestock farming, developing a blockchain network and a system called eCattle for herd monitoring and management. The research addresses the challenges of current systems and presents a blockchain-based prototype for the sector. The study emphasizes the revolutionary potential of blockchain to strengthen trust and sustainability in the livestock production chain.**

*Index Terms*—**Smart Contracts, Productive Efficiency, Traceability, Livestock.**

## I. Introduction

Livestock farming is integral to food security, the global economy, and community livelihoods, offering products like meat and milk and contributing to land and ecosystem management. Yet, it encounters challenges in sustainability, animal welfare, and environmental concerns, particularly in herd traceability, crucial for product quality assurance [9], [30], [35].

Challenges in animal life cycle traceability, crucially augmented by blockchain technology, include lack of standardization, inefficient tracking systems, and information sharing difficulties. These issues pose risks to both animal and human health and may enable illegal activities due to unreliable verification and validation of animals and their products [29], [40]. Traditional tracking technologies, without blockchain, face limitations like standardization absence, centralization, data sharing difficulties, and high implementation costs [30], [36].

Blockchain emerges as a promising solution with decentralization, immutability, security, and transparency, enhancing trust, real-time secure information sharing, and tracking system efficiency [30], [42]. Growing consumer demand for food supply chain transparency, driven by health, welfare, sustainability, and ethical concerns, aligns with blockchain's ability to ensure accurate and reliable information about animal-derived products.

This paper introduces the eCattle system, utilizing blockchain to enhance traceability, security, and quality in the livestock industry. The study includes:

- Critical Analysis of Current Tracking Systems: The study begins with a detailed investigation of the challenges faced by existing animal tracking systems, identifying significant gaps where Blockchain can offer substantial improvements. This analysis provides a crucial backdrop for our academic contribution, situating our work within the broader context of IS research.
- Innovation in Architecture and Data Model: The paper proposes an innovative architecture and data model for a Blockchain-based cattle tracking system. This model has been carefully designed to meet the specific needs of the livestock industry, offering a more efficient, secure, and transparent solution compared to traditional systems. The adopted approach represents a significant advancement in the IS field, offering new perspectives and tools for researchers and practitioners.
- Prototype and Analysis of Results: The development of a functional prototype of the proposed system is accompanied by a rigorous analysis of its results. This section of the paper not only demonstrates the feasibility of the proposed Blockchain solution but also highlights its contributions to efficiency and transparency in the livestock industry. The analysis of the results provides valuable insights into the practical implications of the system and its relevance compared to other works in the area, emphasizing its unique contribution to the IS field.

The remainder of this paper is organized as follows: Section II discusses the theoretical framework related to the study proposed in this paper; Section III presents the methodology used; Section IV outlines the procedures for the development of the proposed system; and finally, Section V discusses the final considerations and premises for future work.

## II. Theoretical Background

This section presents the theoretical framework related to this study, discussing challenges in the traceability process within the livestock sector, Blockchain technology, and related works.

### A. Challenges in Livestock Traceability

The livestock industry, though crucial for global nutrition, faces several traceability challenges concerning tracking animals throughout their life cycle, up to the slaughter phase [30], [36]. These include a lack of standardization and interoperability in tracking systems, vulnerability due to centralized systems, difficulties in data access and sharing, high costs, and complexity in implementing effective systems, resistance to adopting new technologies, and differences in traceability laws and regulations [29].

Current herd tracking technologies are vital for livestock management, assisting in monitoring the health, location, and performance of animals. These technologies include visual and electronic identification of animals, location systems like GPS (Global Positioning System), and Geofencing, health and performance monitoring through biometric sensors, automated milking systems, and electronic scales. Furthermore, centralized databases and agricultural information systems, as well as cloud-based traceability systems, are used to store and manage information about animals. However, these technologies still face challenges, such as standardization, interoperability, security, and cost [3], [30], [42].

The lack of standardization and interoperability in cattle tracking systems presents significant challenges that go beyond operational limitations. These gaps can lead to elevated risks for animal and human health, particularly due to the inability to efficiently trace diseases and ensure food safety [30].

For instance, without proper standardization, vital information about vaccinations, disease treatments, or even the origins of animals can be lost or misinterpreted [29]. This increases the risk of zoonotic disease outbreaks, which can be transmitted from cattle to humans, causing significant public health impacts [3]. Moreover, the lack of interoperability between different systems hampers the exchange of information among various stakeholders [42].

Inefficient traceability also facilitates illegal practices, such as the sale of sick or unregulated animals [16]. Without a reliable system that tracks the history of each animal, it becomes difficult for consumers and regulators to verify the authenticity and quality of animal-derived products.

Economically, the lack of efficient traceability hinders the optimization of the cattle supply chain [22]. Farmers and businesses face challenges in monitoring livestock performance, implementing management improvements, and meeting specific quality standards required in the global market [23].

Finally, traceability challenges affect consumer trust [43]. In an increasingly sustainability and animal welfare-conscious world, the ability to trace an animal's journey from farm to table is crucial [39].

In this context, Blockchain technology emerges as a potential solution to overcome many of the limitations of current tracking systems, offering a more efficient and reliable alternative for traceability in the livestock industry.

### B. Blockchain Technology

With the advent of digital technology and the growing need for transparency and security, blockchain architecture has emerged as a robust and decentralized solution. It can be defined as a decentralized, secure, and transparent distributed ledger, composed of interconnected blocks that store and protect information. Each block contains transactions or data records, and once added to the chain, its information becomes virtually immutable, ensuring the reliability of stored data [20], [30].

This technology operates on concepts like distributed ledger, cryptography, immutability, consensus, transparency, and *smart contracts*. Its functioning involves network initialization, transaction execution, block formation, mining and consensus, verification and addition of blocks, chain update, and incentives through rewards [12], [42].

Furthermore, Blockchain can support *smart contracts*, which are programs that execute predefined actions when certain conditions are met. This allows for process automation and facilitates cooperation between different parties [30].

The blockchain architecture operates on a decentralized network of nodes, where each node has a complete copy of the chain. Consensus is achieved through specific protocols, such as PoW (Proof of Work) or PoS (Proof of Stake), ensuring transaction integrity and validation [8]. One of the main advantages of this architecture is its resistance to failure, fraud, and manipulation, as altering a block would require changing all subsequent blocks in the chain.

In the agricultural sector, blockchain technology has been used to improve traceability, efficiency, and reliability. In the context of livestock, particularly the cattle market, it faces significant challenges in terms of tracking, transparency, and transaction efficiency. Examples of its application include traceability of cattle and dairy supply chains, animal welfare certification, *smart contracts* and financing, and veterinary record management [15], [26]. By following this process, Blockchain allows for information transparency and verifiability, increasing consumer trust in the origin and authenticity of animal products [20].

To address these issues, this project developed a blockchain network and a web system to manage cattle transactions. This innovative system, called eCattle, aims to provide a transparent and secure solution for transaction management, as well as a mechanism for tracking events related to animals.

### C. Blockchain Applications in Livestock

Blockchain technology is being applied in the livestock industry to improve traceability, efficiency, and trust in the sector. Various recent works have explored different aspects of this application. For example, BeefLedger focuses on the traceability of the beef supply chain, while Ambrosus develops solutions for the dairy supply chain [4], [21]. Vion Food Group and AgriChain address, respectively, animal welfare certification and facilitation of financial and payment transactions through smart contracts [1], [45]. The company Vetsource uses blockchain for veterinary record management [44].

In contrast to current solutions that predominantly focus on isolated aspects of the livestock chain, such as animal welfare, food traceability, or veterinary records, the eCattle project represents a significant innovation in agricultural technology. This integrated system has been developed to holistically encompass livestock management, extending from breeding to complete animal traceability. The main distinction of eCattle lies in its ability to offer a comprehensive view, unifying traceability, animal welfare management, and administrative process efficiency into a single system. Besides ensuring the quality of the meat produced, eCattle stands out by introducing significant improvements in tracking accuracy, efficient herd management, and proactive animal welfare monitoring, all coupled with an intuitive interface and optimized administrative processes. This integrated approach not only simplifies day-to-day operations for producers but also offers significant added value in terms of transparency and reliability for end consumers, positioning eCattle as a pioneer in comprehensive solutions for the agricultural sector.

To develop the proposed system, the methodology presented in the next section was defined.

## III. Methodology

This section presents the methodology adopted for the development of the eCattle system. The main languages and frameworks used are discussed, along with the choice of the Blockchain platform.

### A. eCattle System Architecture

Figure 1 presents the system architecture. For the development of a herd management and tracking system using Blockchain, a structured and modular approach was adopted, ensuring the system's scalability and maintainability. The system development was stratified into several layers. The *frontend* corresponds to the part of the system that directly interacts with the user. It was developed using technologies such as HTML (HyperText Markup Language), CSS (Cascading Style Sheets), and JavaScript, along with the Bootstrap framework.

The *backend* corresponds to the part of the system responsible for processing application logic, database management, and communication with the Blockchain. It was developed using PHP (Hypertext Preprocessor) programming language [27] and the CodeIgniter framework [13].

The implementation of blockchain in this project aimed to provide a secure and decentralized mechanism for recording and tracking transactions and information related to animals and owners.

For the eCattle system, which involves registering and tracking cattle herds using Blockchain, Hyperledger Fabric was chosen. It is an open-source Blockchain framework, developed by the Linux Foundation, designed to be highly modular, scalable, and secure [2], [18]. The reasons for choosing Hyperledger Fabric are: permission and privacy; performance and scalability; modularity and flexibility; support for *smart contracts* [18].

The eCattle system uses a hybrid database, combining a traditional local database management system (DBMS) with a blockchain platform. This approach allows the system to leverage the advantages of both types of data storage, ensuring security and immutability for critical information and greater flexibility for less sensitive data [28].

### B. Blockchain Network Structure

For the configuration and deployment of the Hyperledger Fabric network, it was necessary to define the organizations, peers, orderers, and a channel, in addition to defining access and consensus policies, creating and installing chaincodes. *Chaincode* refers to the specific business logic of an application on a blockchain network, functioning similarly to a "smart contract." It defines and executes rules for transactions, ensuring the integrity and confidentiality of operations within the Hyperledger Fabric platform, and creating communication channels between organizations [18]. A vital component of the business logic defined in these chaincodes is smart contracts.

To achieve integration between the web application and the blockchain, a RESTful API (Application Programming Interface) was developed [10]. This API allows the execution of chaincode functions and transactions, and it is used to query and modify data stored in the blockchain, in addition to invoking smart contracts to execute the business logic.

### C. Modeling of the eCattle System

The eCattle system has specific functionalities for herd management, such as registration and updating of animal information, as well as data analysis and customized reports. These functionalities aim to allow users to monitor herd performance (weight gain, milk production, health issues, and transactions between owners) and make informed decisions based on reliable and up-to-date data.

The system architecture alludes to the overall structure, encompassing its components and interactions between them. In this context, the organization and communication among the system's parts proved essential for ensuring scalability, maintainability, and efficiency.

The system's architecture is divided into five main components: *View*, *Controller*, *Model*, MariaDB Database [24], and Hyperledger Fabric Blockchain.

- ***View*:** Written in PHP, Javascript, CSS, and HTML, this container is the user interface. It provides pages with forms and buttons for the "Owner" (system user) to interact. The communication between the *View* and the client is made via HTTPS (Hypertext Transfer Protocol Secure).
- ***Controller*:** Using the PHP CodeIgniter framework, this container acts as an intermediary between the *View* and the *Model*. It contains calls for the execution of the commands requested by the user. The *Controller* is triggered when the client makes a request via HTTPS, and then updates the *View*.
- ***Model*:** Also built on the PHP CodeIgniter framework, this container defines rules, methods, objects, and database connections. It is called by the *Controller* to perform the requested operations and returns the necessary information to update the *View*.
- **MariaDB Database:** This database container stores information about users, animals, and farms. The *Model* reads and writes in this database through the PDOMARIADB connection.
- **Hyperledger Fabric Blockchain:** This container specializes in storing transaction information and cattle tracking.

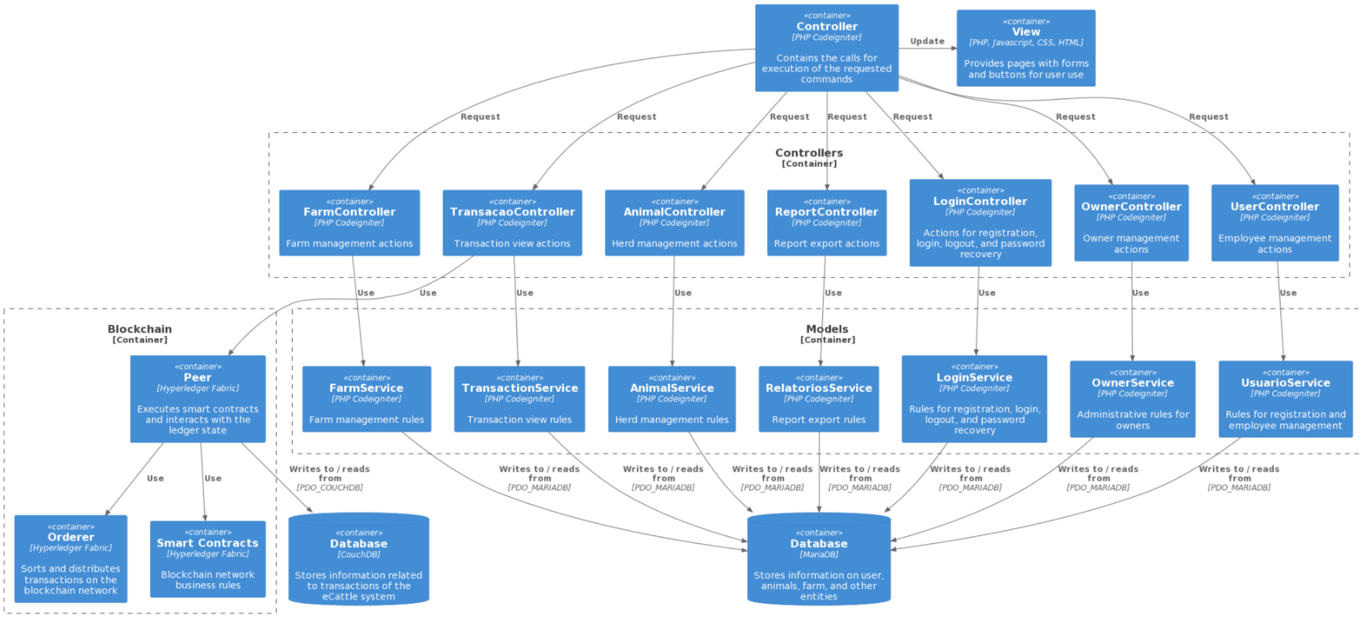


Fig. 1. eCattle Components.

The *Model* can read and write on the blockchain using the Fabric SDK [19].

The containers are interconnected in a way that reflects the operations and interactions that occur within the system. The architecture highlights modularity and clearly shows the responsibilities and interactions between each component. Figure 1 shows a granular view of the architecture of the eCattle system. The complexity of the system is divided into various specific components (Controllers, Models, and Blockchain), each with its own function and responsibility. Each *Controller* has a corresponding *Model* that defines the business rules and interacts with the MariaDB database through the PDOMARIADB connection.

- ***LoginController:*** Handles actions for registration, login, logout, and password recovery. Uses "*LoginService*" from the *Model* for related rules.
- ***OwnerController:*** Manages actions related to the farm owner. Uses "*OwnerService*" from the *Model* for administrative rules.
- ***UserController:*** Controls employee management actions. Uses "*UserService*" from the *Model* for registration and management rules.
- ***FarmController:*** Manages actions related to farm management. Uses "*FarmService*" from the *Model* for farm management rules.
- ***AnimalController:*** Handles herd management. Uses "*AnimalService*" from the *Model* for management rules.
- ***ReportsController:*** Controls actions for report exportation. Uses "*ReportsService*" from the *Model* for export rules.
- ***TransactionController:*** Manages transaction views. Uses "*TransactionService*" from the *Model* for view rules.
- ***MariaDB:*** Stores information about users, animals, farms, and other entities. Each service in the *Model* interacts with this database.
- ***CouchDB:*** Stores information related to transactions in the eCattle system. The *Peer* in the blockchain interacts with this database.
- ***Orderer*:** Orders and distributes transactions on the Hyperledger Fabric blockchain network.
- ***Peer*:** Executes the smart contracts and interacts with the state of the ledger. Also interacts with *CouchDB* to store and read information.
- ***Smart Contracts*:** Defines the business rules of the blockchain network. It is used by the *Peer* for the execution of smart contracts.

The structure highlights the system's modularity, allowing a clear understanding of the components and their interactions.

Implementing the eCattle system in a real-world environment demands a blockchain network composed of multiple peer nodes, operated by various independent organizations. This structure is crucial for ensuring the decentralization and effectiveness of the proposed solution. The analysis of the system's scalability reveals that adding new nodes and organizations is feasible but requires careful assessment of network capacity and available computational resources. This approach ensures that the system can adapt and scale according to the needs of the agricultural sector. The next section presents the development stages of the eCattle system.

## IV. Development of the eCattle System

The eCattle system was designed and developed in a modular and scalable manner. This means that it is possible to integrate with external systems, such as mobile apps and other farm management software, through APIs. The system originated from conversations with professionals in the field.

Access control and security, crucial aspects of the system, were implemented using advanced authentication and authorization techniques and technologies, provided by the integrated APIs of the CodeIgniter framework. These APIs provided robust mechanisms for user authentication and permission-based access control, ensuring that only authorized users could access and modify sensitive information. This authentication and authorization system was complemented with the validation and authentication of rural producers, in accordance with their state registrations. The modular structure of the system and the component-based architecture of CodeIgniter not only facilitate the implementation of new functionalities but also problem-solving and continuous performance improvement of the system.

In summary, the proposed system offers a complete and efficient solution for the management, tracking, and execution of cattle transactions, combining the security and transparency of blockchain technology with the ease of use and flexibility of a modern application. The project was developed with a focus on usability, scalability, and integration, ensuring that the system can grow and evolve along with the needs of users and the market.

The definition of the requirements of the eCattle system was based on a detailed information-gathering process, which included in-depth interviews with inspectors from the IMA (Instituto Mineiro de Agropecuária). A total of 15 interviews were conducted with professionals who have significant experience in the agricultural sector, ranging from field inspectors to regional administrators. The interviews were conducted in a semi-structured manner, allowing for a detailed exploration of practical needs and challenges faced in the daily management of livestock. Each interview session lasted approximately 1 hour and was conducted both in person and via videoconference, depending on the participants' availability. During the interviews, aspects such as current cattle tracking challenges, process efficiency, and specific requirements for improving livestock management were discussed. The information gathered was fundamental in shaping the functional and non-functional requirements of the system, aiming for a design that meets the real needs of the sector. Table I refers to the functional requirements and Table II refers to the non-functional requirements.

TABLE I
FUNCTIONAL REQUIREMENTS

| | |
|---|---|
| User Registration and Management | The system allows the registration of owners and their respective employees, as well as the maintenance of their personal information, including name, email, and password. |
| Authentication and Authorization | The system provides authentication and authorization mechanisms to ensure that only authorized users have access to relevant functionalities and information. |
| Livestock Registration and Management | The system allows for the recording and maintenance of detailed information about herd animals, such as identification, species, breed, age, weight, sex, and health history. |
| Cattle Tracking and Monitoring | The system integrates with the blockchain network to store and track relevant cattle information throughout their lives, including movements, medical treatments, breeding events, and slaughter, when applicable. |
| Data Visualization and Analysis | The system offers graphical interfaces for the visualization and analysis of stored data, allowing users to monitor herd performance, identify trends, and make informed decisions. |
| Access Control and Security | The system ensures the security and privacy of stored information by implementing access control mechanisms and encryption. Only users authenticated as owners have access to herd-related registration functionalities. The user's access password is stored in the database with hash encryption, which has 64 hexadecimal characters. |
| Integration with External Systems | The system is capable of integrating with other systems and platforms, such as agricultural management systems and environmental monitoring systems, to collect and share relevant information. |

TABLE II
NON-FUNCTIONAL REQUIREMENTS

| | |
|---|---|
| Scalability | The system is designed to support an increase in the number of users and data volume. |
| Availability | The system must be available for access and use at any time, minimizing interruptions and downtime. This can be ensured by hosting the system on a virtual machine in a datacenter. |
| Security | The system must ensure the protection of stored information against unauthorized access, attacks, and data leakage. This is achieved through TLS encryption and digital certificates configured on the blockchain network. |
| Portability | The system is compatible with various devices and browsers, allowing users to access and use it on different platforms and environments. This is ensured through the standardization of languages and frameworks used in the system's development. |
| Maintainability | The system is designed in a modular way with clear and documented code, facilitating maintenance, updates, and bug fixes. |

### A. *eCattle System Artifacts*

The initial phase of the eCattle system development involved defining the modeling artifacts. These artifacts included UML (Unified Modeling Language) diagrams, a standardized language for visualizing, specifying, constructing, and documenting aspects of software systems [6].

Figure 2 presents the generated use case diagram, with users represented by actors, positioned outside the rectangle referring to the system. The system functionalities are described through balloons, representing the use cases.

The functionalities presented include animal management, farm and owner management, monitoring of animal health conditions, animal tracking, transaction management via blockchain, visualization and general data analysis, and integration with external systems.

The class diagram was another visual modeling tool employed. Used in UML language, the class diagram represents the design of an object-oriented system. It illustrates the classes involved in the system, their attributes, methods, and the relationships between them. This diagram is fundamental for understanding the functioning and organization of a system during the software development phase. Figure 3 shows the proposed class diagram for this project.

### B. *Blockchain Network Development*

The network is composed of two organizations, a Certificate Authority, an order node, and two peer nodes, one peer for each organization. The services are defined and managed through Docker Compose [38]. The network operates within a single channel called eCattle Channel. The file configtx.yaml defines organizations, policies, and capabilities. Certificate generation is managed by crypto-config.yaml. Policies and certificates ensure the network's security and governance.

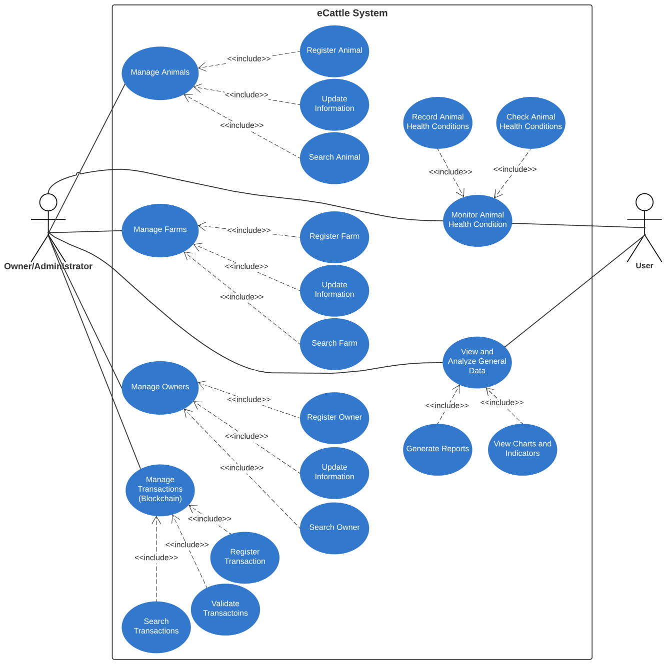


Fig. 2. Use case diagram of the proposed system.

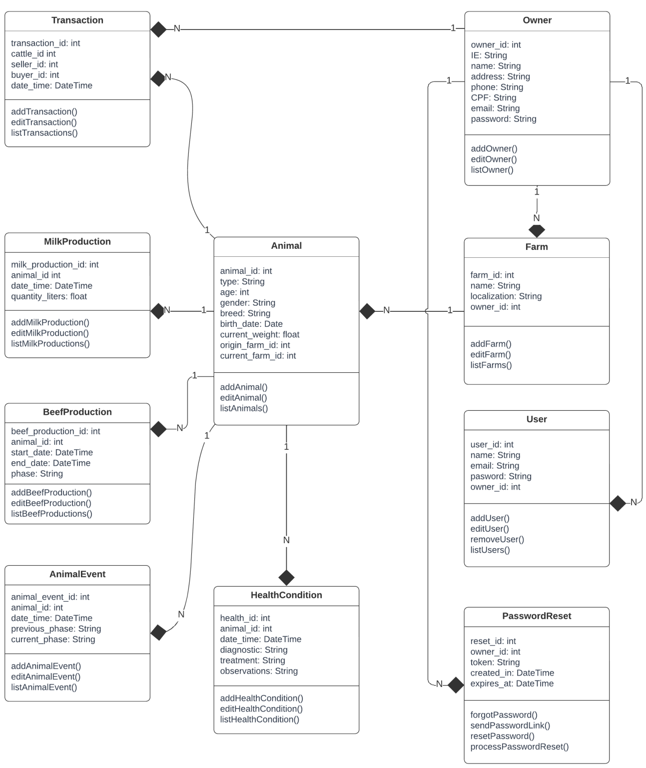


Fig. 3. Class Diagram.

Identity management and access control are fundamental components to ensure the integrity, transparency, and security of transactions. In the system, digital certificates issued by a specific certification authority are used to authenticate and identify the peer nodes in the blockchain network. These certificates are akin to a digital identity card, providing verifiable and reliable information about each node. In this project, the nodes, such as Peer 1 and Peer 2, are validated and associated with the eCattleOrg and Org2 organizations, respectively, through two MSPs (Membership Service Providers), known as eCattleOrg.MSP and Org2.MSP.

MSPs are not just identity mappers; they are the essential mechanism that defines the role and privileges of each node within the organizations. They specify the operations a node can perform and the data it can access or modify within the blockchain. Each peer node in the network is unique to one organization, in this case, eCattleOrg and Org2, and is therefore linked to its own MSP.

The functionality of this identity system is extendable to all entities interacting with the eCattle system's blockchain network. This includes not only the peer nodes but also applications, end-users, and administrators, all of whom must have a digital identity and an associated MSP to interact securely and effectively with the network.

The MSP feature provides a robust layer of security and governance, allowing the eCattle system to operate with the necessary reliability and efficiency to manage complex transactions and sensitive data related to animal, farm, and owner management. In summary, the MSP serves as the backbone connecting digital identity to the specific organizational function, ensuring a secure and effective operation of the entire eCattle network.

Four smart contracts responsible for managing animals, farms, owners, and transactions have been developed. These contracts are vital for handling the entities within the system.

- ***AnimalContract:*** this contract deals with the creation and manipulation of animals on a farm and includes various classes for animal production and health.
- ***FarmContract:*** this contract deals with the creation and manipulation of farms.
- ***OwnerContract:*** this contract deals with the creation and manipulation of farm owners.
- ***TransactContract:*** this contract deals with the creation and manipulation of livestock-related transactions, such as the sale of an animal.

The mechanism by which the web platform and the peers interact with each other to ensure that the record of all peers is kept consistent is mediated by special nodes called orderers. Figure 4 presents a flowchart of how the interaction between peers and the system's orderer operates in eCattle.

The interaction between the peers and the orderer is crucial for maintaining the consistency of the ledger. The ledger update occurs through a three-phase process:

1) **Proposal:** The web platform generates a transaction proposal (P) from transaction T1 and sends it to a subset of endorsing peers (Peer 1 and Peer 2). These peers evaluate the proposal by running the chaincodes (in this case, one of the 4 developed smart contracts), but do not apply it to the ledger; they merely sign it and return

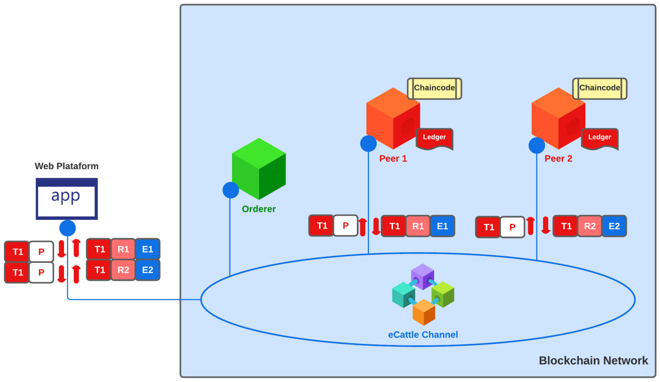


Fig. 4. Interaction between peers and orderer.

the responses R1 and R2, endorsed by E1 and E2. The decision about which peers will endorse the transaction is guided by an endorsement policy linked to the eCattle channel.

2) **Ordering and Packaging Transactions into Blocks:** The orderer comes into play here. It receives the endorsed transactions and organizes them into blocks. This process is vital for maintaining order and consistency among the peers.
3) **Validation and Confirmation:** The blocks are distributed back to the peers through the orderer. Each peer validates the transactions in the blocks to ensure they are consistently endorsed by the eCattleOrg organization before being confirmed on the ledger, as can be observed in Figure 5.

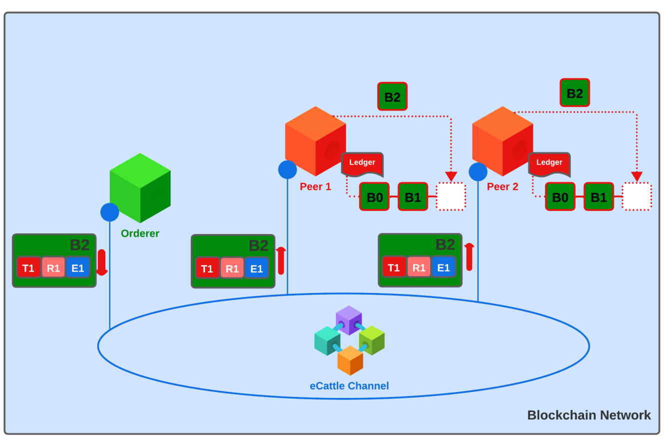


Fig. 5. Validation and confirmation of transaction blocks.

The eCattle system integrates blockchain technology to record and validate all cattle buying and selling transactions, ensuring an immutable and transparent audit trail. Moreover, the management of events related to the animals, such as vaccination, birth, and death, is also captured on the blockchain, providing a complete and accurate view of each animal's history.

The system provides a robust framework for managing animals, farms, and owners, as well as for handling complex transactions related to these entities. The implementation includes stringent checks to ensure all necessary parameters are present and valid according to business rules.

The business rules define the underlying logic and system constraints, including the classification of animals as 'beef' or 'milk'; the association of each animal with an owner and two farms (origin and current); tracking of the animals' stage and health; management of specific events for types of animals; and management of animal transfer or buying and selling transactions.

To ensure data integrity and consistency, several validations have been implemented:

- **Farm Validation:** Ensures that the current farm belongs to the same owner as the animal.
- **Event Type Validation:** Verifies that the event corresponds to the type of animal.
- **Animal Stage Validation:** Ensures that the current stage complies with the permitted stages for that type of animal.
- **Owner Validation:** Confirms that the owner conducting the operation is logged in.
- **Slaughter Validation:** Checks that the animal has not been slaughtered prior to updating or adding an event.
- **Health Validation:** Certifies that the health condition belongs to the logged-in owner and that the date is not in the future.

After the modeling of the eCattle System and the creation of the blockchain network, the integration between them was carried out.

### *C. Integration between the eCattle System and the Blockchain Network*

The proposed integration aims to align the web system's versatility and accessibility with the security and immutability of blockchain. This alignment allows system users to benefit from a transparent and unalterable record of transactions and data related to cattle. Table III shows the benefits of integration with blockchain. Table IV shows the challenges and considerations of that integration.

The integration was planned to be bidirectional. The web system, built on the Codeigniter framework, communicates with the blockchain network (based on Hyperledger Fabric) through dedicated APIs. This ensures that any activity or transaction recorded in the web system is simultaneously recorded on the blockchain, providing an additional layer of verification and security.

Figure 6 shows the initial screen of the eCattle system, commonly referred to as the dashboard, serving as the command center for effective farm and livestock management. Designed to offer an immediate and comprehensive overview, the interface displays critical information organized in an intuitive and easily accessible manner. At the top, the owner can see essential statistics such as 'Total Animals' and 'Total Farms,' providing a quick summary of their managed farm and livestock operations.

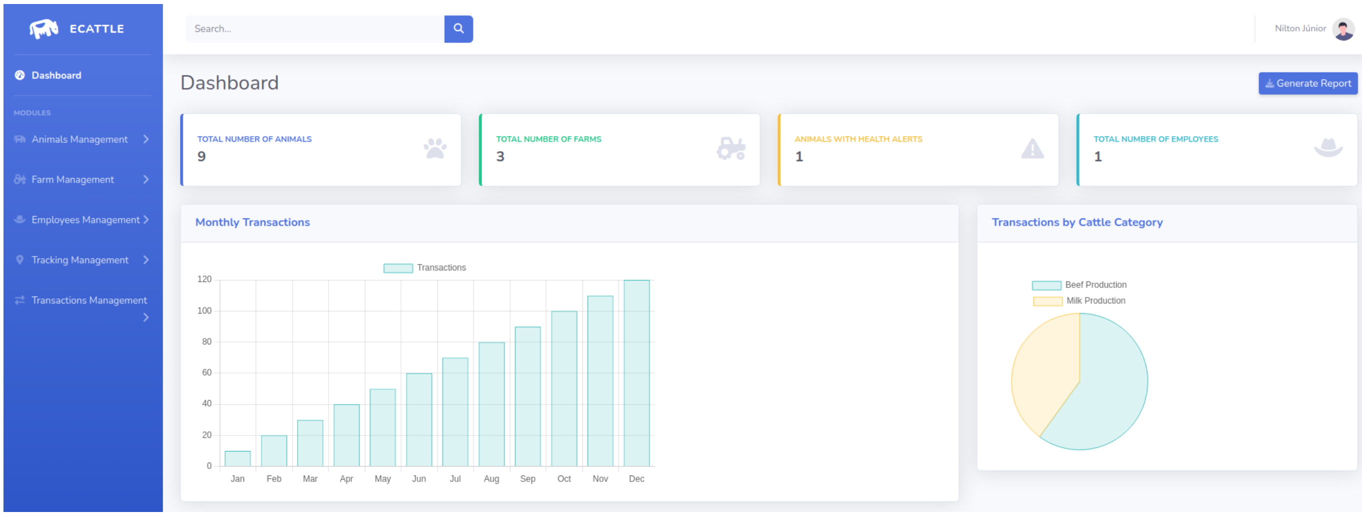


Fig. 6. Dashboard of the eCattle system in its current version.

TABLE III
BENEFITS OF INTEGRATION WITH BLOCKCHAIN

| | |
|---|---|
| Enhanced Security | The decentralized nature of blockchain ensures that data is tamper-proof. |
| Transparency | All transactions are transparently recorded, allowing for more efficient audits and better traceability. |
| Reduction of Inconsistencies | The integration reduces the possibility of outdated or conflicting data between the web system and the blockchain network. |
| Process Automation | Smart contracts can be triggered based on defined criteria, allowing for the automation of various activities and decisions. |

TABLE IV
CHALLENGES AND CONSIDERATIONS OF INTEGRATION WITH BLOCKCHAIN

| | |
|---|---|
| Latency | The consensus nature of blockchain can introduce minor latencies during the recording of transactions. |
| Maintenance | Ensuring that updates to the web system and blockchain network are compatible requires continuous monitoring. |
| Costs | While the integration brings numerous benefits, the costs associated with maintaining a blockchain network must be considered. |

Furthermore, the 'Health Alert Animals' section highlights any impending need for veterinary attention, allowing quick actions to preserve the herd's health. The 'Total Employees' provides an overview of the team size responsible for animal care and farm maintenance.

Last but not least, the option for 'Report Generation' is readily available, facilitating the creation of detailed reports that can be used for performance analysis, strategic planning, or regulatory compliance. Each of these elements is designed to enable users to make well-informed decisions directly from the initial screen, making farm management more efficient and effective.

## V. CONCLUSIONS AND FUTURE WORK

Despite the pressing challenges in livestock farming, particularly around herd traceability, this industry remains a crucial pillar in the global economy. The inherent barriers, encompassing issues like lack of standardization and inefficient tracking systems, highlight an imperative need for innovative solutions. This research sought to bridge this gap, emphasizing the transformative potential of Blockchain technology in tackling these challenges.

The essence of our exploration revolved around the intersection of Blockchain's unique features with the demanding requirements of herd traceability. Our focus was not just on scrutinizing the current shortcomings of animal tracking systems but chiefly on revolutionizing these systems. The eCattle system represents this revolution, radically transforming how cattle herds are registered, managed, and monitored. It introduces a new level of transparency and security, offering a disruptive and innovative solution that redefines industry standards, establishing a new model for efficient and secure herd management.

Throughout this paper, the detailed development of the web system and its planned architecture for integration with the blockchain network have been described. The complete integration and validation of operational tests will be developed in future works, considering usability tests with users from this sector.

## REFERENCES

[1] P. Gallo, F. Daidone, S. F. Sgroi, and M. Avantaggiato, "AgriChain: Blockchain Syntactic and Semantic Validation for Reducing Information Asymmetry in Agri-Food," in Proceedings http://ceur-ws.org ISSN, vol. 1613, 2022, pp. 0073.

[2] E. Androulaki et al., "Hyperledger fabric: a distributed operating system for permissioned blockchains," in Proceedings of the thirteenth EuroSys conference, 2018, pp. 1–15.

[3] M. M. Aung and Y. S. Chang, ”Traceability in a food supply chain: Safety and quality perspectives,” Food control, vol. 39, 2014, pp. 172–184, Elsevier.
[4] C. Zhang, Y. Gong, and S. Brown, ”Case Analysis: BeefLedger,” in Blockchain Applications in Food Supply Chain Management: Case Studies and Implications, Springer, 2023, pp. 99–139.
[5] J. Bonneau et al., ”Sok: Research perspectives and challenges for bitcoin and cryptocurrencies,” in 2015 IEEE symposium on security and privacy, IEEE, 2015, pp. 104–121.
[6] G. Booch, The unified modeling language user guide, Pearson Education India, 2005.
[7] S. Brown, The Art of Visualising Software Architecture, Leanpub, 2015.
[8] V. Buterin et al., ”A next-generation smart contract and decentralized application platform,” white paper, vol. 3, no. 37, 2014, pp. 2–1.
[9] Food and Agriculture Organization of the United Nations et al., The State of Food Security and Nutrition in the World: 2022: Repurposing Food and Agricultural Policies to Make Healthy Diets More Affordable, FAO, 2022.
[10] R. T. Fielding, Architectural styles and the design of network-based software architectures, University of California, Irvine, 2000.
[11] D. Flanagan, JavaScript: The Definitive Guide, O’Reilly, London, 2006.
[12] J. F. Galvez, J. C. Mejuto, and J. Simal-Gandara, ”Future challenges on the use of blockchain for food traceability analysis,” TrAC Trends in Analytical Chemistry, vol. 107, 2018, pp. 222–232, Elsevier.
[13] A. Griffiths, CodeIgniter 1.7 Professional Development, Packt Pub., 2010.
[14] K. G. Grunert, S. Hieke, and J. Wills, ”Sustainability labels on food products: Consumer motivation, understanding and use,” Food policy, vol. 44, 2014, pp. 177–189, Elsevier.
[15] H. Hasan et al., ”Smart contract-based approach for efficient shipment management,” Computers & industrial engineering, vol. 136, 2019, pp. 149–159, Elsevier.
[16] B. Hässler et al., ”The economic value of One Health in relation to the mitigation of zoonotic disease risks,” One Health: The Human-Animal-Environment Interfaces in Emerging Infectious Diseases: The Concept and Examples of a One Health Approach, 2013, pp. 127–151, Springer.
[17] T. Hesterberg, ”Bootstrap,” Wiley Interdisciplinary Reviews: Computational Statistics, vol. 3, no. 6, 2011, pp. 497–526, Wiley Online Library.
[18] C. Cachin et al., ”Architecture of the hyperledger blockchain fabric,” Workshop on distributed cryptocurrencies and consensus ledgers, Chicago, IL, 2016, pp. 1–4.
[19] Linux Foundation, Hyperledger Fabric SDK Documentation, 2023, [Online; accessed 30-June-2023].
[20] S. Kamble, A. Gunasekaran, and H. Arha, ”Understanding the Blockchain technology adoption in supply chains-Indian context,” International Journal of Production Research, vol. 57, no. 7, 2019, pp. 2009–2033, Taylor & Francis.
[21] K. Kampan, T. W. Tsusaka, and A. K. Anal, ”Adoption of blockchain technology for enhanced traceability of livestock-based products,” Sustainability, vol. 14, no. 20, 2022, pp. 13148, MDPI.
[22] A. Kamilaris, A. Fonts, and F. X. Prenafeta-Boldú, ”The rise of blockchain technology in agriculture and food supply chains,” Trends in food science & technology, vol. 91, 2019, pp. 640–652, Elsevier.
[23] S. K. Kraft and F. Kellner, ”Can Blockchain Be a Basis to Ensure Transparency in an Agricultural Supply Chain?,” Sustainability, vol. 14, no. 13, 2022, pp. 8044, MDPI.
[24] E. Kenler and F. Razzoli, MariaDB Essentials, Packt Publishing Ltd, 2015.
[25] A. Leff and J. T. Rayfield, ”Web-application development using the model/view/controller design pattern,” Proceedings fifth ieee international enterprise distributed object computing conference, IEEE, 2001, pp. 118–127.
[26] K. Leng et al., ”Research on agricultural supply chain system with double chain architecture based on blockchain technology,” Future Generation Computer Systems, vol. 86, 2018, pp. 641–649, Elsevier.
[27] R. Lerdorf, K. Tatroe, B. Kaehms, and R. McGredy, Programming Php, ” O’Reilly Media, Inc.”, 2002.
[28] L. Luo et al., ”On the security and data integrity of low-cost sensor networks for air quality monitoring,” Sensors, vol. 18, no. 12, 2018, pp. 4451, MDPI.
[29] R. Meeusen, A. Ciancio, and E. Pieragostini, ”Animal traceability for official control: An overview of the current situation and challenges in the European Union,” EFSA Supporting Publications, 2018.
[30] F. J. Mgonja, Z. Jing, X. Li, and S. V. Manyele, ”Enhancing Food Safety and Integrity Through Blockchain Technology: A Review of the Existing Gaps, Challenges, and Opportunities,” Food Reviews International, 2021.
[31] W. Mougayar, The business blockchain: promise, practice, and application of the next Internet technology, John Wiley & Sons, 2016.
[32] S. Nakamoto, ”Bitcoin: A peer-to-peer electronic cash system,” Decentralized business review, 2008, pp. 21260.
[33] K. T. Nguyen, ”Building Habit Tracking App with Modern Web Development,” 2022.
[34] D. Ongaro and J. Ousterhout, ”In search of an understandable consensus algorithm,” 2014 {USENIX} Annual Technical Conference ({USENIX}{ATC} 14), 2014, pp. 305–319.
[35] S. Pouliot and D. A. Sumner, ”Traceability, liability, and incentives for food safety and quality,” American Journal of Agricultural Economics, vol. 90, no. 1, 2008, pp. 15–27, Wiley Online Library.
[36] S. Radas, M. F. Teisl, and B. Roe, ”An open mind wants more: opinion strength and the desire for genetically modified food labeling policy,” Journal of Consumer Affairs, vol. 42, no. 3, 2008, pp. 335–361, Wiley Online Library.
[37] D. Raggett, A. Le Hors, and I. Jacobs, ”HTML 4.01 Specification,” W3C recommendation, vol. 24, 1999.
[38] D. Reis, B. Piedade, F. F. Correia, J. P. Dias, and A. Aguiar, ”Developing docker and docker-compose specifications: A developers’ survey,” Ieee Access, vol. 10, 2021, pp. 2318–2329, IEEE.
[39] A. Rejeb, J. G. Keogh, and H. Treiblmaier, ”How blockchain technology can benefit marketing: Six pending research areas,” Frontiers in Blockchain, vol. 3, 2020, pp. 3, Frontiers.
[40] J. Rushton and W. Gilbert, ”The economics of animal health: direct and indirect costs of animal disease outbreaks,” Working Document, vol. 84, 2016.
[41] D. Tapscott and A. Tapscott, Blockchain revolution: how the technology behind bitcoin is changing money, business, and the world, Penguin, 2016.
[42] F. Tian, ”An agri-food supply chain traceability system for China based on RFID & blockchain technology,” 2016 13th international conference on service systems and service management (ICSSSM), IEEE, 2016, pp. 1–6.
[43] Y. P. Tsang et al., ”Blockchain-driven IoT for food traceability with an integrated consensus mechanism,” IEEE access, vol. 7, 2019, pp. 129000–129017, IEEE.
[44] Vetsource, ”Home delivery for veterinary practices,” 2023, [Online; accessed 10-January-2023].
[45] Master Student and J. G. Janine Diepenhorst, ”Proof of concept: Demand driven supply through farming techniques on carcass quality control points,” 2021.