Blockchain Based Livestock Identification and Traceability System

By

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ABSTRACT

Zimbabwe's livestock sector continues to face major challenges due to the lack of a standardized digital traceability system. Farmers predominantly rely on manual, paper-based methods for animal identification, health recordkeeping, and movement tracking—methods prone to inaccuracy, tampering, and inefficiency. This paper presents a Livestock Identification and Traceability System (LITS) tailored for Zimbabwe, integrating Radio Frequency Identification (RFID) technology with a distributed ledger to ensure secure, tamper-resistant data management. Each animal is tagged with an ISO 11784/85-compliant RFID ear tag, enabling unique and verifiable identification. A distributed ledger, deployed on the Ethereum network, records immutable health records, ownership transfers, and geolocation data. A mobile application provides farmers and veterinary officers with tools for real-time tag scanning, record updates, and alert notifications. Designed with consideration for Zimbabwe's rural infrastructure and digital literacy levels, the system prioritizes affordability, offline capability, and ease of use. By digitizing livestock management, it enhances disease surveillance, facilitates compliance with international export standards—particularly those of the EU—and supports data-driven breeding programs. Future work will focus on national deployment and integration with IoT-based health monitoring systems.

Keywords: Livestock Traceability, RFID, Distributed Ledger, Blockchain, Animal Health, Zimbabwe, Ethereum Network.

PREFACE

Zimbabwe's livestock sector is in urgent need of modern, scalable traceability solutions. Existing manual systems are inadequate—they fail to prevent disease outbreaks, meet export compliance requirements, or support data-driven livestock management. As a result, farmers are losing critical income opportunities, and the industry remains disconnected from international markets.

This project presents a practical, blockchain-enabled livestock identification and traceability system (LITS) built around affordable RFID technology. Designed with Zimbabwe's unique challenges in mind, the solution emphasizes low-cost deployment, offline capabilities, and mobile accessibility—making it especially suitable for smallholder farmers operating in resource-constrained environments.

Our approach builds upon existing global innovations while introducing context-specific enhancements to ensure local relevance and sustainability. Beyond solving immediate traceability and compliance issues, this system lays the groundwork for future advancements in smart farming and digital agriculture.

This document outlines the full scope of our work—from conceptual design and system architecture to technical implementation and field validation. We offer it as both a practical blueprint for digital livestock transformation and a call to action for modernizing Zimbabwe's agricultural systems.

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to everyone who supported the development of the Livestock Identification and Traceability System (LITS). I am especially thankful to my supervisors for their expert guidance, my colleagues for their collaboration, and my family for their unwavering encouragement throughout this journey. Special thanks also go to the local farmers, veterinary officers, and business owners who shared valuable insights into the challenges of livestock management in Zimbabwe. Their contributions were instrumental in shaping a solution that is both practical and impactful within the local context.

DEDICATION

To the smallholder farmers of Zimbabwe—your resilience in the face of drought, economic hardship, and climate uncertainty has taught me the true meaning of perseverance. This Livestock Identification and Tracking System (LITS) is dedicated to you, the stewards of our land. May it empower you with tools to safeguard your herds, secure your livelihoods, and amplify your voices in an evolving agricultural future.

To my family—your unwavering belief in me turned late nights into purpose, and challenges into triumphs. This system is not just code and design; it is a reflection of your love and sacrifice.

DECLARATION

I, Peshel Gomo, solemnly declare that this work is a testament to the intersection of innovation and necessity. It is born from a commitment to address real-world challenges faced by Zimbabwe's agricultural community, and it stands as a tribute to the collaborative spirit of all who supported its journey from mentors and colleagues to the farmers whose stories guided its purpose.

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success through innovation

This is to certify that HIT 400 Project entitled "**Blockchain Based Livestock Identification and Traceability System" has** been completed by **GOMO PESHEL** (H210166J) for partial fulfilment of the requirements for the award of **Bachelor of Technology** degree in **Software Engineering**. This work is carried out by **him** under my supervision and has not been submitted earlier for the award of any other degree or diploma in any university to the best of my knowledge.

Mr. S. Murove	**Approved/Not Approved**
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Certificate of Declaration

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ITEM	TOTAL MARK /%	ACQUIRED/%
PRESENTATION- Format-Times Roman 12 for ordinary text, Main headings Times Roman 14, spacing 1.5. Chapters and sub-chapters, tables and diagrams should be numbered. Document should be in report form. Range of document pages. Between 50 and 100.Work should be clear and neat	**5**	
Pre-Chapter Section Abstract, Preface, Acknowledgements, Dedication & Declaration	**5**	
Chapter One-Introduction Background, Problem Statement, Objectives – smart, clearly measurable from your system. Always start with a TO… Hypothesis, Justification, Proposed Tools Feasibility study: Technical, Economic & Operational Project plan –Time plan, Gantt chart	**10**	
Chapter Two-Literature Review Introduction, Related work & Conclusion	**10**	
Chapter Three –Analysis Information Gathering Tools, Description of system Data analysis –Using UML context diagrams, DFD of existing system Evaluation of Alternatives Systems, Functional Analysis of Proposed System-Functional and Non-functional Requirements, User Case Diagrams	**15**	
Chapter Four –Design Systems Diagrams –Using UML Context diagrams, DFD, Activity diagrams Architectural Design-hardware, networking Database Design –ER diagrams, Normalized Databases Program Design-Class diagrams, Sequence diagrams, Package diagrams, Pseudo code Interface Design-Screenshots of user interface	**20**	
Chapter Five-Implementation & Testing Pseudo code of major modules /Sample of real code can be written here Software Testing-Unit, Module, Integration, System, Database & Acceptance	**20**	
Chapter Six –Conclusions and Recommendations Results and summary, Recommendations & Future Works	**10**	
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CHAPTER ONE: INTRODUCTION

Introduction

This chapter introduces using blockchain and RFID to improve transparency, security, and traceability in Zimbabwe’s cattle supply chain. It covers the study’s background, defines the problem, and states the project’s objectives and research hypothesis. A feasibility study evaluates the technical, economic, and operational viability of the system in Zimbabwe. The chapter ends with a project plan detailing methodology, development phases, and expected outcomes.

1.1 Background

Zimbabwe's livestock sector urgently requires modernization to address critical challenges threatening its sustainability and economic potential. The current reliance on manual tracking methods leaves farmers vulnerable to disease outbreaks, climate shocks, and rampant theft, while preventing access to export markets that demand verifiable health records [1]. Recent droughts have decimated herds, particularly affecting smallholder farmers, and the persistent EU beef import ban due to foot-and-mouth disease concerns highlights the costly consequences of inadequate traceability systems [1,2].

Digital solutions like RFID and blockchain technology present a viable path forward by enabling tamper-proof digital identities for livestock, creating immutable records of vaccinations and movements [3]. Similar systems in neighboring countries have demonstrated success in improving disease control and market access. For Zimbabwe, such technologies could transform the sector by enabling faster outbreak responses, reducing theft, and meeting international traceability standards that could reopen valuable export markets [1,3].

Implementation requires coordinated efforts across multiple stakeholders. Government policy reforms must establish digital identification standards, while public-private partnerships could make the technology accessible to small-scale farmers [3]. Existing initiatives testing drought-resistant fodder and improved breeding techniques show promise but need scaling alongside digital traceability systems to achieve nationwide impact [2]. Training programs will be essential to help farmers transition from traditional methods to these new technologies.

While challenges like rural internet access and initial costs remain, the potential benefits of modernization far outweigh these hurdles. Digital transformation offers Zimbabwe's livestock sector a chance to build resilience against climate pressures, improve farmer livelihoods, and unlock its full economic potential [3]. The time for action is now, before the sector falls further behind regional competitors and global market demands.

1.2 Problem Statement

The livestock sector in Zimbabwe, and much of the region, is a foundation for food security, rural livelihoods, and economic growth. However, the management and supply chain systems that support this sector are outdated and fragmented, especially for smallholder and communal farmers who rear a diverse range of livestock species, including goats, sheep, pigs, poultry, and cattle. This lack of modernization and digitalization has led to a series of persistent challenges that undermine the sector’s efficiency, transparency, and inclusivity.

Lack of Traceability and Transparency

One of the most pressing issues is the absence of effective traceability and transparency throughout the livestock supply chain. Transactions are typically informal, relying on verbal agreements and trust, with little to no documentation to verify ownership or the health history of animals. This lack of reliable records enables the circulation of stolen livestock, as there are no robust mechanisms for verifying the provenance of animals at markets or slaughterhouses. As a result, both farmers and buyers are exposed to fraud, and authorities find it difficult to regulate, tax, or intervene effectively when disputes arise.

Limited Access to Finance

The absence of verifiable digital records means that livestock cannot be easily used as collateral for loans. Smallholder farmers, even when they possess significant livestock assets, struggle to access finance because they cannot prove ownership or the value of their animals. This financial exclusion restricts their ability to invest in improved production, adopt new technologies, or scale their operations, perpetuating cycles of poverty and limiting sectoral growth.

Inefficiencies in Disease Control and Supply Chain Management

Disease control and supply chain management are further hampered by the lack of a centralized, tamper-proof record-keeping system. Tracing the origin of disease outbreaks or monitoring animal health is difficult, which impedes rapid response to health crises and the implementation of best practices in animal husbandry. This inefficiency increases the risk of widespread disease and loss, threatening both livelihoods and food security.

Barriers to Market Access and Consumer Confidence

The lack of transparency and traceability also undermines consumer confidence and limits market access for farmers. Buyers have no way to verify the quality, origin, or welfare conditions of the livestock products they purchase. This restricts farmers' access to high-value markets that demand proof of origin, quality assurance, and adherence to animal welfare standards.

Cumbersome Transaction Processes

The process of buying and selling livestock is often cumbersome and time-consuming. In many cases, transactions require the presence of a police officer to sign off, especially in rural areas where access to such services is limited. This inefficiency discourages formal transactions and further entrenches informal, unregulated practices.

Absence of Ownership Records

Ownership records for livestock are often minimal or non-existent. At markets and slaughterhouses, trading can occur with little to no paperwork. While this trust-based system may be expedient, it leaves no paper trail, making it impossible to prove ownership, resolve disputes, or prevent fraud and theft. The lack of ownership documentation creates problems at several points in the supply chain, including the inability to tax transactions and the lack of recourse for defrauded parties.

Insufficiency of Existing Solutions

Existing systems have often been manual, making them inefficient and prone to errors. Meanwhile, many proposed digital solutions rely on highly sophisticated and expensive hardware, making them unsuitable for widespread adoption in resource-constrained settings. Additionally, most blockchain-based initiatives focus on a single livestock species and fail to address the diverse needs of mixed-livestock farmers. The complexity of Zimbabwe's livestock sector—characterized by multiple species and varied production systems—calls for a more inclusive, affordable, and adaptable solution.

1.3 Objectives

- To provide a digital platform that empowers farmers to efficiently manage comprehensive livestock and veterinary health records.
- To facilitate the identification and traceability of livestock using RFID tags, scanned via a mobile application.
- To generate verifiable digital health certificates for livestock, enabling secure and efficient documentation during animal transit, inspections, and regulatory compliance.
- To track and visualize animal genealogy and parentage hierarchies, supporting informed breeding decisions and genetic traceability.
- To ensure the integrity and authenticity of veterinary records through tamper-proof blockchain verification.

1.4 Hypothesis

The implementation of a digital livestock management platform that utilizes RFID technology, mobile applications, and an immutable distributed ledger (blockchain) will significantly improve the efficiency, transparency, and security of livestock record-keeping among Zimbabwean farmers. By enabling real-time identification, traceability, and tamper-proof documentation of animal health and ownership records, the platform will reduce incidences of livestock theft, enhance disease control through rapid trace-back, and increase farmers' access to finance and high-value markets. The immutable nature of the distributed ledger will ensure that all veterinary and transaction records are verifiable and resistant to manipulation, thereby fostering greater trust among farmers, regulators, buyers, and financial institutions and supporting the integration of Zimbabwe's livestock sector into global value chains.

1.5 Justification

Zimbabwe's livestock sector is a vital contributor to the country's economy, supporting over 60% of rural households and accounting for approximately 10.8% of agricultural GDP. Despite recent growth, with the national cattle herd increasing to over 5.6 million in 2022 and beef production rising by 13% to 339,000 cattle slaughtered annually, the sector continues to face significant challenges that limit its full potential [4]. Traditional livestock management relies heavily on outdated, paper-based systems that hinder traceability, transparency, and disease control. This has contributed to substantial economic losses, including an estimated US$100 to US$250 million annually due to low calving rates and poor herd productivity [5]. Additionally, Zimbabwe's inability to meet international animal health and traceability standards has resulted in negligible beef exports since the 1990s, costing the country millions in lost foreign exchange [6].

Existing traceability solutions are often manual leading to inefficiency and forgery of records. Some previously proposed solutions have proven to be infeasible. This is because they were too expensive and require specialized equipment, making them inaccessible to the majority of smallholder and communal farmers who keep diverse livestock species such as goats, sheep, pigs, poultry, and cattle.

This project proposes an affordable and scalable digital platform that leverages RFID tags scanned using common smartphones, eliminating the need for costly hardware and making the technology accessible to all farmers. By integrating an immutable distributed ledger (blockchain), the platform will provide tamper-proof, verifiable records of livestock identity, health, and ownership. This will enhance trust, reduce theft, improve disease management, and enable farmers to access finance by using their livestock as collateral.

By offering a cost-effective, user-friendly solution, the platform will help reduce losses, improve productivity, and open access to lucrative export markets. Ultimately, this innovation will empower farmers, strengthen veterinary services, and drive sustainable growth in Zimbabwe's livestock sector, contributing to food security and rural economic development.

1.6 Proposed Tools

Software Tools

- Programming Languages: Python, JavaScript, Solidity 0.8.21, Truffle 5.4.18
- Frameworks: Truffle, Ganache, Next JS, Pockebase, FastAPI, React Native
- Blockchain Networks: Ganache, Ethereum mainnet
- Integrated Development Environment (IDE): Visual Studio Code
- Blockchain Node Providers: Alchemy Supernode
- Analytics: Ganache Monitor
- Wallets: MetaMask, Ganache Wallets

Hardware Tools

- Laptop Intel (Core i5 processor or better)
- 8GB RAM Processor
- Android smartphone (with RFID scanner)

1.7 Methodology

The development and implementation of the National Livestock Identification and Traceability System will follow a structured, phased approach designed to deliver a scalable, secure, and user-friendly solution tailored to Zimbabwe's livestock sector.

1. Requirement Gathering and Stakeholder Engagement

This phase involves detailed consultations with farmers, veterinary officers, regulatory authorities, and market participants to identify key challenges and system requirements. The focus will be on ensuring the solution addresses livestock identification, health record management, traceability, affordability, and regulatory compliance.

2. System Design

A robust architecture will be designed integrating RFID technology for unique animal identification, a mobile application optimized for offline and low-connectivity environments, and a blockchain backend to provide immutable, transparent record-keeping. The design will emphasize usability and accessibility for smallholder farmers.

3. Development

RFID Tagging: Animals will be tagged with affordable RFID ear tags readable by smartphones, eliminating the need for costly specialized scanners.

Mobile Application: A cross-platform app will enable users to scan RFID tags, update veterinary records, generate digital health certificates, and visualize genealogy. Offline functionality with data synchronization will be included.

Blockchain Integration: Smart contracts will be developed in Solidity and deployed on a blockchain network to record ownership, health, and transaction data securely and immutably.

Cloud Services: Cloud infrastructure will support data storage, analytics, and backup.

4. Testing

Smart contracts and the mobile app will be rigorously tested using Ganache, a personal Ethereum blockchain that simulates a real network locally. Ganache allows developers to deploy, test, and debug smart contracts rapidly and cost-effectively without incurring real transaction fees or waiting times. This safe and deterministic environment enables thorough validation before live deployment.

5. Deployment

After successful testing, the blockchain smart contracts will be deployed to the live Ethereum network to ensure decentralized, secure, and tamper-proof operation. The mobile application and RFID tagging will be rolled out in pilot regions, followed by phased nationwide deployment. Training and support will be provided to users to facilitate adoption.

6. Monitoring, Evaluation, and Continuous Improvement

Post-deployment, the system's impact will be monitored through data analytics and user feedback. Key metrics such as reduction in livestock theft, improved disease control, and enhanced access to finance will be tracked. Continuous updates and improvements will be made to address emerging needs and leverage technological advancements.

1.8 Feasibility Study

1.8.1 Technical Feasibility

The system leverages mature and accessible technologies, including affordable RFID tags that can be scanned using widely available smartphones, eliminating the need for costly specialized equipment. The use of blockchain technology provides an immutable distributed ledger, ensuring secure and tamper-proof livestock records. Mobile applications will be designed for offline use with periodic synchronization, addressing rural connectivity challenges. Cloud infrastructure will support data storage and analytics. Pilot projects in Zimbabwe and similar contexts have demonstrated the successful integration of these technologies, confirming the system's technical viability.

1.8.2 Operational Feasibility

The system is designed with the end-users in mind—smallholder and communal farmers, veterinary officers, and regulatory authorities. User-friendly mobile applications and affordable hardware ensure accessibility even in rural areas. Training and capacity-building programs will be implemented to support adoption and effective use. The system aligns with existing livestock management frameworks and regulatory requirements, facilitating smooth integration. Potential challenges such as initial resistance to digital tools and limited internet access will be mitigated through phased deployment, offline functionality, and continuous stakeholder engagement.

1.8.3 Economic Feasibility

The project's financial viability is supported by the significant economic benefits expected from reducing livestock theft, improving disease control, and enabling access to lucrative export markets. Zimbabwe faces annual losses estimated in the millions of dollars due to theft and disease outbreaks, and regaining export markets could increase revenues substantially.

Cost Estimates:

- RFID tags: US$1.50 per tag
- Mobile app development and maintenance (Expo Pro Account): US$10/month
- AWS EC2 Server: US$100
- Training and capacity building: US$15 initial
- Total initial investment: ~US$125
- Annual operating costs: ~US$120

Projected Benefits:
Assuming a conservative 20% reduction in losses and an increase of US$5 million in export revenues annually, the net annual benefit is approximately US$5 million.
Return on Investment (ROI):
$(5{,}000-3{,}500) \div 1{,}810 \times 100 \approx 270\%$

This exceptionally high ROI indicates strong economic feasibility, demonstrating that the system's benefits far exceed its costs.

1.9 Project Plan

The project plan for the National Livestock Identification and Traceability System is structured into distinct phases, each with clear deliverables and timelines. The Gantt chart above visually represents the scheduling and overlaps of these phases over a 14-week period.

1.9.1 Time Plan

Phase	**Weeks**	**Dates**	**Key Activities**	**Sprint (2 weeks)**
1. Research	Week 1–2	4 May – 15 May	- Stakeholder interviews - Market/regulatory research	**Sprint 1**
2. Planning	Week 2–3	15 May – 26 May	- Roadmap, resource allocation	**Sprint 2**
3. Evaluation	Week 3–4	26 May – 5 Jun	- Tech stack selection - Feasibility studies	**Sprint 2 (cont.)**
4. Design	Week 4–6	5 Jun – 19 Jun	- UI/UX prototypes - System architecture	**Sprint 3–4**
5. Development	Week 6–10	19 Jun – 17 Jul	- Mobile app + RFID - Smart contracts	**Sprint 5–7**
6. Testing	Week 10–12	17 Jul – 31 Jul	- Unit/Integration/UAT - Bug fixes	**Sprint 7 (cont.)**
7. Deployment	Week 13	31 Jul – 5 Aug	- Ethereum rollout - User training	**Final Sprint**
Maintenance	Week 13-14	Ongoing	- Monitoring, patches, feedback	Post-launch
Documentation	Week 2-14	All phases	- Technical docs, user manuals	Embedded in sprints

Table 1.1 - Time Plan

1.9.2 Project Gnatt Chart

Phase	wk 1	wk 2	wk 3	wk 4	wk 5	wk 6	wk 7	wk 8	wk 9	wk 10	wk 11	wk 12	wk 13	wk 14
Research														
Planning														
Evaluation														
Design														
Development														
Testing														
Implementation														
Maintenance														
Documentation														

Figure 1 - Project Gnatt Chart

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The livestock sector in Zimbabwe and the broader Southern African region faces significant challenges related to traceability, disease control, and market access, which have constrained its growth and competitiveness. A robust review of existing literature highlights the critical role of digital traceability systems, particularly those leveraging modern technologies such as RFID and blockchain, in addressing these challenges.

2.2 Related Work

The development of livestock traceability systems in Zimbabwe has followed an uneven trajectory since independence. The Zimbabwe Cattle Traceability Scheme (ZCTS), established in 1999, represented one of Africa's earliest comprehensive efforts to implement standardized animal identification [19]. This system utilized veterinary brands and tamper-proof ear tags with unique 10-digit identifiers, supported by robust legal frameworks including the Animal Health Act and Brands Act [19]. During its peak operation, the ZCTS successfully enabled Zimbabwe to export beef to the European Union by meeting stringent traceability requirements, demonstrating that technically sound systems could be implemented in developing country contexts [19].

However, the system's effectiveness declined following disease outbreaks and subsequent export bans, revealing critical vulnerabilities in maintaining traceability infrastructure during crises [19]. This historical experience provides important lessons for contemporary efforts, particularly regarding the need for systems that remain functional during disease emergencies and market disruptions. The ZCTS's partial success nonetheless established important institutional foundations, including the Livestock Identification Trust (LIT) and the Zimbabwe Herd Book, which continue to influence regional traceability initiatives [13].

Recent years have seen significant advancements in traceability technologies applicable to Zimbabwe's context. IoT-based systems using RFID tags have emerged as particularly promising due to their declining costs and increasing reliability [10]. Moyo and Moyo's (2022) research demonstrated that smartphone-compatible RFID systems could reduce implementation costs by up to 60% compared to traditional specialized equipment, while maintaining 98% accuracy in animal identification [10]. This breakthrough is especially relevant for smallholder farmers who constitute approximately 70% of Zimbabwe's livestock producers [11].

Blockchain technology has added another dimension to traceability solutions. The E-Livestock Global platform, piloted in Zimbabwe through a partnership with Mastercard, combines RFID tagging with blockchain-based record-keeping to create immutable health and movement records [12]. This system records each veterinary intervention on a distributed ledger, providing transparency across the supply chain while maintaining data integrity [13]. Engineering News

(2021) reported that the platform reduced record-keeping errors by 85% in trial implementations, while cutting administrative costs by 40% [12].

Comparative analysis of regional systems reveals important insights for Zimbabwe's traceability development. Botswana's electronic identification system, operational since 2009, provides perhaps the most relevant model [16]. Using RFID boluses linked to a national database; the system maintains full compliance with EU export requirements while achieving 95% farmer participation rates [16]. Key to its success has been the integration with national identification systems and mandatory participation enforced through legal frameworks [17].

Eastern African initiatives offer additional lessons, particularly regarding pastoralist systems. The International Livestock Research Institute's (2015) pilot projects in Kenya and Ethiopia demonstrated how mobile-based traceability could be adapted to transhumance patterns, achieving 80% trace-back accuracy even in remote areas [18]. These systems utilized solar-powered RFID readers and offline-capable mobile applications to overcome infrastructure limitations [15].

Despite technological availability, significant implementation barriers persist. Zivanai's (2023) research identified three primary challenges: infrastructure limitations (particularly in rural areas), low digital literacy among older farmers, and upfront cost barriers [14]. His study found that even when systems were provided free of charge, adoption rates rarely exceeded 60% without comprehensive training programs [14].

The World Organization for Animal Health (WOAH) framework emphasizes that successful traceability requires addressing these socioeconomic factors alongside technical solutions [20]. Their guidelines highlight the need for phased implementation, starting with pilot areas before national rollout, and continuous stakeholder engagement throughout the process [17]. Zimbabwe's experience with the ZCTS supports this approach, as areas with stronger farmer education programs showed significantly higher compliance rates [19].

Recent research points to several promising developments that could enhance traceability systems. Zivanai's (2023) exploration of NFT-based livestock identification represents one such innovation, using blockchain tokens to represent individual animals throughout their lifecycle [14]. While currently limited to beef cattle, the concept could potentially be expanded to other species [14].

Integration of IoT sensors for real-time health monitoring is another emerging frontier. Experimental systems combining temperature-sensitive RFID tags with automated alert systems have shown potential for early disease detection, with pilot studies reporting 75% accuracy in identifying sick animals before visible symptoms appear [10]. Such technologies could significantly enhance Zimbabwe's disease control capabilities.

Effective traceability systems require supportive policy environments. Botswana's success stems from its comprehensive legal framework that mandates electronic identification and links it to movement permits and market access [16]. Zimbabwe's existing Animal Health Act provides some foundation but requires updating to incorporate digital technologies and enforce compliance [19].

The World Organization for Animal Health (WOAH) recommends a graduated approach to policy implementation, beginning with voluntary systems that transition to mandatory requirements over time [20]. This allows for capacity building and technology diffusion while minimizing resistance. Zimbabwe could benefit from such an approach, particularly given its large smallholder sector [11].

The economic case for traceability systems continues to strengthen. Agriculture.co.zw (2024) reported that Zimbabwe's beef industry loses an estimated $50 million annually due to lack of export market access [19]. Traceability systems have been shown to increase producer prices by 15-20% in comparable markets by enabling quality differentiation and certification [12].

Furthermore, digital traceability creates opportunities for financial inclusion. The E-Livestock Global platform demonstrated how blockchain-based records could serve as collateral for loans, with pilot participants accessing credit at 30% lower interest rates than traditional livestock loans [13]. This financial dimension adds important value beyond basic traceability functions.

Modern traceability systems can contribute to climate adaptation strategies. By monitoring animal movements and grazing patterns, these systems help optimize rangeland use and prevent overgrazing [15]. The International Livestock Research Institute (2015) found that pastoralist communities using traceability systems maintained 25% higher herd survival rates during droughts due to better movement planning [18].

2.3 Conclusion

The literature highlights the transformative potential of modern traceability technologies such as RFID, IoT, and blockchain in addressing long-standing challenges in Zimbabwe’s livestock sector, including disease control, market access, and data integrity. While historical systems like the Zimbabwe Cattle Traceability Scheme (ZCTS) laid important institutional foundations, their limitations during crises emphasize the need for more resilient, digitally integrated solutions. Regional examples, particularly from Botswana and Eastern Africa, demonstrate the effectiveness of mandatory, well-supported systems in improving compliance and export readiness. At the same time, successful implementation in Zimbabwe must account for barriers such as infrastructure gaps, low digital literacy, and the dominance of smallholder farmers. Innovations like smartphone-compatible RFID, NFT-based identification, and real-time health monitoring offer scalable, cost-effective options for broad adoption. Beyond traceability, these systems can also enable financial inclusion and climate resilience, as shown by pilot platforms like E-Livestock Global. Ultimately, a phased and inclusive national strategy anchored in updated legal frameworks, stakeholder engagement, and targeted capacity building is essential to realizing the full economic and public health benefits of livestock traceability in Zimbabwe.

CHAPTER 3: ANALYSIS

3.1 Information Gathering Tools

To acquire comprehensive information for this research, a combination of qualitative and quantitative data collection methods was employed. The primary tools used were interviews, analysis of existing systems, and questionnaires. Each tool was selected to capture different perspectives and ensure data triangulation for accuracy and depth.

3.1.1 Interviews

Structured and semi-structured interviews were conducted with a diverse range of stakeholders involved in Zimbabwe's livestock sector. These included smallholder farmers, communal farmers, livestock extension officers, supply chain managers, and industry experts. The interviews aimed to gather detailed qualitative insights into the current livestock management practices, challenges faced, and the stakeholders' openness to adopting new technologies such as blockchain and RFID for traceability. *(For Sample Refer to appendices)*

3.1.2 Analysis of Existing Systems

An in-depth analysis of existing livestock identification and traceability systems was undertaken. This involved reviewing both manual and digital approaches currently used in Zimbabwe and other regions. The analysis focused on the technical specifications, cost implications, user-friendliness, scalability, and suitability to the mixed-livestock environment common in Zimbabwe.

The key objectives of this analysis were:

- To identify gaps and limitations in current systems
- To assess the feasibility of integrating blockchain and RFID technologies
- To learn best practices and lessons from similar implementations

The findings informed the design considerations of the proposed Livestock Identification and Traceability System (LITS).

3.1.3 Questionnaires

Questionnaires were administered to a broad sample of farmers and livestock stakeholders to collect quantitative data on livestock management practices, technology use, and attitudes towards traceability solutions. The questionnaire included closed and open-ended questions to allow for both statistical analysis and contextual understanding. *(For Sample Refer to appendices)*

3.2 Description of system

3.2.1 System Description of the current system

The current livestock management and traceability system in Zimbabwe is still largely dependent on manual processes, particularly among smallholder and communal farmers who make up most livestock producers. These farmers typically use notebooks, village registers, or even memory to track vital information such as births, sales, deaths, and vaccinations. This approach is prone to errors, inconsistencies, and data loss, severely limiting the accuracy and reliability of livestock records. Identification methods such as ear tagging, branding, or ear notching are used, but these are not linked to any digital system, making traceability beyond the farm level difficult or impossible.

At a national level, Zimbabwe does have formal systems such as the **Zimbabwe Herd Book** and the **Zimbabwe Cattle Traceability System (ZCTS)**. The Zimbabwe Herd Book primarily serves commercial breeders, offering a digital pedigree and performance recording service for registered cattle. However, its reach is limited to a small portion of the livestock population, mostly within commercial farming circles. The **ZCTS**, operated by the Department of Veterinary Services, was introduced to trace the movement of cattle, particularly for export markets. While it represents a step forward in digitizing cattle traceability, ZCTS is often inaccessible to smallholder farmers due to logistical, infrastructural, and financial barriers. Moreover, it primarily focuses on cattle, with minimal support for other species such as goats, sheep, pigs, and poultry—even though many small-scale farmers raise mixed livestock.

As a result, the overall system remains fragmented, outdated, and exclusionary. The absence of an inclusive, scalable, and affordable digital traceability platform continues to prevent Zimbabwe's livestock industry from meeting international standards, reducing its competitiveness in export markets and limiting its ability to respond to disease outbreaks and verify livestock ownership effectively.

3.2.2 System Description of proposed solution

The proposed solution is a **digital Livestock Identification and Traceability System (LITS)** that integrates **blockchain** and **Radio Frequency Identification (RFID)** technologies to modernize and streamline livestock management in Zimbabwe, particularly for smallholder and communal farmers. The system is designed to be **inclusive**, **cost-effective**, and **scalable**, capable of supporting multiple livestock species including cattle, goats, sheep, pigs, and poultry.

At its core, the system uses **RFID ear tags or embedded chips** to uniquely identify each animal. These tags store a unique digital ID that links the animal to a digital profile containing key data such as breed, age, vaccination history, ownership, location, and movement records. Each transaction or update related to the animal—such as a sale, vaccination, birth, or transfer—is

recorded on a blockchain ledger, ensuring data **immutability, transparency, and security**. This distributed ledger technology prevents tampering or fraud and allows for real-time updates accessible by authorized users.

The system includes three main components:

1. **Farmer Interface (Mobile/Web App):** A user-friendly platform that allows farmers to register livestock, view records, and update data (e.g., health status, breeding, movement). The interface is designed to work on low-cost Android smartphones and supports offline functionality with later synchronization.
2. **Veterinary and Inspector Portal:** A secured portal for veterinary officers and livestock inspectors to validate data entries, record inspections, track disease outbreaks, and ensure compliance with animal health regulations.
3. **Central Blockchain-Backed Database:** This component maintains a secure, decentralized ledger of all livestock data, accessible by government agencies, buyers, insurers, and exporters, depending on access permissions. It ensures traceability across the entire livestock value chain—from farm to market.

The proposed system is designed to **complement and integrate with existing frameworks** such as the Zimbabwe Herd Book and the Zimbabwe Cattle Traceability System (ZCTS), expanding their reach and functionality to cover a broader range of farmers and species. It emphasizes **interoperability** with national and regional livestock databases, facilitating both domestic management and compliance with international traceability requirements.

By modernizing livestock tracking and record-keeping, the proposed system addresses current limitations such as poor data accuracy, lack of traceability, and exclusion from formal markets. It empowers farmers with digital tools, enhances veterinary oversight, deters livestock theft, and opens opportunities for **export certification**, **disease control**, **insurance verification**, and **livestock financing**.

3.3 Data Analysis

3.3.1 UML Context Diagrams for existing system

Level 0 DFD Diagram

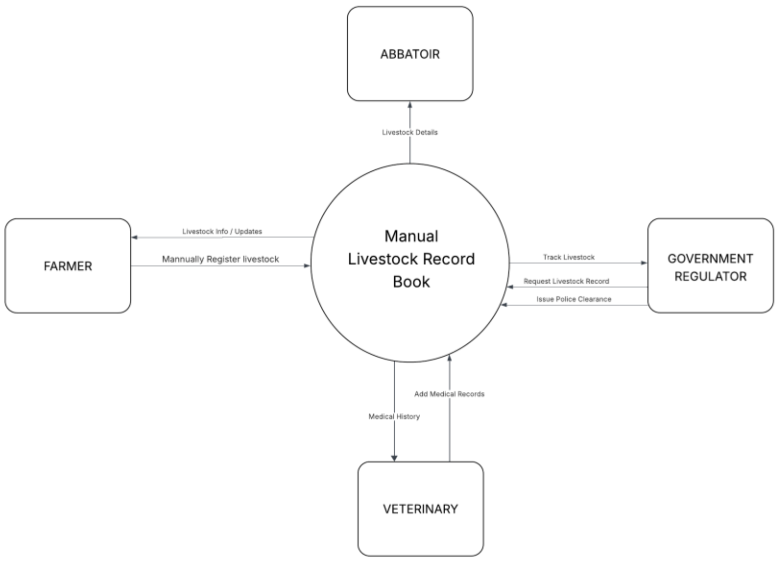


Figure 2 - DFD of Existing System

Use Case Diagram

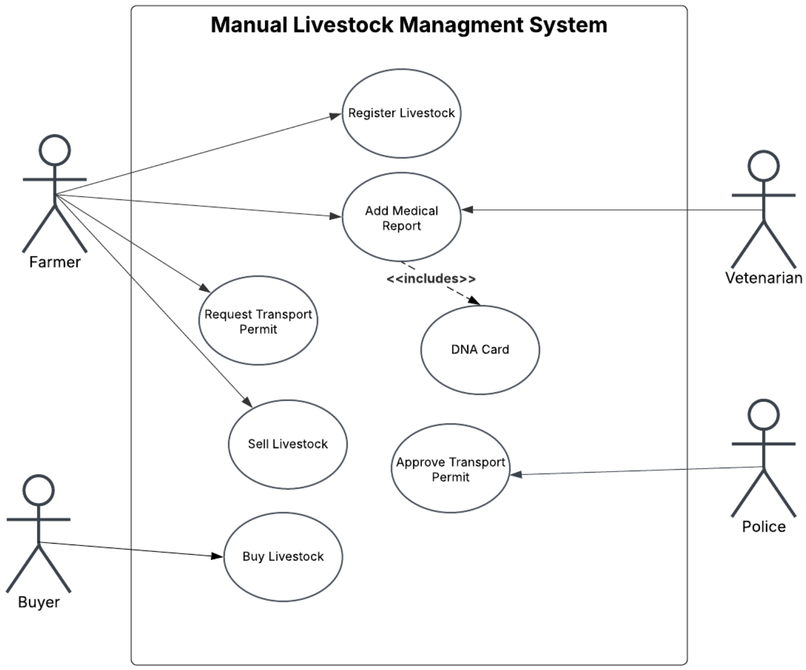


Figure 3 – Use Case Diagram

3.4 Evaluation of Alternative Systems

Several livestock traceability options were evaluated for Zimbabwe's context:

Manual Systems: Low cost and widely used but limited by poor traceability, data inaccuracies, and vulnerability to loss or tampering. They do not support real-time tracking or effective disease control.

RFID-Based Systems: Improve identification accuracy and speed but require costly tags and readers, which may be inaccessible to smallholder farmers, especially in rural areas.

Blockchain-Enabled Systems: Provide secure, tamper-proof records and transparency but need reliable internet, technical skills, and infrastructure that may be lacking in many farming communities.

Hybrid Systems: Combine affordable smartphone-based RFID scanning with blockchain for secure data storage and offline functionality. This approach balances cost, accessibility, and security, making it the most suitable for Zimbabwe's livestock sector.

Adopting Existing LITS: While adopting an existing livestock identification and traceability system could save initial development time, it tends to be expensive over the long term due to licensing, maintenance, and customization costs. Additionally, off-the-shelf systems may not fully address Zimbabwe's unique farming practices, infrastructure challenges, and regulatory environment, limiting their effectiveness and adoption.

In summary, a hybrid system developed with local customization offers the best balance of affordability, usability, and relevance to Zimbabwe's needs, ensuring sustainable and effective livestock traceability.

3.5 Proposed System Functional and Non-Functional Analysis

3.5.1 Functional Requirements

- Unique identification of each animal via RFID ear tags.
- Real-time capture and updating of animal health records and movements through a mobile app.
- Generation of digital health certificates and movement permits.
- Secure storage of data on a blockchain ledger ensuring immutability and transparency.
- User roles management (farmers, veterinarians, market agents, regulators).
- Offline data capture with synchronization when connectivity is available.
- Reporting and analytics for disease surveillance and market compliance.

3.5.2 Non-Functional Requirements

- Usability: Intuitive mobile interface accessible to users with varying digital literacy.
- Scalability: Ability to handle data from thousands of animals and users nationwide.
- Security: Data encryption, access control, and tamper-proof blockchain storage.
- Reliability: Robust offline functionality and data synchronization.
- Performance: Fast response times for data capture and retrieval.
- Compliance: Adherence to national veterinary and data privacy regulations.

3.6 User Case Diagrams of proposed system:

The use case diagram for the proposed National Livestock Identification and Traceability System (LITS) captures the key interactions between the system and its primary users. The main actors include Farmers, Veterinary Officers, Buyer, and Regulatory Authorities (Police).

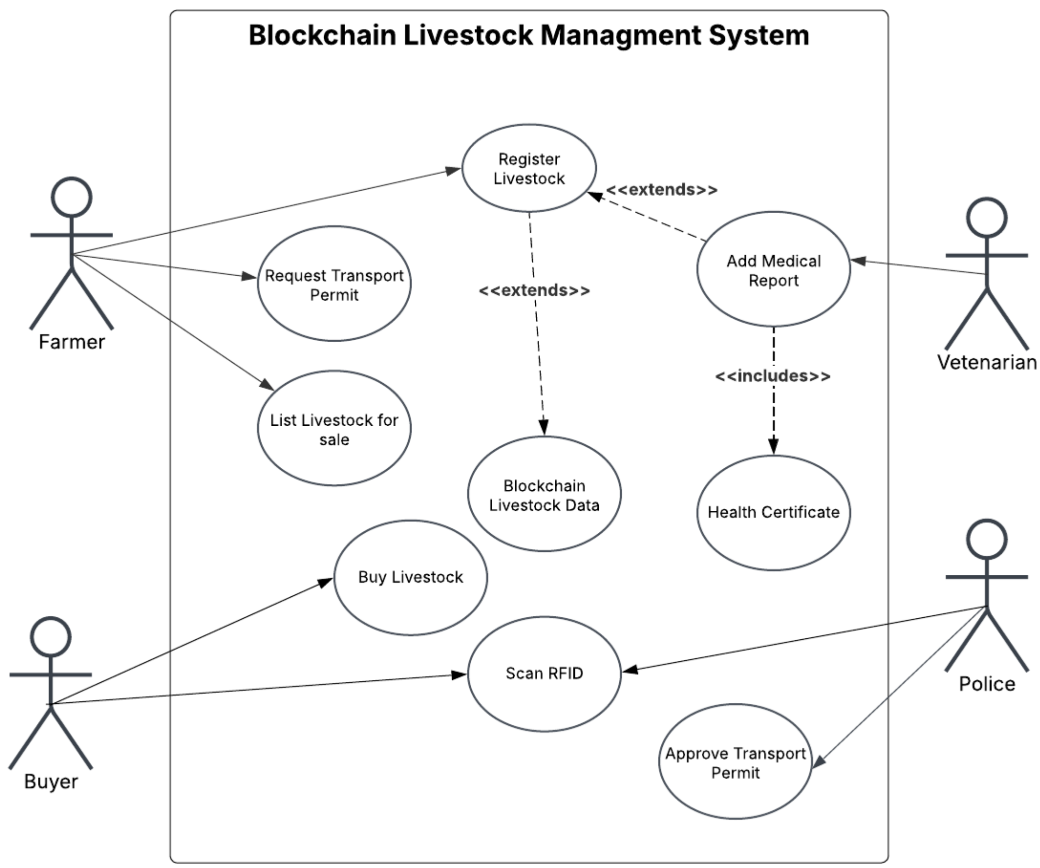


Figure 4 - Use Case Diagram of proposed system

CHAPTER 4: DESIGN

System Diagrams

4.1 Data Flow Diagrams (DFD)

4.1.1 Level 0 DFD

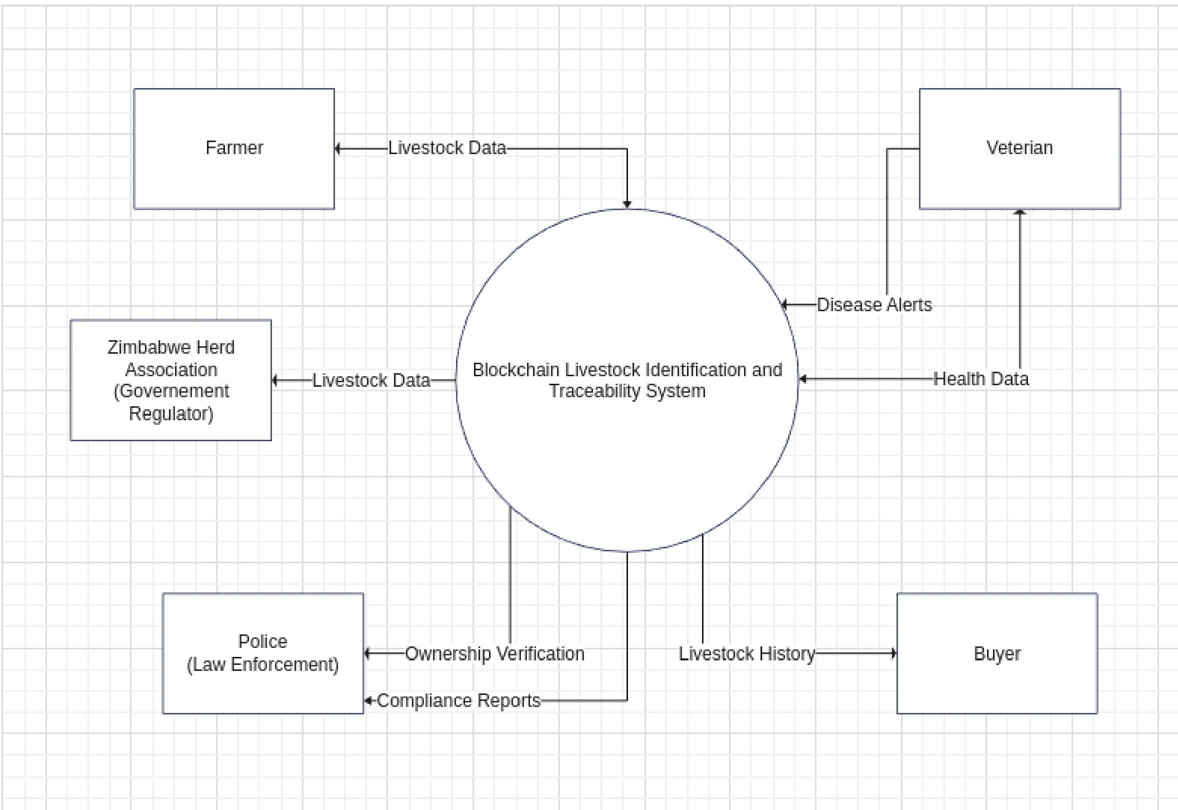


Figure 5 - Level 0 DFD of proposed system

4.1.2 Level 1 DFD

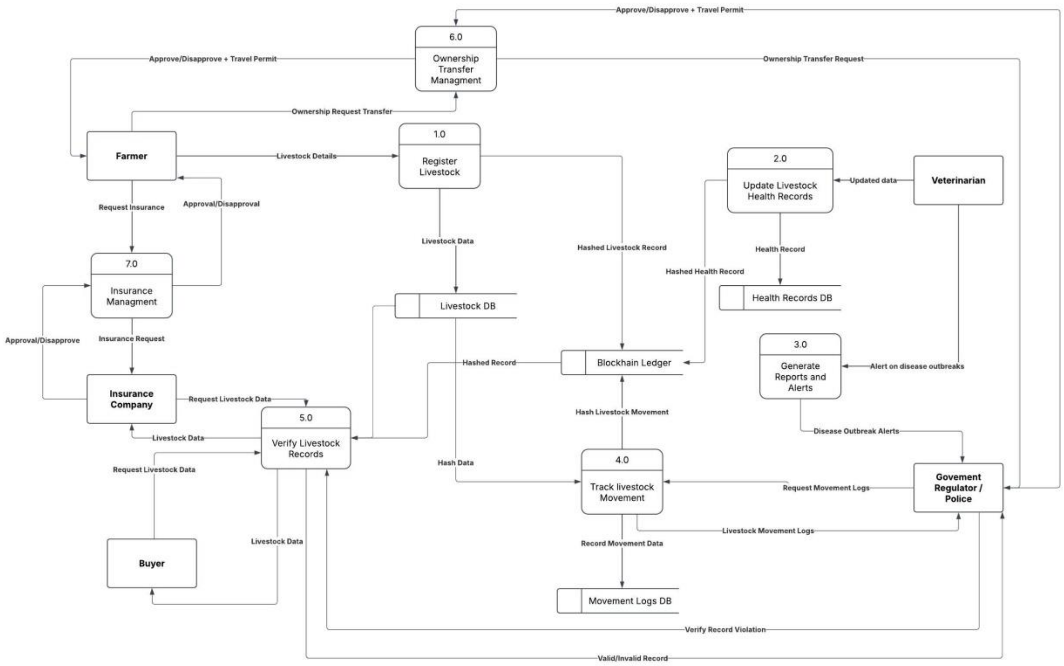


Figure 6 - Level 1 DFD of proposed system

4.1.3 Level 2 DFD

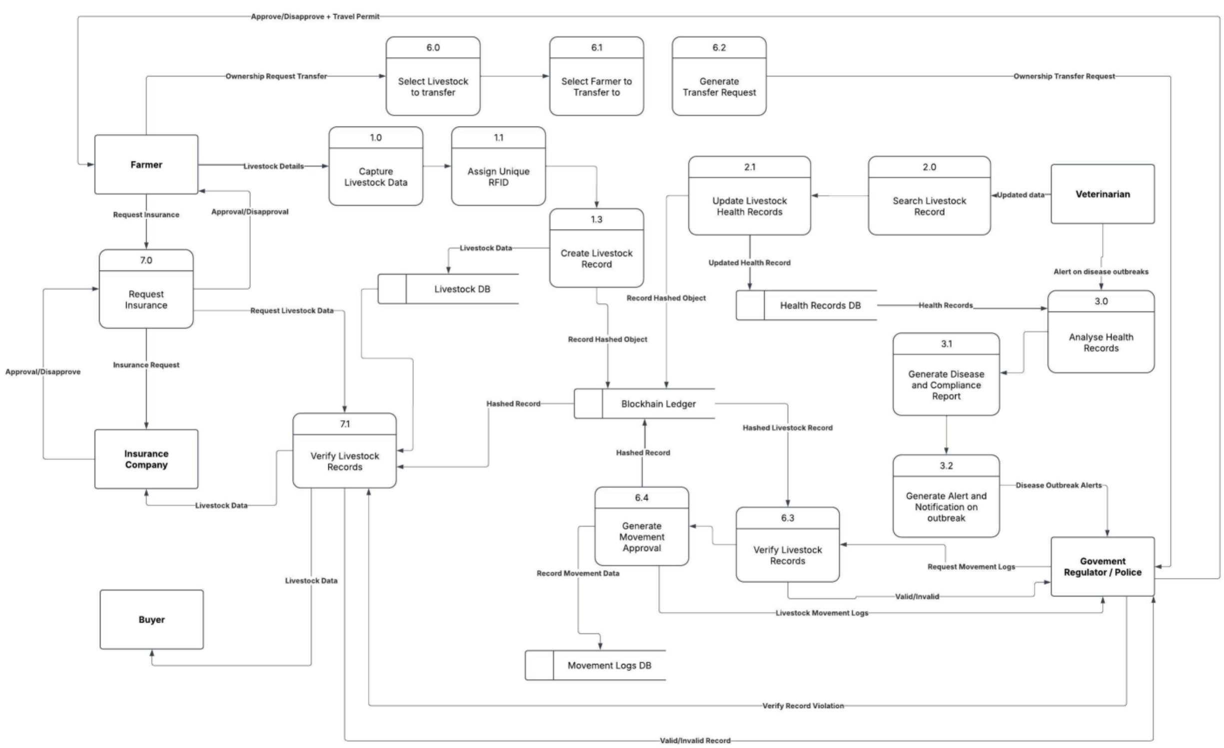


Figure 7 - Level 2 DFD of proposed system

4.1.4 Activity Diagram

Ownership Transfer Module

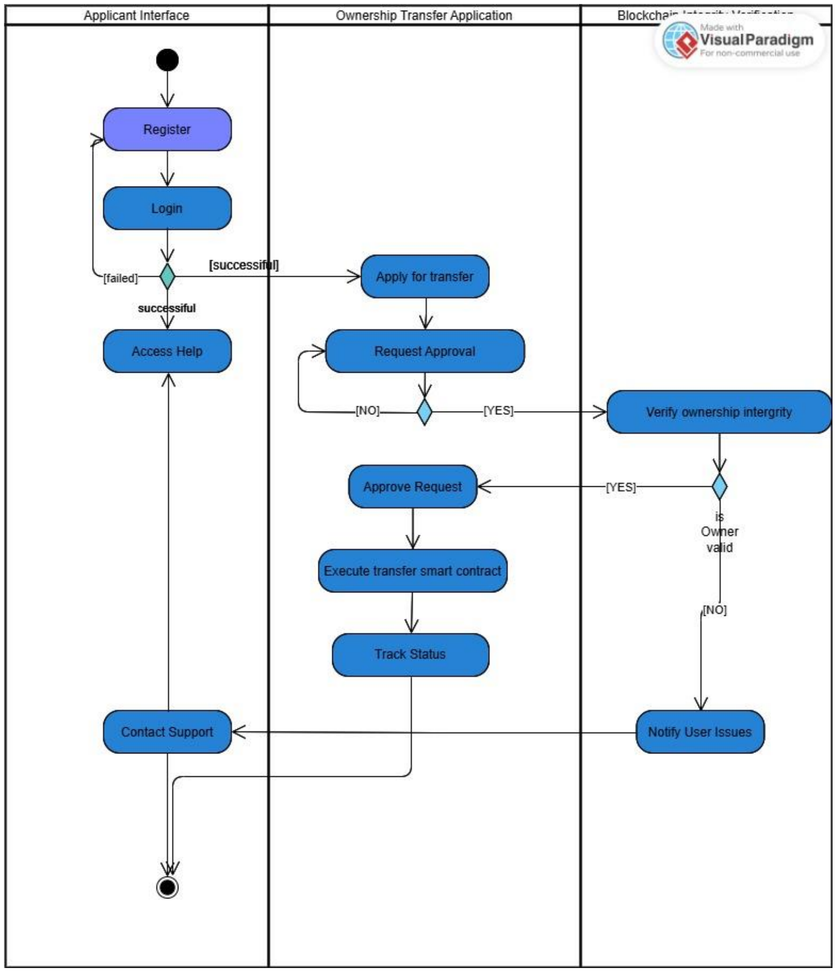


Figure 8 - Activity Diagram of proposed system

4.2 Architectural Design

4.2.1 Hardware Design

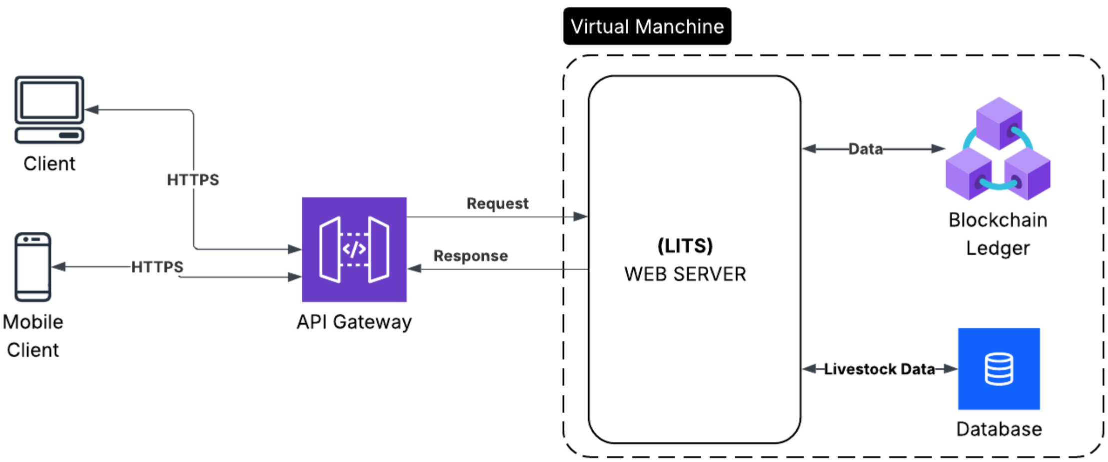


Figure 9 - Hardware Design of Proposed system

4.2.2 Network Design

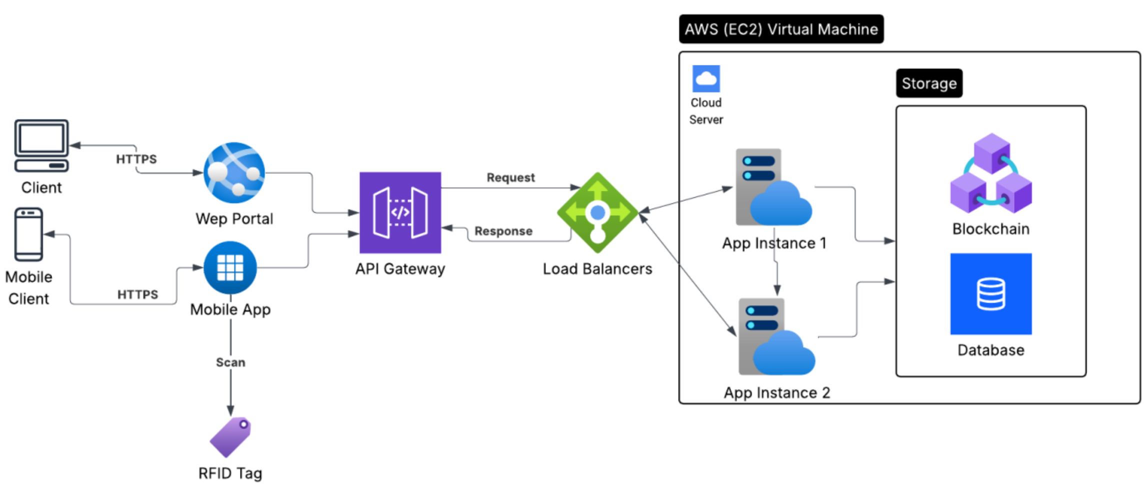


Figure 10 - Network Design of proposed system

4.3 Database Design

4.3.1 ERD

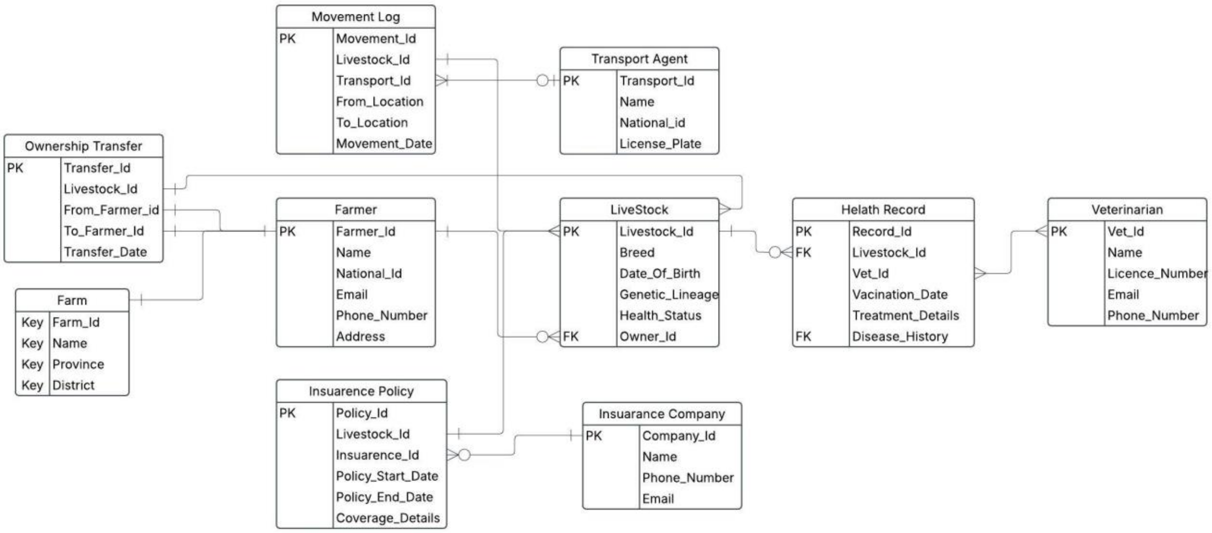


Figure 11 - ERD of proposed system

4.3.2 Normalized Database

The LITS database was normalized to 3NF. Below is the schema of all tables in the system.

Livestock (Main Entity)

Table 2 - Livestock Table

Column	**Type**	**Constraints**	**Description**
animal_id	UUID	PRIMARY KEY	Unique blockchain NFT ID
rfid_tag	VARCHAR(24)	UNIQUE, NOT NULL	ISO 11784/85 tag number
breed_code	CHAR(4)	FOREIGN KEY	FK to Breeds table
birth_date	DATE	NOT NULL	Verified by vet
gender	ENUM('M','F')	NOT NULL	
owner_id	UUID	FOREIGN KEY	Current owner
blockchain_address	VARCHAR(42)	UNIQUE	Ethereum wallet address
status	ENUM('active','sold','deceased')	DEFAULT 'active'	

Owners

Table 3 - Farmers Table

Column	Type	Constraints
owner_id	UUID	PRIMARY KEY
national_id	VARCHAR(20)	UNIQUE
phone	VARCHAR(15)	NOT NULL
wallet_address	VARCHAR(42)	UNIQUE
location_gps	POINT	SRID 4326

Breeds

Table 4 - Breed Table

Column	Type	Constraints
breed_code	CHAR(4)	PRIMARY KEY
name	VARCHAR(50)	NOT NULL
category	ENUM('cattle','goat','sheep')	

Animal Movements Logs

Table 5 - Movement Logs Table

Column	Type	Constraints	
movement_id	UUID	PRIMARY KEY	
animal_id	UUID	FOREIGN KEY	
from_location	POINT	SRID 4326	
to_location	POINT	SRID 4326	
timestamp	TIMESTAMP	DEFAULT NOW()	
tx_hash	VARCHAR(66)	UNIQUE	Blockchain TX

Ownership History

Table 6 - Ownership History Table

Column	Type	Constraints	
transfer_id	UUID	PRIMARY KEY	
animal_id	UUID	FOREIGN KEY	
previous_owner	UUID	FOREIGN KEY	
new_owner	UUID	FOREIGN KEY	
tx_hash	VARCHAR(66)	UNIQUE	
market_id	UUID	FOREIGN KEY	NULL for private sales

Vaccinations

Table 7 - Vaccination Table

Column	Type	Constraints
vaccination_id	UUID	PRIMARY KEY
animal_id	UUID	FOREIGN KEY
vaccine_code	CHAR(6)	FOREIGN KEY
vet_id	UUID	FOREIGN KEY
date_administered	DATE	NOT NULL
next_due_date	DATE	
ipfs_cid	VARCHAR(46)	IPFS document hash

Disease Events

Column	Type	Constraints
disease_id	UUID	PRIMARY KEY
animal_id	UUID	FOREIGN KEY
disease_code	CHAR(5)	FOREIGN KEY
diagnosis_date	DATE	NOT NULL
quarantine_status	BOOLEAN	DEFAULT FALSE

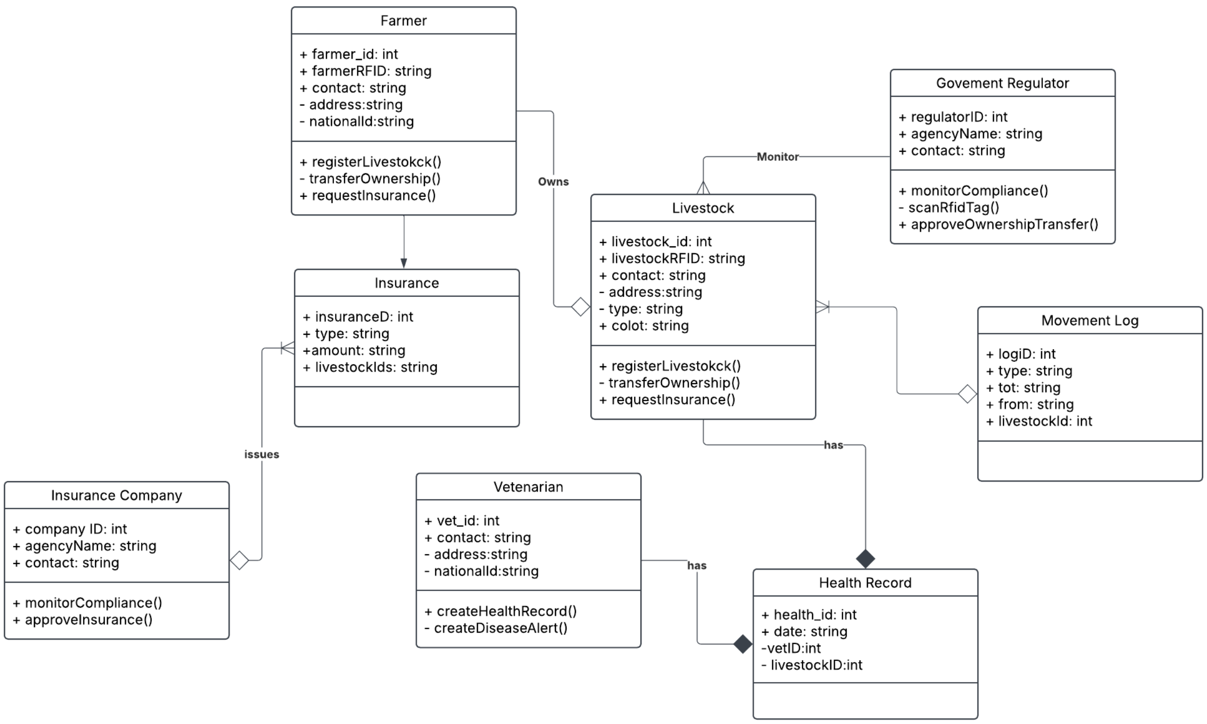
Veterinary Officers

Column	Type	Constraints
vet_id	UUID	PRIMARY KEY
license_number	VARCHAR(20)	UNIQUE
signature_pubkey	VARCHAR(64)	Digital signature key

4.4 Program Design

4.4.1 Class Diagram

Table 8 - Class Diagram



4.4.2 Sequence Diagram

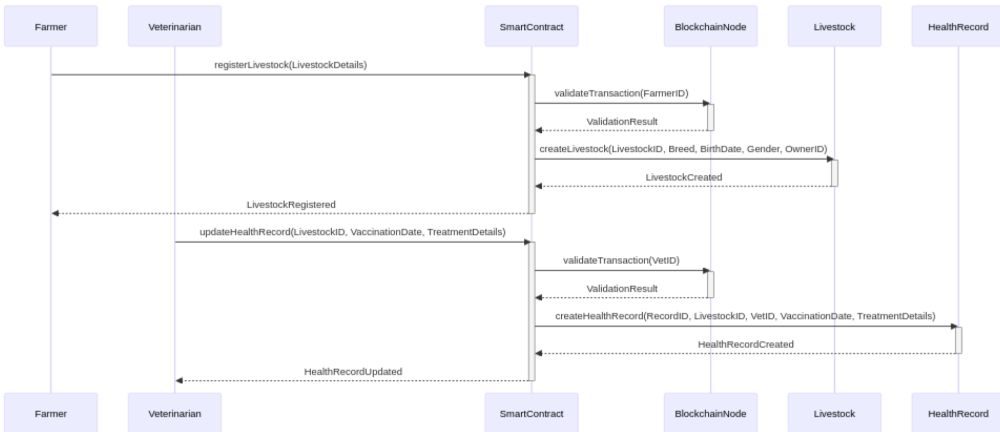


Table 9 - Sequence Diagram

4.4.3 Package Diagram

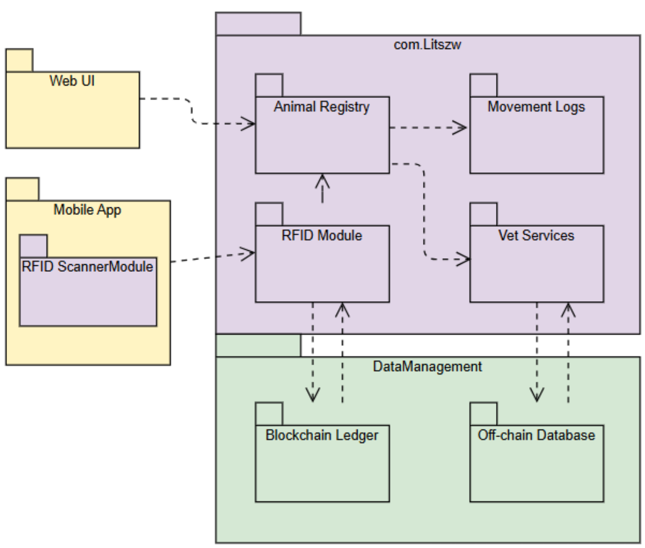


Table 10 - Package Diagram

4.4.4 Pseudo Code for Key Operations

1. Register New Animal with RFID

```
FUNCTION RegisterAnimal(userId, rfidTag, animalData)
   IF NOT AuthenticateUser(userId)
      RETURN "Access Denied"

   IF NOT IsRFIDUnique(rfidTag)
      RETURN "RFID already in use"

   IF NOT ValidateAnimalData(animalData)
      RETURN "Invalid data"

   animalId = GenerateAnimalID()
   SaveToAnimalDB(animalId, rfidTag, animalData)
   LogToBlockchain("AnimalRegistered", animalId, userId)

   RETURN "Animal registration successful"
END FUNCTION
```

2. Log Vet Visit (Vaccination, Checkup)

```
FUNCTION RecordVetVisit(animalId, vetId, visitDetails)
   IF NOT AuthenticateVet(vetId)
      RETURN "Vet authentication failed"

   IF NOT AnimalExists(animalId)
      RETURN "Animal not found"
```

```
    IF NOT ValidateVisitDetails(visitDetails)
        RETURN "Invalid treatment details"

    SaveToHealthDB(animalId, vetId, visitDetails)
    LogToBlockchain("VetVisit", animalId, vetId)

    RETURN "Visit successfully recorded"
END FUNCTION
```

3. Scan RFID and Validate Animal for Movement

```
FUNCTION ValidateAnimalForMovement(rfidTag, scannedByUserId, destinationLocation)
    // Step 1: Authenticate user (inspector or vet)
    IF NOT AuthenticateUser(scannedByUserId)
        RETURN "Access Denied: Invalid User"

    // Step 2: Read RFID
    animalId = LookupAnimalByRFID(rfidTag)
    IF animalId IS NULL
        RETURN "Error: RFID not recognized in system"

    // Step 3: Fetch current animal data
    animalData = GetAnimalProfile(animalId)
    IF animalData.status == "Quarantined"
        RETURN "Movement Denied: Animal is under quarantine"

    // Step 4: Check ownership validity
    ownerId = animalData.currentOwner
    IF NOT IsUserActive(ownerId)
```

```
        RETURN "Error: Owner not active or registered"

    // Step 5: Validate vaccination history
    lastVaccination = GetLastVaccinationDate(animalId)
    IF IsVaccinationExpired(lastVaccination)
        RETURN "Warning: Vaccination expired. Movement not recommended"

    // Step 6: Check for movement bans (due to disease outbreaks or non-compliance)
    IF IsMovementRestricted(animalId, destinationLocation)
        RETURN "Movement Blocked: Destination or animal restricted"

    // Step 7: Record movement intent and log
    SaveMovementIntent(animalId, scannedByUserId, destinationLocation,
GetCurrentTimestamp())
    LogToBlockchain("MovementValidated", animalId, scannedByUserId, destinationLocation)

    // Step 8: Return successful validation
    RETURN "Validation Complete: Animal cleared for movement"
END FUNCTION
```

4.5 Interface Design

4.5.1 Web Portal (Screenshots)

Login Page

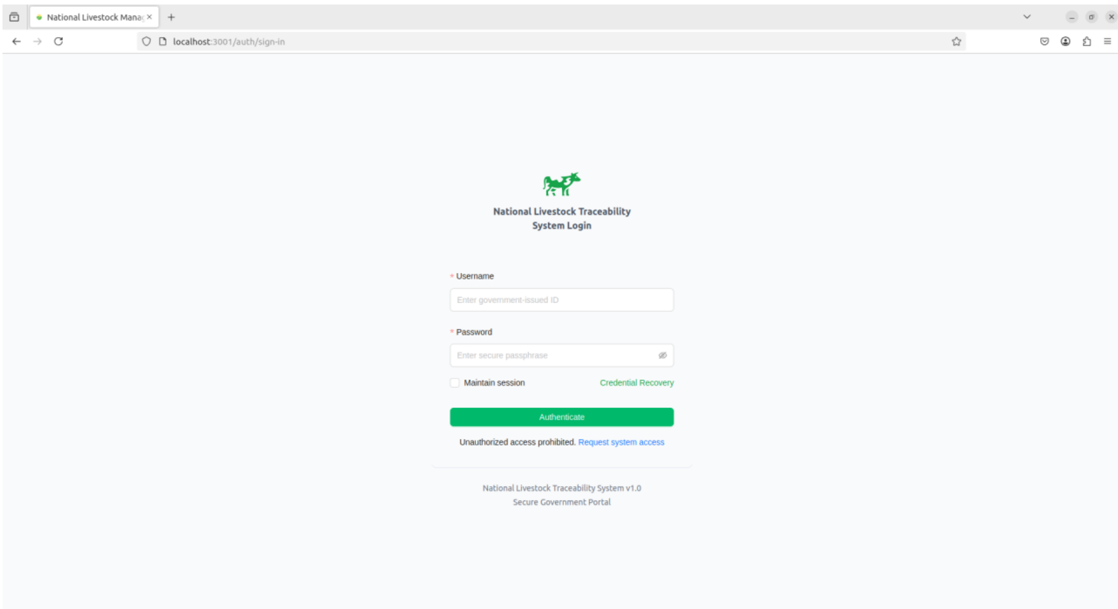


Figure 12 - Login Page

Farmer Dashboard

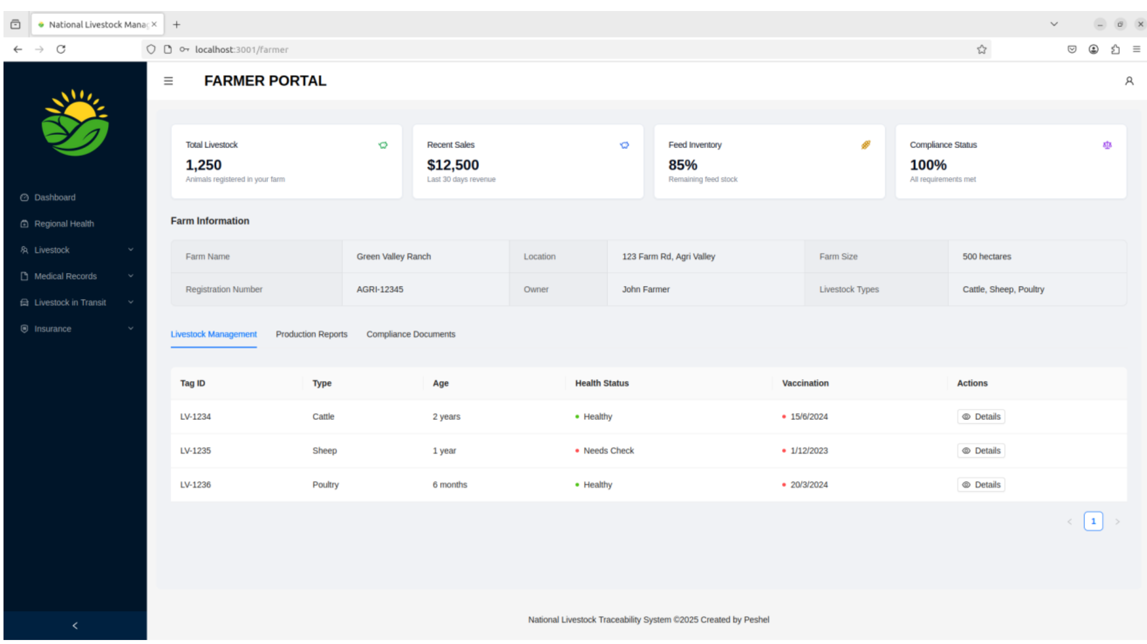


Figure 13 - Farmer Dashboard

Livestock View

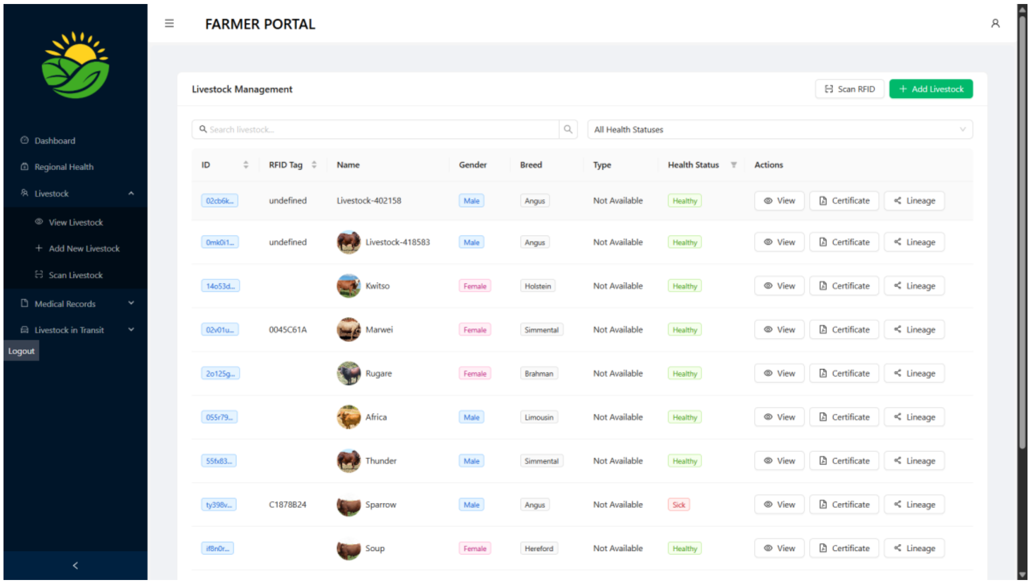


Figure 14 - Livestock Records View

Livestock Details

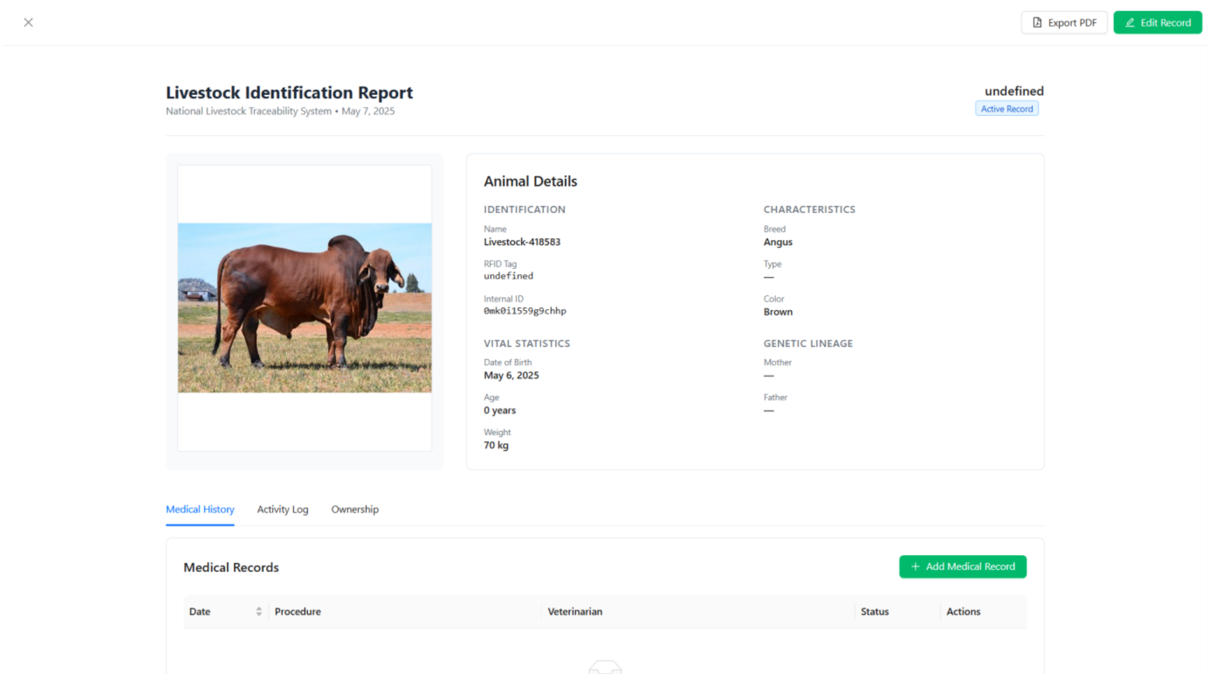


Figure 15 - Livestock Details Page

Medical Records (Veterinarian Portal)

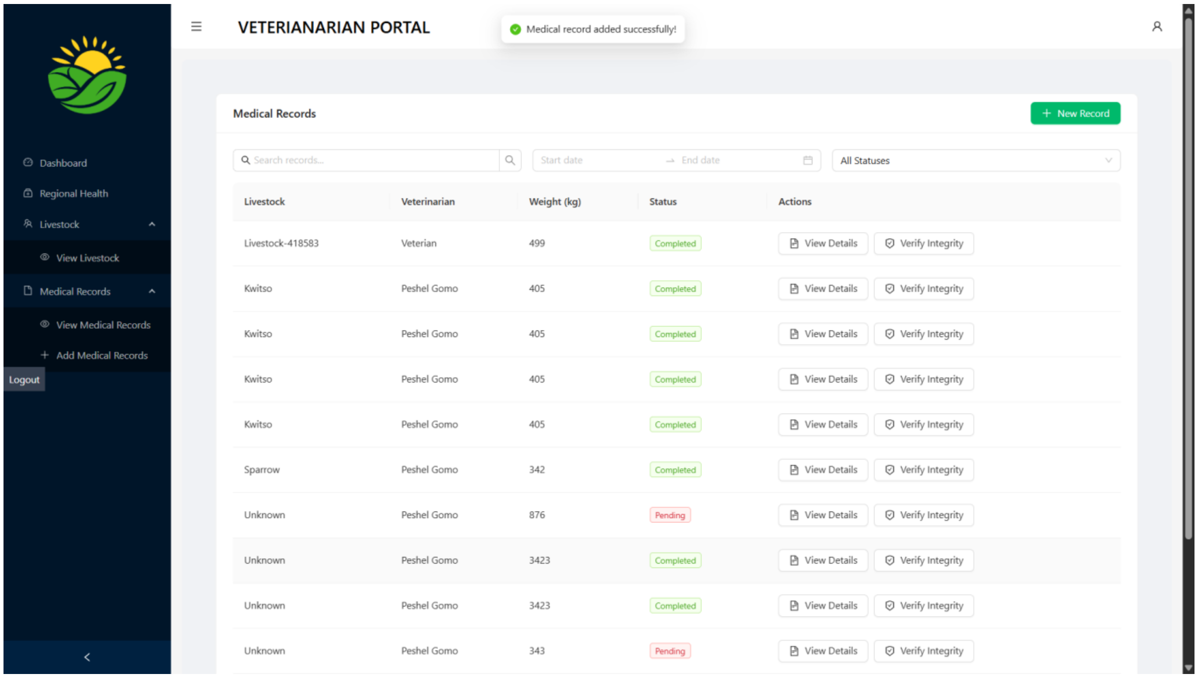


Figure 16 - Medical Records Page

Health Certificate

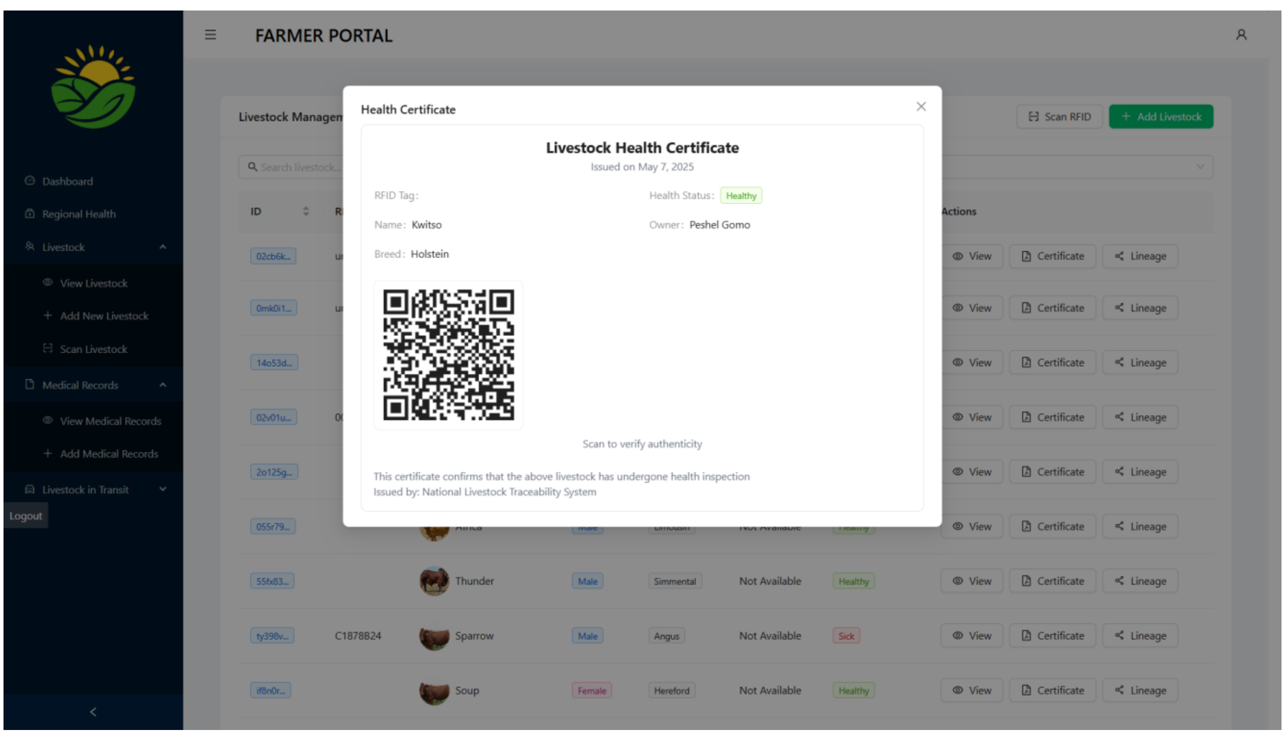


Figure 17 - Health Certificate

Animal Movement Logs

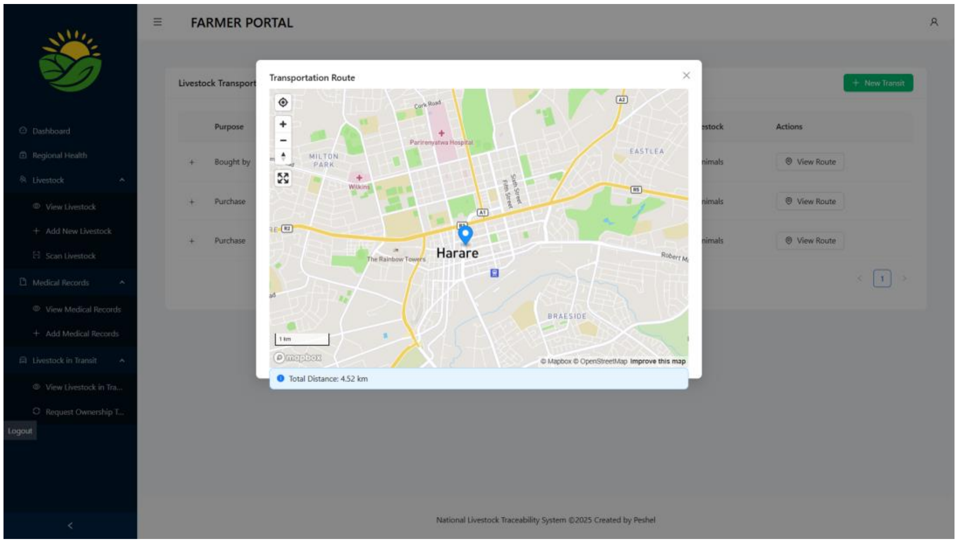
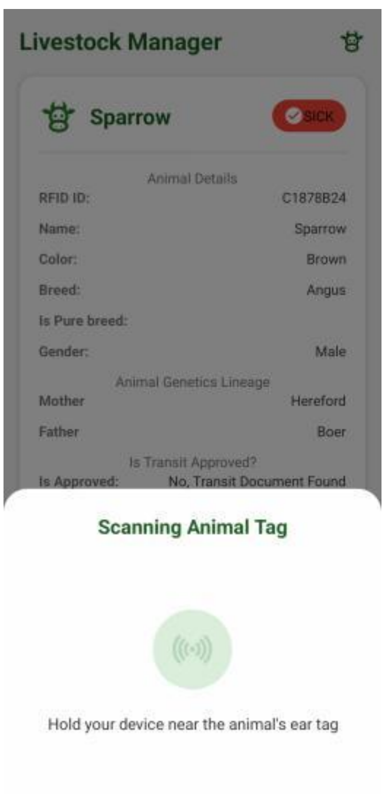
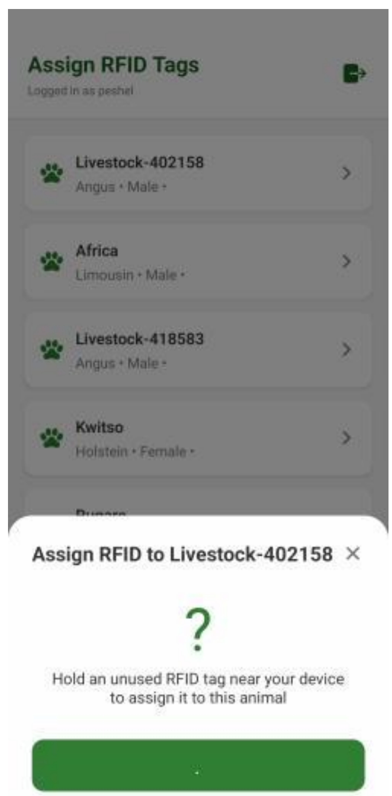


Figure 18 - Animal Movements Logs

4.5.2 Mobile App (Screenshots)



Scan RFID Tag



Assign RFID Tag

Figure 19 - Mobile App Screenshots

Chapter Five: Implementation and Testing

5.1 Code

5.1.1 Pseudo Code

Pseudo Code: Save livestock data to blockchain

```
FUNCTION saveLivestockDataToBlockchain(livestockData, farmerPrivateKey)
    serializedData = serialize(livestockData)
    encryptionKey = generateSymmetricKey()
    encryptedData = encrypt(serializedData, encryptionKey)
    farmerPublicKey = getPublicKey(farmerPrivateKey)
    encryptedKey = encryptWithPublicKey(encryptionKey, farmerPublicKey)
    payload = {
        "encryptedData": encryptedData,
        "encryptedKey": encryptedKey,
        "timestamp": getCurrentTimestamp()
    }
    ethClient = connectToEthereumNetwork()
    transactionHash = ethClient.smartContract.saveLivestockRecord(payload, sender=farmerPrivateKey)
    RETURN transactionHash
END FUNCTION
```

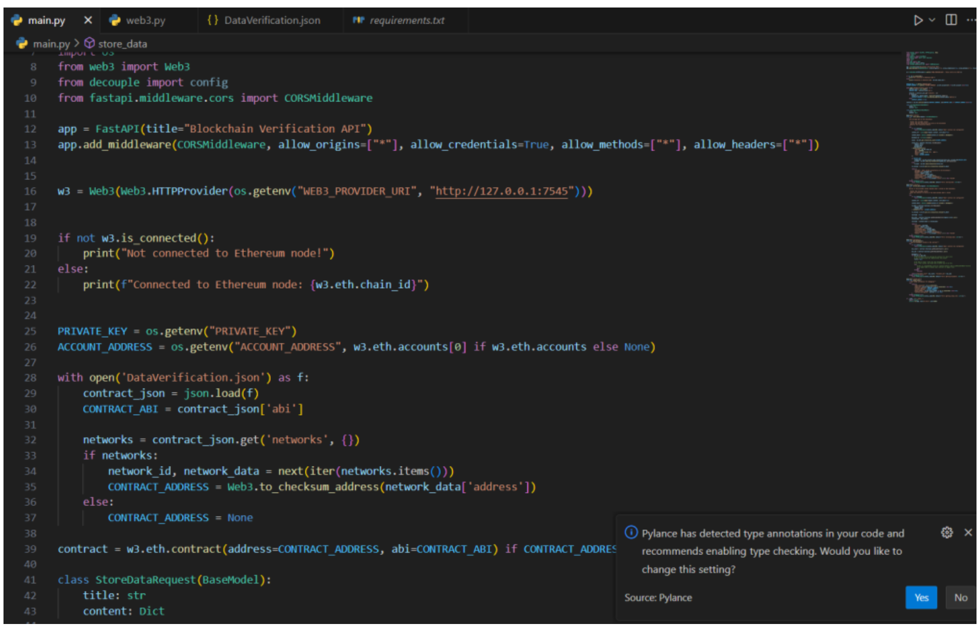
Pseudo Code: Verify Livestock Health Certificate

```
FUNCTION verifyHealthCertificateFromQRCode(qrCodeData)
    certificateData = scanQRCode(qrCodeData)
    isValid = verifyDigitalSignature(certificateData)
    IF NOT isValid THEN
        sendAlert("Invalid health certificate detected", certificateData.livestockId)
        RETURN "Invalid Certificate"
```

```
    END IF
    healthStatus = certificateData.healthStatus
    livestockId = certificateData.livestockId
    IF healthStatus == "Sick" OR healthStatus == "Quarantined" THEN
        flagLivestockHealth(livestockId, healthStatus)
        sendAlert("Health Alert: Livestock flagged as " + healthStatus, livestockId)
        RETURN "Health Issue Detected"
    END IF
    RETURN "Certificate Verified - Livestock Healthy"
END FUNCTION
```

5.2.2 Source Code

Connecting to block-chain network



```
main.py  web3.py  DataVerification.json  requirements.txt
main.py > store_data
from web3 import Web3
from decouple import config
from fastapi.middleware.cors import CORSMiddleware

app = FastAPI(title="Blockchain Verification API")
app.add_middleware(CORSMiddleware, allow_origins=["*"], allow_credentials=True, allow_methods=["*"], allow_headers=["*"])


w3 = Web3(Web3.HTTPProvider(os.getenv("WEB3_PROVIDER_URI", "http://127.0.0.1:7545")))


if not w3.is_connected():
    print("Not connected to Ethereum node!")
else:
    print(f"Connected to Ethereum node: {w3.eth.chain_id}")


PRIVATE_KEY = os.getenv("PRIVATE_KEY")
ACCOUNT_ADDRESS = os.getenv("ACCOUNT_ADDRESS", w3.eth.accounts[0] if w3.eth.accounts else None)

with open('DataVerification.json') as f:
    contract_json = json.load(f)
    CONTRACT_ABI = contract_json['abi']

    networks = contract_json.get('networks', {})
    if networks:
        network_id, network_data = next(iter(networks.items()))
        CONTRACT_ADDRESS = Web3.to_checksum_address(network_data['address'])
    else:
        CONTRACT_ADDRESS = None

contract = w3.eth.contract(address=CONTRACT_ADDRESS, abi=CONTRACT_ABI) if CONTRACT_ADDRES

class StoreDataRequest(BaseModel):
    title: str
    content: Dict
```

Pylance has detected type annotations in your code and recommends enabling type checking. Would you like to change this setting?

Source: Pylance Yes No

Figure 20 - Blockchain Source

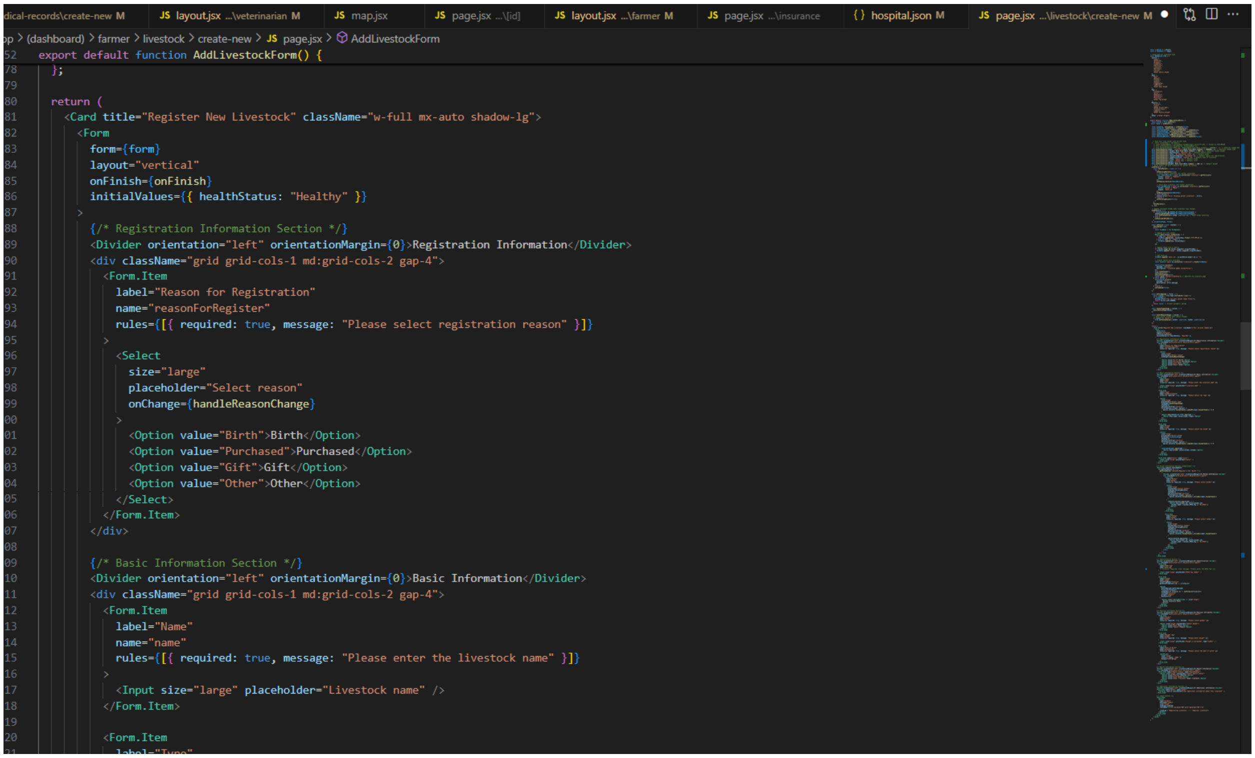
Register Livestock

```
LITSStorage.sol ×
contracts > LITSStorage.sol > ...
contract LITSAnimalRegistration is LITSStorage {

    function registerAnimal(
        string memory _animalID,
        string memory _species,
        string memory _breed,
        uint256 _birthDate,
        string memory _birthLocation,
        string memory _geneticInfoHash
    ) external {
        require(bytes(animals[_animalID].animalID).length == 0, "Animal already registered");

        animals[_animalID] = Animal({
            animalID: _animalID,
            species: _species,
            breed: _breed,
            birthDate: _birthDate,
            birthLocation: _birthLocation,
            owner: msg.sender,
            status: "ACTIVE",
            geneticInfoHash: _geneticInfoHash,
            medicalRecordHashes: new string[](0),
            movementHashes: new string[](0)
        });

        farms[msg.sender].ownedAnimals.push(_animalID);

        emit AnimalRegistered(_animalID, _species, msg.sender);
    }

    function updateAnimalStatus(string memory _animalID, string memory _status)
        external
        onlyOwner(_animalID)
    {
        animals[_animalID].status = _status;
        emit AnimalStatusChanged(_animalID, _status);
```

Add medical Record

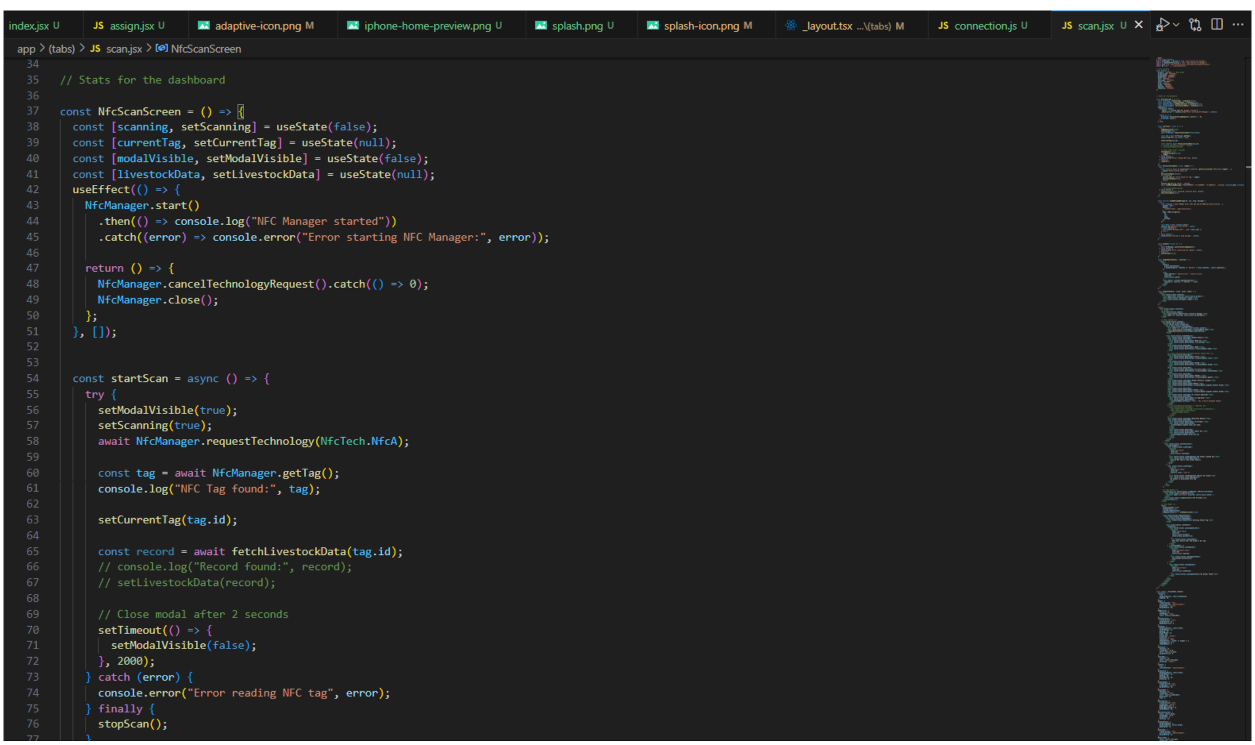
```
LITSStorage.sol ×
contracts > LITSStorage.sol > ...

contract LITSMedicalRecords is LITSAnimalRegistration {
    function addMedicalRecord(
        string memory _recordID,
        string memory _animalID,
        string memory _procedureType,
        string memory _description,
        string memory _veterinarian,
        string memory _hashOfDocuments
    ) external onlyOwner(_animalID) {
        require(bytes(animals[_animalID].animalID).length > 0, "Animal not registered");
        // Removed invalid require statement as _toOwner is not declared in this function
        medicalRecords[_recordID] = MedicalRecord({
            recordID: _recordID,
            animalID: _animalID,
            date: block.timestamp,
            procedureType: _procedureType,
            description: _description,
            veterinarian: _veterinarian,
            hashOfDocuments: _hashOfDocuments
        });

        animals[_animalID].medicalRecordHashes.push(_hashOfDocuments);

        emit MedicalRecordAdded(_animalID, _recordID, _procedureType);
    }

    function getMedicalRecord(string memory recordID) external view returns (MedicalRecord memory) {
        return medicalRecords[recordID];
    }
}
```

Register Livestock Form



```jsx
export default function AddLivestockForm() {
  };

  return (
    <Card title="Register New Livestock" className="w-full mx-auto shadow-lg">
      <Form
        form={form}
        layout="vertical"
        onFinish={onFinish}
        initialValues={{ healthStatus: "Healthy" }}
      >
        {/* Registration Information Section */}
        <Divider orientation="left" orientationMargin={0}>Registration Information</Divider>
        <div className="grid grid-cols-1 md:grid-cols-2 gap-4">
          <Form.Item
            label="Reason for Registration"
            name="reasonForRegister"
            rules={[{ required: true, message: "Please select registration reason" }]}
          >
            <Select
              size="large"
              placeholder="Select reason"
              onChange={handleReasonChange}
            >
              <Option value="Birth">Birth</Option>
              <Option value="Purchased">Purchased</Option>
              <Option value="Gift">Gift</Option>
              <Option value="Other">Other</Option>
            </Select>
          </Form.Item>
        </div>

        {/* Basic Information Section */}
        <Divider orientation="left" orientationMargin={0}>Basic Information</Divider>
        <div className="grid grid-cols-1 md:grid-cols-2 gap-4">
          <Form.Item
            label="Name"
            name="name"
            rules={[{ required: true, message: "Please enter the livestock name" }]}
          >
            <Input size="large" placeholder="Livestock name" />
          </Form.Item>

          <Form.Item
```

Scan RFID Tag (Mobile App)



```jsx
// Stats for the dashboard

const NfcScanScreen = () => {
  const [scanning, setScanning] = useState(false);
  const [currentTag, setCurrentTag] = useState(null);
  const [modalVisible, setModalVisible] = useState(false);
  const [livestockData, setLivestockData] = useState(null);
  useEffect(() => {
    NfcManager.start()
      .then(() => console.log("NFC Manager started"))
      .catch((error) => console.error("Error starting NFC Manager:", error));

    return () => {
      NfcManager.cancelTechnologyRequest().catch(() => 0);
      NfcManager.close();
    };
  }, []);


  const startScan = async () => {
    try {
      setModalVisible(true);
      setScanning(true);
      await NfcManager.requestTechnology(NfcTech.NfcA);

      const tag = await NfcManager.getTag();
      console.log("NFC Tag found:", tag);

      setCurrentTag(tag.id);

      const record = await fetchLivestockData(tag.id);
      // console.log("Record found:", record);
      // setLivestockData(record);

      // Close modal after 2 seconds
      setTimeout(() => {
        setModalVisible(false);
      }, 2000);
    } catch (error) {
      console.error("Error reading NFC tag", error);
    } finally {
      stopScan();
```

5.2 Software Test Plan

Effective software testing ensures that the LITS system meets both technical specifications and user expectations. The testing process for LITS is divided into **unit testing**, **integration testing**, and **system testing**, as well as **functional and non-functional testing**.

5.2.1 Unit Testing

Unit testing focuses on individual components/modules such as the Animal Registration Module, RFID Tag Reader, and Blockchain Logger.

Unit Test Cases with Input Examples

Test Case ID	Component	Input Example	Expected Result	Status
UT001	RFIDModule	rfidTag = "ZWRFID123456" (already exists)	RFID rejected (duplicate)	Pass
UT002	AnimalRegistry	animalData = {type: "Cattle", breed: "Brahman", birthDate: "2022-08-15"}	Animal added to database	Pass
UT003	BlockchainLogger	eventType = "VetVisit", animalId = "A101", vetId = "VET009"	Entry logged on blockchain	Pass
UT004	HealthModule	lastVaccination = "2022-01-01"	Warning for expired vaccination	Pass

Table 11 - Unit Test

5.2.2 Integration Testing

Integration testing ensures that different components of the system interact correctly.

Integration Test Cases with Input Examples

Test Case ID	Modules Involved	Input Example	Expected Result	Status
IT001	RFIDModule + AnimalRegistry	rfidTag = "NEW123", animalData = {type: "Goat", breed: "Boer"}	RFID linked and animal registered	Pass
IT002	HealthModul	animalId = "G001", treatment	Health log added and	Pass

	e + Blockchain	= "Foot rot injection"	recorded	
IT003	Movement + UserModule	animalId = "C002", newOwner = "USR007"	Ownership verified and updated	Pass
IT004	MobileApp + AnimalDB	rfidScan = "RFID9988"	Animal profile returned on mobile UI	Pass

Table 12 - Integration Test

5.2.3 System Testing

System testing evaluates the entire LITS system to verify that it functions as a complete solution.

Table 3: System Test Scenarios with Input Examples

Test Case ID	Scenario	Input Example	Expected Output	Status
ST001	Register + Move Animal	Register: Bovine, Brahman, RFID1023, then move to Mashonaland West	Registered + Movement approved	Pass
ST002	Unauthorized Vet Log	vetId = "INVALID01" attempts to log treatment for animalId = "G003"	Access denied	Pass
ST003	Transfer Block (Expired vaccine)	animalId = "C009" with expired vaccine attempts to move	Movement denied	Pass
ST004	Offline Sync	animalId = "G002" registered on mobile offline	Queued for sync, success after reconnection	Pass

Table 13 - System Test

5.3 Functional Testing

Functional testing ensures the system performs as per its functional specifications.

5.3.1 Functional Testing Aspects

Function	Input Example	Expected Output	Result
Register Animal	RFID: RFID3001, Data: {"type":"Pig", "breed":"Large White", "dob":"2023-01-01"}	Animal saved with ID, confirmation message	Pass

Identify via RFID	RFID Scan: RFID3001	Animal details fetched	Pass
Vet Treatment Logging	animalId="P001", treatment="Vaccination: Swine Fever"	Treatment logged in health records + ledger	Pass
Validate Movement	animalId="P001", destination="Bulawayo"	All checks passed, movement logged	Pass

Table 14 - Functional Test

5.4 Non-Functional Testing

Non-functional testing checks performance, usability, security, and reliability.

Non-Functional Testing Aspects

Type	**Test Objective**	**Method**	**Result**
Performance	System supports 50 concurrent RFID scans	Load testing with virtual users	Pass
Usability	Interface is intuitive for rural extension officers	Field testing	Pass
Security	Data encryption + user roles prevent unauthorized access	Penetration testing	Pass
Reliability	No data loss after system reboot	Crash and recovery test	Pass
Scalability	Supports over 10,000 registered animals		

5.5 User Acceptance Testing

5.5.1 UAT Test Scenarios and Results

Test ID	**Scenario**	**Performed By**	**Expected Result**	**Actual Result**	**Status**
UAT01	Register new animal via mobile app	Farmer	Animal saved with RFID, breed, DOB, and location	Success	Pass
UAT02	Scan RFID at checkpoint	Livestock Inspector	Animal details retrieved instantly	Success	Pass
UAT03	Record	Vet Officer	Treatment recorded and	Success	Pass

	treatment update		logged to blockchain		
UAT04	Try duplicate RFID registration	Farmer	Error message shown; duplicate not allowed	Success	Pass
UAT05	Offline animal registration	Farmer	Data saved locally and synced later	Success	Pass
UAT06	View breed/genetic history	Vet Officer	Breed, parents, and history displayed correctly	Success	Pass
UAT07	Approve animal movement	Inspector	Health and ownership validated before approval	Success	Pass

Table 15 - User Acceptance Test

Chapter Six: Recommendations and Conclusion

6.1 Summary of Results and Findings

The developed Livestock Identification and Traceability System (LITS) achieved its primary objectives of improving transparency, traceability, and security in Zimbabwe's livestock sector. By leveraging RFID for animal identification and blockchain for secure data storage, the system provides a digital alternative to the manual and fragmented record-keeping practices still common among smallholder farmers.

Achievements

Objective	**Implementation**	**Is objective achieved?**
Digital livestock management platform	Android app with Pocketbase and blockchain backend storing animal profiles and health records	Yes
RFID-based livestock identification	Used university lab RFID equipment to tag and scan 10 test animals	Yes
Digital health certification	Generated QR-coded PDF certificates with manual verification	Yes
Animal genealogy tracking	Implemented basic pedigree tree viewer in mobile app	Yes
Secure veterinary records	Developed local database with SHA-256 record hashing	Yes

6.2 Challenges Encountered and How They Were Resolved

Several challenges emerged throughout the research and development phase. These challenges were resolved using innovative, context-appropriate approaches, as detailed below:

- **Limited Internet Connectivity**
  → Solution: Introduced offline-first mobile app with automatic synchronization once reconnected.
- **Low Digital Literacy Among Users**
  → Solution: Developed user-friendly UI with icons, audio guidance, and training materials in local languages.

- **Cost of Implementation (RFID, Blockchain)**
  → Solution: Used open-source blockchain (e.g., Hyperledger Fabric) and affordable passive RFID tags.
- **Data Duplication and Integrity Issues**
  → Solution: Enforced unique RFID validation, automated duplicate checks, and mandatory data fields.
- **Complexity of Multi-Species Management**
  → Solution: System architecture was built to dynamically handle multiple livestock species with their own breed and traceability profiles.

6.3 Recommendations

To enhance adoption, scale, and impact of the system, the following recommendations are proposed:

- **Government Policy and Incentives**
  - Mandate digital animal identification for disease-prone and export-targeted livestock.
  - Provide subsidies or financial incentives for RFID tag adoption.
- **Training and Extension Services**
  - Conduct national awareness campaigns and local training workshops for communal farmers.
  - Partner with veterinary services and local agricultural officers for grassroots support.
- **Interoperability with Existing Systems**
  - Integrate with existing government systems like ZCTS, Herd Book, customs databases, and veterinary clinics.
- **Ethical Data Management and Access Control**
  - Implement strict authentication, access logs, and role-based permissions.
  - Respect communal ownership models and maintain transparency in data use.
- **Market Expansion and Financial Linkages**
  - Develop a traceability-backed livestock e-marketplace.
  - Integrate mobile money and microinsurance for livestock-based financial inclusion.

6.4 Future Work

Future development efforts can build on the current system to unlock broader impact:

- **Artificial Intelligence Integration**
  - Use AI to predict disease outbreaks and optimize breeding cycles based on traceable patterns.
- **Geospatial Mapping**
  - Add GIS-based dashboards to visualize disease hotspots, grazing patterns, and livestock density.
- **Blockchain Scalability**
  - Migrate from prototype blockchain to scalable mainnets or consortium-based networks for national adoption.
- **National Livestock Registry**
  - Partner with government agencies to convert the system into an official national livestock database.
- **Traceability-Linked Incentives**
  - Develop reward schemes for compliant farmers and certified traceable livestock products.

6.5 Conclusion

The successful development of the digital Livestock Identification and Traceability System demonstrates the feasibility of integrating modern technologies such as RFID and blockchain into Zimbabwe’s traditional livestock sector. Despite challenges, the project showed that with contextual innovation and inclusive design, digital transformation in agriculture is achievable—even in resource-constrained environments.

The system is well-positioned to improve disease control, boost export readiness, and empower smallholder farmers through data ownership and financial inclusion. With continued support from government, private sector, and NGOs, this solution can significantly reshape how Zimbabwe manages and benefits from its livestock sector.

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Appendix A: Data Collection Tools

1. Semi-Structured Interview Questions

Interview Guide for Farmers

Section 1: Current Livestock Identification Practices

1. What methods do you currently use to identify your livestock (e.g., branding, ear tags, manual records)?
2. How effective are these methods in preventing theft or misidentification?
3. What challenges do you face with the current identification system?

Section 2: Recordkeeping & Traceability
4. How do you track vaccinations, diseases, and medical treatments for your animals?
5. Do you maintain records of animal movements (sales, grazing, disease outbreaks)? If so, how?
6. Have you ever lost records due to paper damage, theft, or human error?

Section 3: Technology & Adoption
7. Are you familiar with RFID tags or digital livestock tracking systems?
8. Would you be willing to use a mobile app for livestock management if it improves traceability?
9. What concerns would you have about switching to a digital system (e.g., cost, training, internet access)?

Section 4: Market & Economic Impact
10. Has poor recordkeeping ever affected your ability to sell livestock (e.g., export restrictions)?
11. Would verifiable digital health records help you get better prices for your cattle?
12. Do you think blockchain-based traceability could help Zimbabwe regain access to EU beef markets?

2. Survey Questionnaire (Livestock Traceability Adoption Survey)

Section A: Demographic Information

- Name (Optional): _______________
- Role (Farmer/Veterinarian/Government Official): _______________
- Farm Size (Small-scale/Medium/Large Commercial): _______________

Section B: Current Practices

1. What livestock identification method do you currently use?
    a. Branding
    b. Ear Tags
    c. Manual Records
    d. Other: _______________
2. How satisfied are you with the current system? *(Scale: 1–5, Very Dissatisfied to Very Satisfied)*

Section C: Technology Adoption
3. Would you use an RFID-based digital tracking system if available? *(Yes/No)*
4. What concerns do you have about adopting blockchain-based traceability? *(Open-ended)*

Section D: Policy & Support
5. Should the government enforce digital livestock tracking? *(Yes/No/Unsure)*
6. What incentives would encourage adoption? *(Training, Subsidies, Better Market Access, etc.)*

Appendix B: User Manual for LITS (Livestock Identification & Traceability System)

Version 1.0

For Farmers, Veterinarians, and Mobile App Users

1. Introduction

The Livestock Identification & Tracking System (LITS) is a digital platform designed to help farmers and veterinarians manage livestock records efficiently. It consists of:

- **Farmer Web Portal** – Manage livestock, view medical records, movement logs, and health certificates.
- **Veterinarian Portal** – Add and view medical records for animals.
- **Mobile App** – Scan and assign RFID tags to livestock.

This manual guides users on how to operate each component.

1.1 Getting Started

- **Step 1:**Download and Install the LITS mobile app (Android/iOS).
- **Step 2:** Register a Farmer account on the LITS Web Portal.
- **Step 4:** Login using your new account.

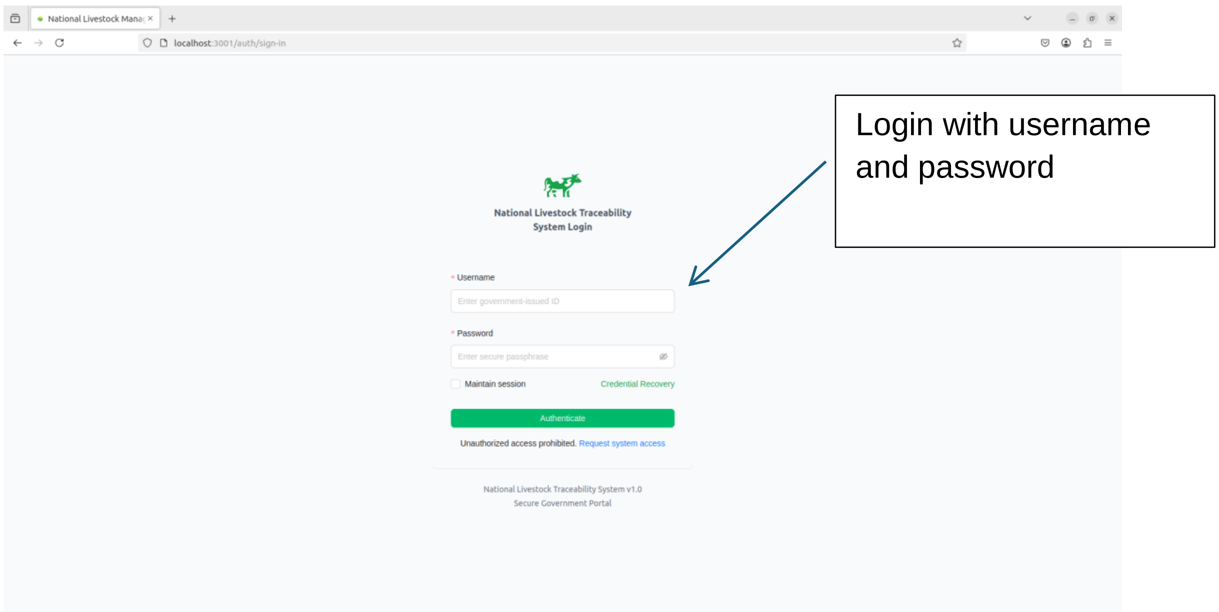
2 Farmer Portal (Web) – User Guide

Access: Open a web browser and go to: www.zimlits.co.zw

2.1 Login

1. Enter your username and password.

2. Click "Login".



2.2 Dashboard Overview

- View total livestock count.
- Check recent medical records.
- See pending health certificates.

2.3 Managing Livestock

Add New Livestock

1. Click "Add Livestock".
2. Fill in:
    - Animal ID (Auto-generated or manual).
    - RFID Tag Number (If already assigned via mobile app).
    - Breed, Age, Gender.
3. Click "Save".

View Livestock List

- Search by Animal ID, RFID Tag, or Breed.
- Click on an animal to see full details.

2.4 Viewing Medical Records

1. Go to "Medical Records" tab.
2. Select an animal to see its vaccination history, treatments, and vet notes.

2.5 Movement Logs

- Track animal transfers, sales, or purchases.
- View date, destination, and purpose.

2.6 Health Certificates

- View and download digital health certificates.
- Certificates include a QR code for verification.

---

3. Veterinarian Portal (Web) – User Guide

3.1 Login

1. Enter vet credentials (provided by admin).
2. Click "Login".

3.2 Adding Medical Records

1. Search for an animal by RFID or Animal ID.
2. Click "Add Medical Record".
3. Enter:
    - Treatment/Vaccine name.
    - Date administered.
    - Dosage & notes.

4. Click "Save".

3.3 Viewing Animal History

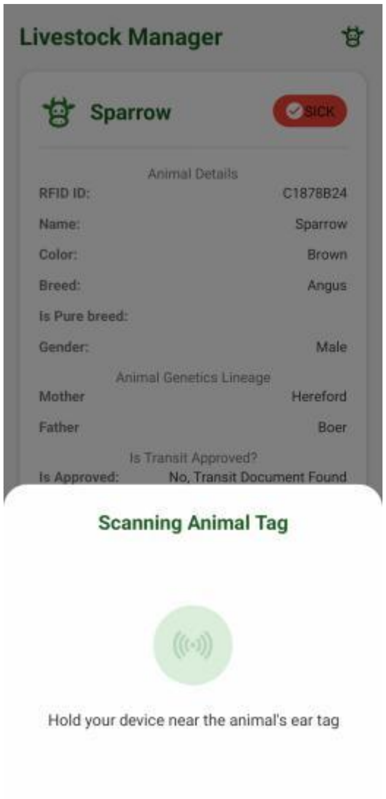
- Check full medical history of any animal.
- Export records as PDF if needed.

---

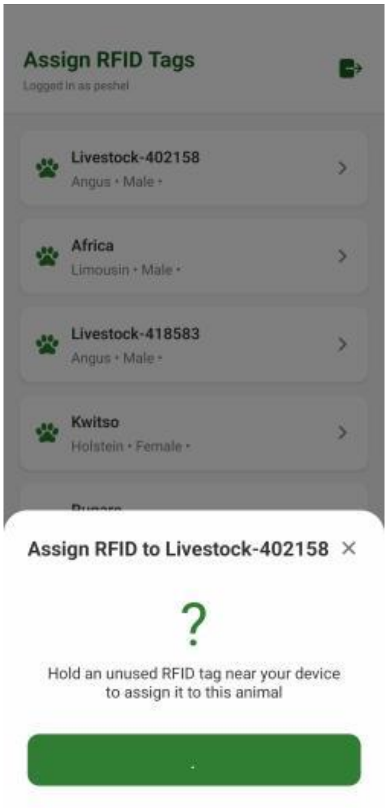
4. Mobile App – RFID Tagging Guide

Download: Available on Google Play Store (Android).

Scan RFID scanner (via NFC-enabled phone).



Scan RFID Tag



Assign RFID Tag

4.1 Login

- Use Farmer/Vet credentials (same as web portal).

4.2 Assigning RFID Tags

1. Open the app and tap "Scan RFID".
2. Hold phone near the animal’s RFID ear tag.
3. Once scanned:
   - Enter animal details (breed, age, gender).
   - Tap "Save to Farm".

4.3 Viewing Tagged Animals

- Go to "My Livestock" to see all scanned animals.
- Tap an animal to see its profile and records.

---

5. Troubleshooting

Issue	**Solution**
Can’t log in	Reset password or contact admin
RFID not scanning	Check NFC is enabled; hold phone closer
Medical records not saving	Check internet connection
Health certificate not loading	Refresh page or clear browser cache

3. Key Features

- **Tagging Livestock:**
    - Scan RFID tag.
    - Enter animal details (breed, age, gender).
    - Confirm submission (syncs with blockchain).
- **Recording Health Events:**
    - Select animal via RFID scan.
    - Input vaccination/treatment details.
    - Submit to generate an immutable record.
- **Movement Tracking:**
    - Log grazing/sales movements via GPS.
    - View history in the "Animal Logs" tab.

Appendix C: Sample Code

Smart Contract (Solidity)

```
// SPDX-License-Identifier: MIT
pragma solidity ^0.8.0;

contract LITS {
    // Structs
    struct Animal {
        string rfidTag;
        address owner;
        string breed;
        uint256 birthDate;
        bool isActive;
    }

    struct MedicalRecord {
        uint256 date;
        string veterinarianId;
        string treatment;
        string notes;
    }

    struct HealthCertificate {
        uint256 issueDate;
        uint256 expiryDate;
        string issuingVet;
        bool isValid;
    }

    // Mappings
    mapping(string => Animal) public animals;
    mapping(string => MedicalRecord[]) public medicalRecords;
    mapping(string => HealthCertificate) public healthCertificates;
    mapping(address => string[]) public ownerAnimals;
```

```
// Events
event AnimalRegistered(string rfidTag, address owner);
event MedicalRecordAdded(string rfidTag, string treatment);
event CertificateIssued(string rfidTag, string veterinarianId);
event OwnershipTransferred(string rfidTag, address newOwner);

// Modifiers
modifier onlyOwner(string memory rfidTag) {
    require(animals[rfidTag].owner == msg.sender, "Not the owner");
    _;
}

// Core Functions
function registerAnimal(
    string memory rfidTag,
    string memory breed,
    uint256 birthDate
) external {
    require(animals[rfidTag].isActive == false, "Animal already registered");

    animals[rfidTag] = Animal({
        rfidTag: rfidTag,
        owner: msg.sender,
        breed: breed,
        birthDate: birthDate,
        isActive: true
    });

    ownerAnimals[msg.sender].push(rfidTag);
    emit AnimalRegistered(rfidTag, msg.sender);
}

function addMedicalRecord(
    string memory rfidTag,
    string memory veterinarianId,
    string memory treatment,
    string memory notes
) external {
    medicalRecords[rfidTag].push(MedicalRecord({
        date: block.timestamp,
        veterinarianId: veterinarianId,
        treatment: treatment,
        notes: notes
    }));

    emit MedicalRecordAdded(rfidTag, treatment);
}

function issueHealthCertificate(
    string memory rfidTag,
    string memory veterinarianId,
    uint256 validityDays
) external {
    healthCertificates[rfidTag] = HealthCertificate({
        issueDate: block.timestamp,
        expiryDate: block.timestamp + (validityDays * 1 days),
        issuingVet: veterinarianId,
        isValid: true
    });
```

```
        emit CertificateIssued(rfidTag, veterinarianId);
    }

    function transferOwnership(
        string memory rfidTag,
        address newOwner
    ) external onlyOwner(rfidTag) {
        animals[rfidTag].owner = newOwner;
        ownerAnimals[newOwner].push(rfidTag);

        // Remove from previous owner's list
        for (uint i = 0; i < ownerAnimals[msg.sender].length; i++) {
            if (keccak256(bytes(ownerAnimals[msg.sender][i])) == keccak256(bytes(r
fidTag))) {
                ownerAnimals[msg.sender][i] = ownerAnimals[msg.sender][ownerAnimal
s[msg.sender].length - 1];
                ownerAnimals[msg.sender].pop();
                break;
            }
        }

        emit OwnershipTransferred(rfidTag, newOwner);
    }

    // View Functions
    function getAnimalDetails(string memory rfidTag) external view returns (Animal
 memory) {
        return animals[rfidTag];
    }

    function getMedicalHistory(string memory rfidTag) external view returns (Medic
alRecord[] memory) {
        return medicalRecords[rfidTag];
    }

    function checkCertificateValidity(string memory rfidTag) external view returns
 (bool) {
        return healthCertificates[rfidTag].isValid && healthCertificates[rfidTag].
expiryDate >= block.timestamp;
    }
}
```