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Original Article

Block Chain For Safer & Traceable Indian Dairy Products

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Abstract

The Indian dairy industry is essential to the economy and supports millions of farmers. However, it faces challenges like adulteration, counterfeit products, and quality issues. The current system relies on paperwork and manual inspections, making it hard to track problems in real-time. Because lack of transparency creates trust issues among stakeholders, as records can be tampered with. To solve these problems, innovative technologies like blockchain can improve safety and traceability. Blockchain is a secure digital ledger that records transactions in an unchangeable and decentralized manner. It ensures transparency and trust across the supply chain, benefiting farmers, producers, processors, and distributors. A blockchain-based system can create a tamper-proof record of every transaction in the supply chain. It allows easy tracking of dairy products from their source to consumers, ensuring safety and quick identification of quality issues. The entire supply chain becomes more transparent, reducing fraud and improving efficiency. By adopting blockchain, the dairy industry can transform itself, boosting consumer confidence and ensuring high-quality products. Automation can also cut costs and streamline operations, helping the industry meet regulatory standards while delivering safe dairy products to the market.

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Keywords

Dairy Products, Food Safety, Traceability, Supply chain Management, Blockchain

Introduction

Information and Communication Technology (ICT) is a vital tool for efficiently producing, organizing, storing, and disseminating information. In agriculture, ICT has significantly improved productivity by delivering timely information [13] to farmers on weather forecasts, market prices, pest control, and other critical areas [1] .It has enabled crop diversification, created job opportunities, expanded market access for cash crops, and promoted sustainable livelihoods, especially in remote rural areas. Modern advancements in ICT, such as blockchain technology, are increasingly relevant in agriculture. Blockchain facilitates decentralized, transparent, and reliable transactions through cryptographic hash functions that ensure data integrity. Once recorded, blockchain data cannot be tampered with, creating secure chains of records linked by cryptographic keys [9] The system is maintained by distributed nodes and audited collectively under a consensus protocol [1] [4].

Blockchain technology balances decentralization, scalability, and security to ensure reliability. Its applications in agriculture include tracking food provenance, enabling smart farming practices, and facilitating transparent transactions [2], By recording every step of the value chain immutably, blockchain fosters trust among stakeholders while addressing fraud and inefficiencies in supply chains. The dairy industry contributes 4% to India's GDP and employs over 2 million people, primarily smallholder farmers. [5] These farmers deliver milk to collection centers where transactions are manually recorded using vulnerable methods like hardcopy files or basic digital formats. Brokers often exploit these systems by altering records to reduce payments to farmers.

To address these challenges, integrating blockchain technology into milk delivery operations can enhance transparency and accountability [4]. A blockchain-based platform ensures immutable data storage across decentralized nodes, protecting farmers—many of whom are illiterate—from exploitation by dishonest intermediaries. Each milk delivery transaction is stored as a secure block with a hash code. Before adding new records, the blockchain verifies the integrity of previous blocks to prevent unauthorized alterations [14] .The system guarantees accurate payments to farmers while safeguarding their earnings. By ensuring end-to-end traceability of milk deliveries, blockchain fosters trust among stakeholders in the dairy supply chain. It also

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streamlines operations through automation and reduces costs while aligning with regulatory standards.

Blockchain integration not only protects farmer earnings but also boosts consumer confidence by guaranteeing product authenticity [10]. The transformative approach strengthens the dairy sector's efficiency and sustainability while benefiting all stakeholders involved.

Related work

The adoption of blockchain technology in dairy supply chains has garnered increasing interest due to its potential to enhance transparency, fairness, and trust among stakeholders [7]. Rambim et al. highlighted how decentralized record-keeping systems, enabled by blockchain, can safeguard smallholder farmers by minimizing the influence of intermediaries and ensuring direct access to market information. [17] Vincent et al. examined the impact of blockchain on dairy logistics, acknowledging its benefits in streamlining operations and improving traceability; however, it also noted the need for significant structural changes within the industry to fully leverage these technologies [12].

In a case study by Varavallo et al., the use of Green Blockchain within the Fontina PDO cheese supply chain demonstrated how blockchain can be employed to promote traceability and reinforce sustainability goals. Khanna et al. proposed an integrated system that combines blockchain with Internet of Things (IoT) devices and smart contracts, thereby offering both economic efficiencies and operational improvements in dairy management.

Li et al. provided a broader analysis of blockchain's benefits and challenges [6], particularly emphasizing its role in enhancing food safety protocols and supply chain visibility. In response to these opportunities, platforms like NUTRIA have been developed to automate traceability processes in dairy production. Meanwhile, [18] Liyanage et al. introduced blockchain-based e-commerce models supported by machine learning algorithms, aimed at improving profitability and operational decision-making. Mangla et al. explored the societal implications of blockchain adoption in the dairy industry, suggesting that it has the potential to contribute toward achieving Sustainable Development Goals (SDGs) through improved economic inclusion and environmental practices. The survey reviews such pioneering initiatives and investigates the wider impact of blockchain innovation in transforming the dairy sector.

Hyperledger Fabric is a permissioned, enterprise-grade blockchain framework recognized for its modular architecture, fine-grained access controls, and robust support for smart contracts—referred to as chaincode [8]. It is specifically designed to meet the requirements of industries such as finance, healthcare, and supply chain management that demand strong security, data privacy, and transaction scalability.

Key attributes of Hyperledger Fabric include modular transaction processing workflows, identity-based participant management, private channels for confidential transactions, and a reliable consensus mechanism.[16] Its infrastructure is built around several core components, including peer nodes (responsible for executing and validating transactions), client applications (interacting with the network), an ordering service (for managing the order of transactions), and membership services provided by Certificate Authorities and Membership Service Providers (MSPs) to ensure identity verification and access control.

Nevertheless, despite its many advantages, Hyperledger Fabric presents several operational and technical challenges [3]. The initial setup and ongoing maintenance of the network can be highly complex, often requiring specialized technical knowledge and meticulous configuration, which may lead to deployment errors. Its permissioned model, while beneficial for security, can inadvertently centralize authority, reducing the decentralized nature typically associated with blockchain technologies [18] and potentially introducing single points of failure. Moreover, the requirement for participants to disclose their identities may not align with use cases where anonymity or partial identity of concealment is essential. Smart contracts, though powerful, are susceptible to programming errors and vulnerabilities, which can compromise system integrity if not rigorously tested and audited [15]. Additionally, the consensus protocol used in Hyperledger Fabric—while effective in ensuring transaction consistency—can become a bottleneck [16] under high transaction volumes, limiting scalability and potentially leading to increased latency during peak loads.

Methodology

To address the limitations of the existing system, the work proposes migrating inventory management to a blockchain-based platform, where data is immutable and cannot be altered once stored. Blockchain operates as a decentralized network, distributing data across multiple nodes, ensuring data availability even if some nodes fail. Each record is stored as a block, linked with a unique hash. Before adding a new block, the system verifies the hash of previous blocks, allowing new data to be stored only if the integrity of the entire chain is confirmed—making tampering virtually impossible. The approach can prevent financial exploitation of farmers by brokers.

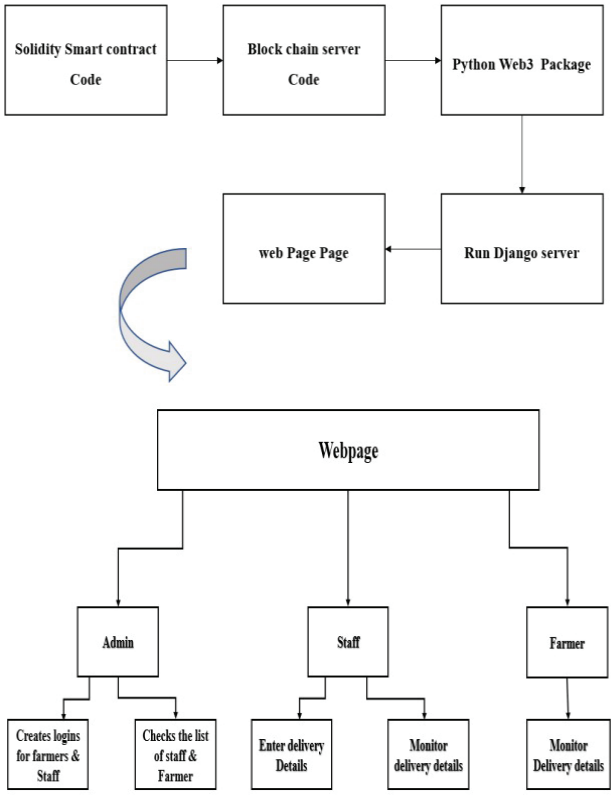

Figure 1: *Overall design of proposed methodology.*

To implement it, smart contracts will be developed using Solidity, defining all necessary functions for storing farmer and staff information. These contracts will be deployed on the Ethereum blockchain. Post-deployment, the Python Web3 library will be used to interact with the contract, enabling secure reading and writing of data to the blockchain.

The figure-1 illustrates the integration of a blockchain system with a Django-based web application using the Python Web3 library. It starts with writing smart contracts in Solidity, which define the decentralized logic. These contracts are deployed to a blockchain server, which executes the contract functions and securely stores data. The Python Web3 package connects the Django backend to the blockchain, allowing it to perform operations like reading from the chain and sending transactions. The Django server handles these interactions, processes user requests, and applies business logic. The processed data is displayed on the web interface, enabling users to interact with the system. It creates a continuous loop where frontend actions trigger backend processes that communicate with the blockchain, delivering a responsive and decentralized user experience.

It presents a web-based system designed to support agricultural logistics through role-based access. The central webpage allows three types of users—Admin, Staff, and Farmers—to perform specific tasks based on their roles. Admins manage user accounts by creating logins for staff and farmers and viewing user lists. Staff members handle delivery operations by entering and tracking delivery details. Farmers can monitor their own delivery information to stay updated on the status of their goods.

The system ensures organized user management and transparent delivery tracking, making agricultural operations more efficient and accessible.

Advantages of Block Chain :

here are several advantages to using blockchain technology:

- **Decentralization:** The decentralized nature of blockchain technology means that it is not controlled by any single entity, which increases transparency and security.
- **Immutability:** Once data has been recorded on a blockchain, it cannot be altered or deleted, which ensures that it is tamper-proof and provides a high degree of data integrity.
- **Security:** Blockchain technology uses cryptographic algorithms to secure transactions and data exchange, making it highly resistant to hacking and cyber attacks.
- Transparency: Blockchain technology provides a high degree of transparency, as all participants in the network have access to the same information, making it easier to verify and track transactions.
- **Efficiency:** Blockchain technology can reduce the need for intermediaries in transactions, reducing the time and cost associated with processing and verifying transactions.
- **Trust:** The security and transparency provided by blockchain technology can increase trust among participants in a network, leading to more efficient and secure transactions.

Overall, the advantages of blockchain technology make it a promising technology for a wide range of applications in various industries.

The integration of blockchain in India's dairy industry presents a powerful solution for improving traceability, quality, and efficiency. It enables real-time tracking of products, ensuring transparency from farm to consumer, and reduces reliance on intermediaries, thus lowering costs and enhancing trust. Smart contracts can automate payments, guaranteeing timely and fair compensation for farmers. When combined with IoT, blockchain can monitor milk quality in real time, helping prevent adulteration. Successful global examples like Milkchain (Italy) and IBM Food Trust (USA) highlight its impact. For India, blockchain can empower small farmers to validate product quality and compete more effectively in local and global markets. However, widespread adoption will require joint efforts, infrastructure development, and farmer training.

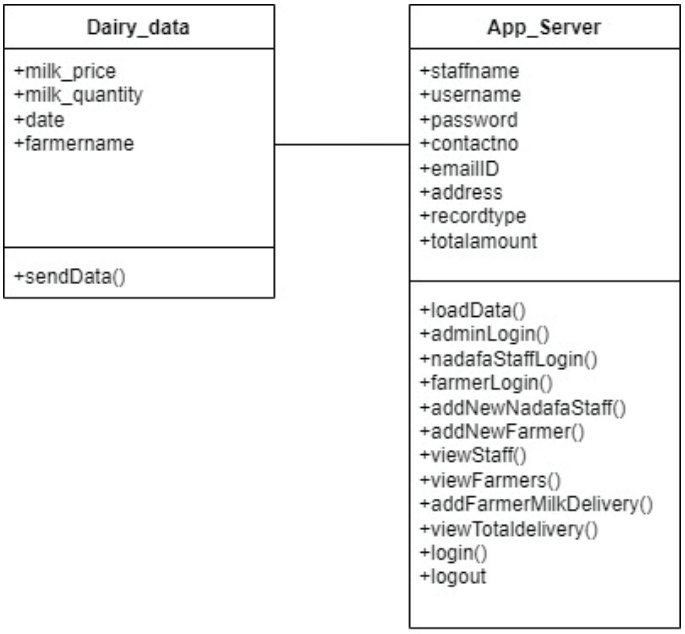

Figure 2: *Class Diagram*

The system employs blockchain technology to manage dairy-related data efficiently and securely by incorporating two primary components: Dairy_data and App_Server. The Dairy_data class is designed to capture and maintain critical information about milk supply transactions. It includes attributes such as the price per unit, the quantity of milk supplied, the date of delivery, and the identity of the farmer. It also includes a method dedicated to transmitting the data to the blockchain network, ensuring that each transaction is permanently recorded, tamper-proof, and traceable. By leveraging the immutability and transparency features of blockchain, the component enhances accountability in milk procurement and ensures accurate historical records for all stakeholders.

On the other hand, figure-2 the App_Server class functions as the central controller for user interactions and administrative operations. It manages a variety of tasks, including user authentication, access control, and system record-keeping. The attributes of the class cover a range of user-related information such as login credentials, contact details (e.g., phone number or email), and financial data like transaction amounts. In addition to data storage, App_Server features several operational methods, such as loading user data into the system, validating login sessions, managing new and existing user accounts, tracking delivery statuses, and handling active user sessions. These functions are critical in maintaining the integrity of user operations and ensuring that data flows within the system are both secure and consistent.

Together, the Dairy_data and App_Server components form a cohesive framework for monitoring and managing the dairy supply chain within a blockchain ecosystem. By combining decentralized data storage with robust user management and authentication mechanisms, the system enables transparent, real-time tracking of dairy products from farm to consumer. It not only helps prevent fraud and reduce reliance on intermediaries but also fosters greater trust among farmers, processors, and consumers in the dairy value chain.

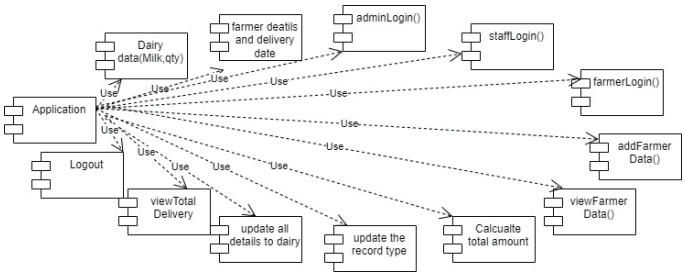

Figure 3: *Component Diagram*

The application of figure-3 is structured around specialized modules that collaboratively manage dairy-related data, farmer profiles, and delivery records, ensuring a streamlined and traceable system. The Dairy data module plays a central role in tracking the quantity of milk supplied by individual farmers. It records essential details such as the amount delivered, the date, and associated metadata, contributing to a transparent and immutable data trail within the system.

User access and security are maintained through three dedicated authentication modules: adminLogin, staffLogin, and farmerLogin. Each login module is tailored to its respective user role, providing different levels of access and control. The adminLogin module enables full system control and administrative privileges, while staffLogin allows authorized personnel to manage daily operations, and farmerLogin grants farmers secure access to their personal records and transaction histories.

Farmers can actively participate in the system through the addFarmerData function, which allows them to submit their milk delivery data directly. It promotes data ownership and real-time reporting. To maintain transparency, the viewFarmerData module enables farmers to review their submitted information, helping to build trust and accountability across the supply chain.

The application also includes features for operational oversight and data analysis. Users can access delivery records through a function that allows the viewing of all total deliveries made within a defined period. Furthermore, the system supports updating key dairy parameters and record types, ensuring the database reflects the most accurate and current information. A figure-3 built-in calculation module computes total transaction amounts based on milk quantity and price, facilitating efficient financial reconciliation and reporting.

At the core of the application is the Application module, which serves as the orchestration layer. It integrates all components—handling workflow management, coordinating user interactions, and ensuring smooth execution of backend processes. Session management is handled by the Logout module, which safely terminates user sessions and clears temporary data to protect system integrity and user privacy.

Together, these interconnected components create a cohesive and functional ecosystem for managing dairy operations. The modular design not only enhances system efficiency and user accessibility but also ensures full traceability and reliability of data across all stages of the dairy supply chain.

Results

To addresses the issue of unfair payments to Kenyan dairy farmers due to manual or centralized milk delivery records managed by brokers or NADAFA staff. Since many farmers have limited education, records can be easily manipulated, leading to underpayment. To resolve the authors propose a blockchain-based system where milk delivery data is securely stored in an immutable, decentralized network. Each transaction is stored as a block with a unique hash, and data can only be added after verification of previous records, making tampering impossible. It ensures transparency and fair compensation for farmers.

The system includes two main modules:

1. **Admin Module** – Allows the admin to log in, register farmers and staff, and view their details.

The Admin Module functions as the system's control center, beginning with a secure login interface where administrators authenticate via password or multi factor verification. Once inside, it can create and manage user accounts for both farmers and staff—entering essential information such as names, contact details, and assigned roles. The module provides a searchable dashboard that lists all registered users, allowing the admin to inspect individual profiles, update or deactivate accounts, and track registration dates. Built in validation checks ensure data integrity at entry, while audit logs record every change for accountability. Together, these features give administrators comprehensive oversight and streamlined user management in a single, intuitive interface.

2. **NADAFA Staff Module** – Enables staff to log in and record milk deliveries, which are then stored on the blockchain.

The NADAFA Staff Module provides a secure login for authorized staff members and a streamlined interface for capturing milk-delivery details. After authentication, staff enter each delivery's key data—such as farmer ID, collection time, quantity, and quality parameters—into standardized forms that validate inputs on the spot. Once submitted, these records are packaged as blockchain transactions via the Web3 integration, ensuring every delivery entry is immutably logged on the ledger. The module also offers a delivery-history view where staff can track transaction confirmations, review past entries, and correct minor errors before final confirmation. Comprehensive audit trails record who entered or modified each delivery, making the entire process transparent, tamper proof, and easily verifiable by both internal teams and external auditors.

The platform is implemented using Solidity smart contracts deployed on the Ethereum blockchain. Interaction with the blockchain is managed using the Python Web3 library, enabling secure reading and writing of data.

In Figure - 4 To launch the local blockchain, run runBlockchain. bat in hello-eth/node_modules/.bin. lets you test your smart contract.

In screen Figure - 5 Copy the MILK contract address (shown in white) into your Python code to connect and interact with the blockchain functions.

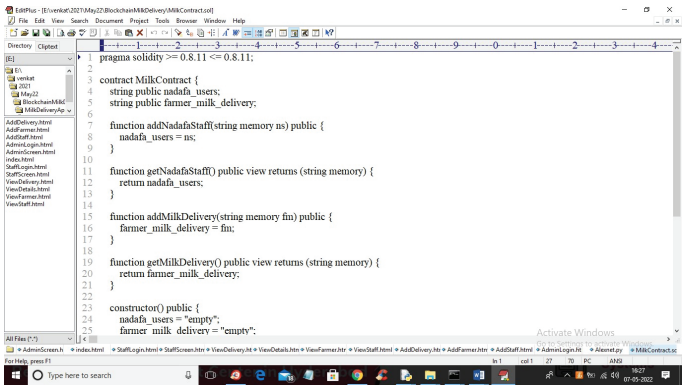

Figure-4: *Solidity Smart contract Code*

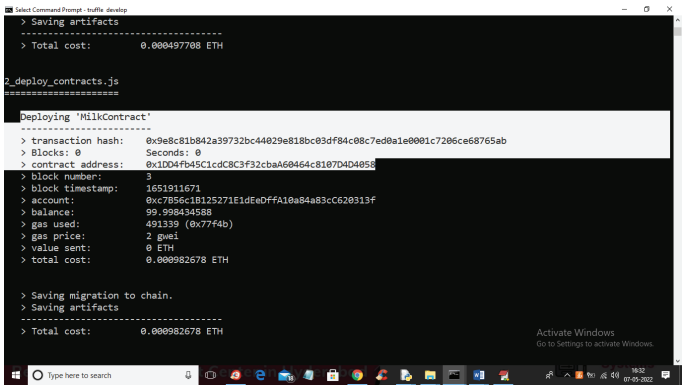

Figure-5: *Deploying contract to Blockchain*

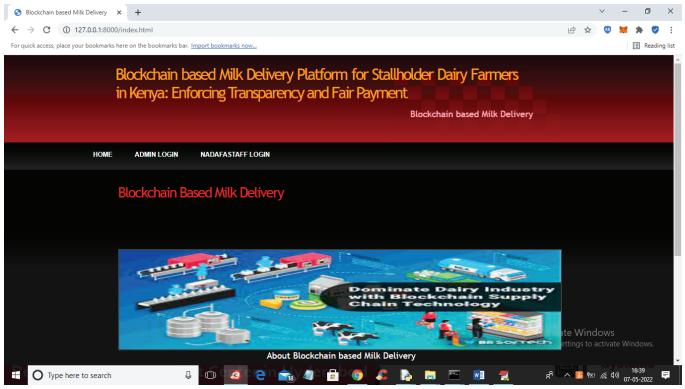

Figure-6: *Blockchain Based Milk Delivery Webpage*

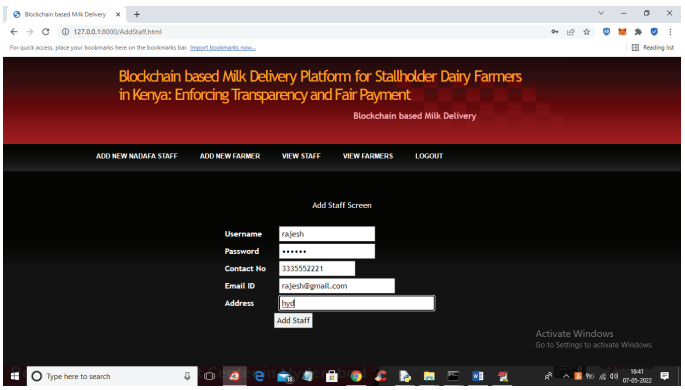

Figure-7: *Adding Staff's Screen*

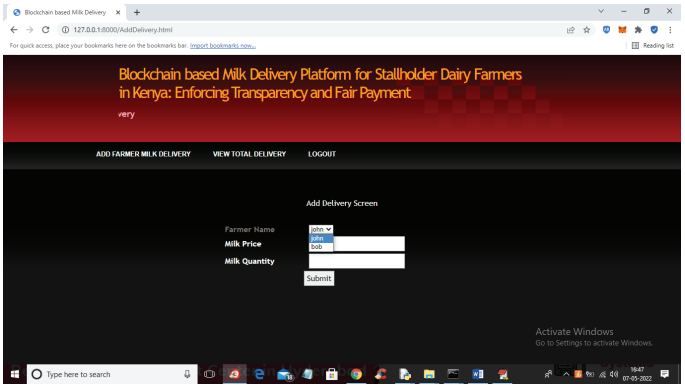

Figure-8: *Adding Delivery Screen (select Farmer)*

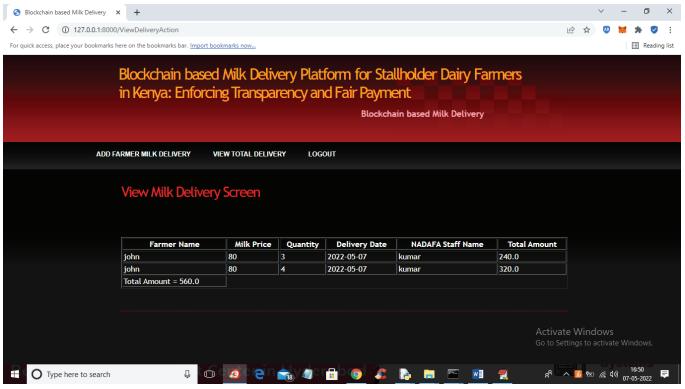

Figure-9: *Milk Delivery Screen*

In Figure 6 click on 'Admin Login' link to get below login screen

In Figure - 7 screen admin is entering staff details and then press 'Add Staff' button to get below output

In the Figure - 8 screen, the staff member begins by selecting a farmer's name from a dropdown menu, which lists all registered farmers in the system. It ensures that the milk collection is accurately linked to the correct individual, avoiding data entry errors. Once the farmer is selected, the staff enters the quantity of milk collected and other relevant details such as date and time.

The information is then recorded and securely stored on the blockchain, ensuring it cannot be altered or deleted. The process enables precise tracking of milk contributions from each farmer, promoting fairness and accountability in the supply chain.

In above Figure - 9: staff members have the ability to monitor each farmer's milk delivery records, including the total quantity delivered and the corresponding payment or balance due. It provides real-time visibility into individual farmer contributions and financial settlements.

The system also supports the addition of multiple users—such as new farmers, staff, or administrators—based on operational requirements. Once a user is added, staff can record milk collections directly through the platform. All data, including delivery quantity, date, and farmer identity, is securely stored on the blockchain, ensuring transparency and preventing tampering. The approach ensures an efficient and traceable dairy supply chain, while supporting scalability as more users join the system.

Conclusion

Blockchain for Safer and Traceable Indian Dairy Products: demonstrates the successful application of blockchain technology to enhance the safety, transparency, and traceability of dairy products across the Indian supply chain. By capitalizing on the core principles of blockchain—immutability, decentralization, and distributed consensus—the system ensures that every step in the dairy supply process, from production to consumption, is accurately recorded and verifiable. The level of traceability allows stakeholders to monitor product movement, verify authenticity, and uphold quality standards, significantly reducing the risks of contamination, fraud, and misinformation.

The system underwent rigorous testing throughout its development cycle to validate functionality against the criteria defined in the Software Requirements Specification (SRS). Each core feature—ranging from data entry and user authentication to delivery tracking and transaction validation—was carefully evaluated. As a result, all critical functional requirements were successfully met. The implementation of systematic validation and verification protocols has further ensured the reliability, robustness, and security of the platform, reinforcing its ability to function consistently under varying operational conditions.

Security remains a cornerstone of the architecture. The inherent protections provided by blockchain, such as cryptographic hashing and consensus-based verification, help guard against unauthorized access and data tampering. In addition, the transparency afforded by the system enables users—including farmers, processors, regulators, and consumers—to access relevant information in real time, fostering greater trust and accountability across the supply chain. These features collectively create a secure environment for data exchange and decision-making, positioning the platform as a credible tool for enhancing consumer confidence in dairy products.

While the current system has effectively achieved its primary goals, it also lays the groundwork for continued innovation and expansion. As the platform is deployed in real-world settings, continuous monitoring and iterative improvements will be essential to ensure long-term scalability, user satisfaction, and adaptability to evolving industry needs.

Future development efforts may include performance optimization, refinement of user interface design for better accessibility, and expansion of the system's capabilities to incorporate additional stakeholders or integrate with existing food safety infrastructure. Moreover, the underlying framework could be extended beyond the dairy sector to other food industries, paving the way for a comprehensive, blockchain-based traceability solution in agriculture and food supply chains.

It represents a forward-thinking approach to modernizing the Indian dairy industry. By introducing advanced digital technologies like blockchain, it supports safer, more transparent, and more efficient operations for all participants—from smallholder farmers to end consumers. In doing so, it not only addresses pressing challenges in food safety and supply chain integrity but also contributes to building a more resilient and trustworthy agricultural economy.

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