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MATURITY PREDICTION OF BITTER GOURD USING BITTER-NET

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DECLARATION

I, undersigned hereby declare that the project report entitled **"MATURITY PREDICTION OF BITTER GOURD USING BITTER-NET"**, submitted for partial fulfillment of the requirements for the award of the degree of Master of Computer Applications of the APJ Abdul Kalam Technological University, Kerala is a bonafide work done by me under the supervision of **Prof. Sreejith V P**. This submission represents my ideas in my own words and where ideas or words of others have been included, I have adequately and accurately cited and referenced the original sources. I also declare that I have adhered to the ethics of academic honesty and integrity and have not misrepresented or fabricated any data or idea or fact or source in my submission. I understand that any violation of the above will be a cause for disciplinary action by the institute and/or the University and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been obtained. This report has not been previously formed as the basis for the award of any degree, diploma, or similar title of any other University.

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Finally, I'd like to take this chance to express my gratitude to the Department of Computer Applications' entire teaching and technical team.

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ABSTRACT

This research addresses the need for efficient and accurate classification of bitter gourd images into three distinct classes Immature, Partially matured, and Matured. The current lack of automated solutions blocks agricultural automation and effective crop management. To overcome this challenge, a comparative approach employing several Convolutional Neural Network (CNN) models is proposed. The selected models, including VGG16, MobileNet, InceptionNet, AlexNet, ResNet and DenseNet, offer diverse architectures, allowing for an in-depth evaluation of their effectiveness in bitter gourd classification. VGG16 is recognized for its simplicity and complexity, while MobileNet's lightweight architecture makes it exceptionally efficient. DenseNet promotes dense connectivity for increased feature reuse, AlexNet is known for its groundbreaking design that pushed forward deep learning, ResNet is famous for its ability to train very deep networks effectively, and InceptionNet offers inception modules for improved feature extraction. The evaluation criteria consist of three factors: recall, precision, and F1-score. These factors together provide information about how well the models can classify images of bitter gourds at different stages of development. Furthermore, the model's predictive accuracy is quantitatively evaluated by the Root Mean Square Error (RMSE), which measures the average divergence between the expected and actual maturity phases. Additionally, the classification results are visualized using the confusion matrix, which allows for a thorough analysis of the model's abilities to distinguish between the stages of bitter gourd. The solution involves training these models on a selected dataset of bitter gourd images, with labels corresponding to different maturity stages. The anticipated outcome of this research is to identify the most accurate and efficient deep-learning model for bitter gourd classification. And fine-tuning that model to a new proposed model called Bitter-Net. By doing so, I contribute to the advancement of agricultural automation and crop management.

Keywords: VGG16, MobileNet, InceptionNet, AlexNet, ResNet, DenseNet

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LIST OF ABBREVIATIONS

Abbreviations	**Definition**
CNN	Convolutional Neural Network
VGG16	Visual Geometry Group 16
VGG19	Visual Geometry Group 19
InceptionV3	Inception Version 3
ROC curve	Receiver operating characteristic curve

Chapter 1

INTRODUCTION

This chapter introduces the critical necessity for transforming vaccine supply chains, tackling challenges such as counterfeit vaccines and transparency gaps. It outlines the goal of creating a decentralized data management system using blockchain, emphasizing authenticity and traceability.

1.1 Need for the Project

The project on ”Vaccine Supply Chain Management through Blockchain Technology” [1] is crucial because current vaccine supply chains face significant problems. Vaccines, essential for human health, are at risk due to issues like fake vaccines, tampered expiration dates, and a lack of transparency in tracking their journey. Traditional systems relying on manual records are prone to data tampering, affecting the reliability of vaccine information. The global impact of poor-quality drugs, including counterfeit vaccines, has resulted in numerous deaths, emphasizing the urgent need for a better solution. The complexity of the supply chain, involving various stakeholders, creates challenges in maintaining trust and transparency. Specific issues in the vaccine supply chain, such as the need for a cold chain and vulnerabilities in centralized systems, underline the need for an innovative solution.

The project aims to utilize blockchain technology as a transformative solution to these challenges. Blockchain ensures transparency, traceability, and immutability by storing transaction records in secure and interconnected blocks. The decentralized nature of blockchain mitigates the risk of a single point of failure, which is prevalent in current centralized systems. The integration of smart contracts automates transactions, eliminating the need for cumbersome paperwork and reducing the likelihood of errors. Blockchain’s ability to provide a secure and transparent reputation system addresses concerns related to feedback and user comments, ensuring the reliability of information.

1.2 Objective

The project focuses on designing a decentralized data management system using blockchain technology to address vulnerabilities present in centralized approaches. The primary objective is to ensure the authenticity, immutability, and traceability of vaccine-related information, leveraging blockchain features for tamper-proof records and transparent transaction history throughout the supply chain. Additionally, the project aims to evaluate the performance of the proposed framework through various metrics, assessing its effectiveness, efficiency, and overall functionality in enhancing vaccine supply chain management. These objectives collectively outline a strategic approach to mitigate existing challenges in vaccine supply chains, providing a secure, transparent, and efficient solution through blockchain integration.

1.3 Scope of the Project

The project's scope is extensive, encompassing crucial aspects aimed at addressing challenges prevalent in contemporary vaccine supply chains. Firstly, it involves the integration of blockchain technology into the supply chain, creating a decentralized framework to capitalize on blockchain's features of transparency, immutability, and traceability. The project also delves into securing and maintaining the integrity of vaccine-related data throughout the supply chain process. Through the implementation of smart contracts using the Solidity programming language, the reliance on paperwork is minimized, leading to increased efficiency. Additionally, the project explores Hyperledger tools, tailoring their usage to enhance security measures. Performance metrics will be employed to evaluate the effectiveness, efficiency, and overall functionality of the blockchain-based system. Gas management optimization in public blockchain scenarios is another focal point, striving to reduce costs and enhance transactional efficiency. The versatility of the developed framework for operation on public blockchains is considered, ensuring adaptability across various vaccine supply chain scenarios. The project addresses the rise of online pharmacies, incorporating security measures to safeguard against counterfeit vaccines entering the legitimate supply chain. Cold chain management for temperature controlled vaccines is a critical component, ensuring proper refrigeration transport within the supply chain entities. The project's global applicability is emphasized, aiming to contribute to a standardized and secure approach to vaccine distribution that transcends regional challenges. Overall, the project's scope is comprehensive, covering technical intricacies, performance evaluation, and specific challenges within vaccine supply chains on a global scale.

1.4 Organisation of Thesis

The groundwork has been laid for understanding the pivotal need and objectives of the Vaccine Supply Chain Management through Blockchain Technology project. Chapter 2 embarks on a comprehensive exploration, beginning with a literature review aimed at identifying critical gaps in current research and technology related to vaccine supply chain management and blockchain technology. This review aims to establish the context and rationale for implementing a decentralized system to address transparency, traceability, and security concerns in vaccine distribution. Following this, Chapter 3 introduces the proposed system, detailing its design, methodology, and the tools utilized in its development. This chapter outlines the technical aspects of how blockchain technology is leveraged to create a transparent and accountable vaccine supply chain management system. Chapter 4 presents the results obtained from implementing the proposed system, analyzing findings in the context of the system's objectives. It delves into the performance, efficiency, and security enhancements achieved through blockchain integration, providing insights into the system's effectiveness in addressing the challenges of traditional vaccine supply chains. Finally, Chapter 5 concludes the document by summarizing key insights, implications, and avenues for future research. It reflects on the significance of the findings and proposes potential directions for further advancement in vaccine supply chain management through blockchain technology.

Chapter 2

LITERATURE SURVEY

The literature survey for this project involved exploring existing studies and research articles related to vaccine supply chain management, blockchain technology, and associated challenges in the pharmaceutical industry.

2.1 Existing System

The current vaccine supply chain management system operates within a framework reliant on centralized databases and manual processes. Typically overseen by a central authority, this system suffers from transparency issues due to limited real-time visibility into vaccine movements and relies on error-prone paper-based records and manual data entry for tracking. Centralized data storage also presents security vulnerabilities, with the potential for tampering or unauthorized access, jeopardizing public health through the introduction of counterfeit or compromised products. Moreover, the lack of robust traceability mechanisms complicates tracking vaccine batches from production to distribution and administration, hindering timely response efforts during recalls or disruptions. These challenges underscore the urgent need for a more efficient, transparent, and secure approach to vaccine distribution, with blockchain technology offering promising solutions through its decentralized, tamper-proof nature, enhancing transparency, traceability, and security throughout the supply chain.

2.2 System Study

L. Cui et al proposed a Protecting Vaccine Safety: Improved, Blockchain-Based, Storage-Efficient Scheme [2]. The paper introduces a blockchain solution for bolstering vaccine safety, employing trace codes, transactions, and smart contracts. While tackling data reliability challenges, it encounters potential efficiency issues and cloud security concerns, prompting the need for additional enhancements to optimize performance in practical vaccine circulation scenarios.

T. Fatokun et al proposed a Towards a Blockchain Assisted Patient Owned System for Electronic Health Records [3]. The objective is a patient-centric EHR system using blockchain for security, privacy, and interoperability. Patients control records ensuring secure data exchange.

The research includes functional and performance testing, contributing to enhanced data security, privacy, and interoperability in healthcare.

F. Jamil et al proposed a Novel Medical Blockchain Model for Drug Supply Chain Integrity Management in a Smart Hospital [4]. Objectives include developing a secure drug supply chain record system with Hyperledger Fabric, enhancing transparency in smart hospitals, and providing a global solution to counterfeit pharmaceuticals. Features encompass secure record systems, network topology, smart contracts, access control, CRUD operations, and performance evaluation. Limitations include generalizability, scalability, regulatory considerations, security, privacy, and resource implications, with potential challenges in real-world implementation.

A. R. Nair et al proposed FAIR, a blockchain-based approach for fair and secure vaccine distribution during pandemics [5]. Utilizing smart contracts and IPFS, it addresses challenges in healthcare supply chains. Limitations include potential complexities, costs, scalability issues, and integration challenges with existing systems and data privacy concerns.

I. T. Javed et al. proposed PETchain, a privacy-enhancing technology on a consortium blockchain [6]. PETchain empowers users with control over their data, stored securely on IPFS. It features a user-centric architecture, secure data storage, Trusted Execution Environment (TEE), auditable logs, and smart contract functionality. The objectives involve PETchain development, a smart contract for access control, and performance analysis.

A. Musamih et al. proposed a Blockchain-based solution for COVID-19 vaccine distribution [7] addressing transparency, traceability, and security. Features include accountability through Ethereum smart contracts, decentralized availability, protection against attacks, rigorous security analysis, and a comparative advantage over non-blockchain solutions. Limitations encompass scalability challenges, internet connectivity dependence, off-chain storage costs, smart contract customization complexity, and regulatory compliance hurdles.

S. Bhushan et al. propose a Blockchain-powered vaccine supply chain system [8] to tackle distribution challenges, ensuring transparency, authenticity, and efficacy. Features include decentralized smart contracts, tamper-proof administration, IoT integration for temperature monitoring, and public reporting. Limitations involve technology adoption, regulatory hurdles, resource demands, and integration complexities with existing distribution systems.

Table 2.1: Literature Survey

Sl No.	Title	Author	Objective	Features	Limitations
1	Protecting Vaccine Safety: An Improved, Blockchain-Based, Storage-Efficient Scheme (2022) [2]	L. Cui et al	• Tackle vaccine circulation reliability challenges. • Introduce a secure blockchain for enhanced vaccine safety and traceability in circulation.	• Incorporates cloud technology for off-chain data storage and efficient data management. • Uses consortium blockchain to securely record vital vaccine circulation details.	• Processing Speed Challenges in Packing Step • Computation and Storage Burden
2	Towards a Blockchain Assisted Patient Owned System for Electronic Health Records (2021) [3]	T. Fatokun et al	• Introduce a patient-centric EHR system using blockchain. • Enhance EHR system interoperability for secure data exchange.	• Secure, consistent health records controlled by patients. • Patient-Centric EHR Web Portal	• Bandwidth Overhead • Scalability Challenges
3	A Novel Medical Blockchain Model for Drug Supply Chain Integrity Management in a Smart Hospital (2019) [4]	F. Jamil et al	• Creating a secure drug supply chain with Hyperledger Fabric blockchain. • Handling counterfeit drugs in developing country pharmaceuticals.	• Secure Drug Supply Chain Record System • Access Control and Permissions	• Cost and Resource Implications • Real-world implementation challenges
4	FAIR: A Blockchain-based Vaccine Distribution Scheme for Pandemics (2021) [5]	A. R. Nair et al	• Address healthcare supply chain challenges. • Ensure Secure and Fair Distribution System.	• Focus on trust and forecasting • Distinct working layers	• Blockchain Implementation Challenges • Integrating blockchain into healthcare systems may pose challenges.

Sl No.	Title	Author	Objective	Features	Limitations
5	PETchain: A Blockchain-Based Privacy Enhancing Technology (2021) [6]	I. T. Javed et al	• Introduce PETchain, enhancing privacy for service providers using user data. • Develop and implement PETchain as a user-centric privacy solution.	• Auditable and Immutable Logs • User-Centric Architecture	• Impact of Block-gas-limit • Block-time Variability
6	Blockchain-Based Solution for Distribution and Delivery of COVID-19 Vaccines (2021) [7]	A Musamih et al	• Propose a blockchain solution for COVID-19 vaccine distribution and delivery. • Address vaccine supply chain challenges to ensure data transparency, traceability, and trust.	• Protection Against MITM Attacks • Accountability and Authorization	• Limited Scalability • Cost of Off-Chain Storage
7	Blockchain Powered Vaccine Efficacy for Pharma Sector (2022) [8]	S. Bhushan et al	• Address vaccine distribution challenges: wastage, counterfeits, traceability, authenticity, and transparency. • Ensure proper transportation conditions within the cold chain supply for vaccines.	• Decentralized smart contract-based vaccine monitoring system. • Rating system based on post-vaccination reactions in users.	• Regulatory challenges may arise in implementing the system across global healthcare systems. • The system may need substantial resources for ensuring vaccine data security and privacy.

2.3 Gap Identification

In the current vaccine supply chain management system, several significant gaps have been identified, highlighting areas where improvements are essential. Firstly, there is a notable lack of transparency and visibility, as stakeholders often face challenges accessing real-time information about vaccine movements and status. This opacity hinders decision-making and response efforts during supply chain disruptions. Additionally, the system lacks robust traceability mechanisms, making it difficult to track vaccine batches accurately from production to distribution and administration. Without effective traceability, identifying the source of vaccine-related issues, such as recalls or quality control problems, becomes challenging, delaying response efforts and potentially endangering public health. Moreover, the centralized nature of data storage in the existing system raises concerns about data integrity and security, with vulnerabilities to tampering and unauthorized access compromising the reliability of vaccine records. Manual processes prevalent in the system also contribute to inefficiencies and errors, highlighting the need for automation and digitization to improve efficiency and accuracy. Furthermore, the system's susceptibility to counterfeit vaccines infiltrating the supply chain poses significant risks to consumer safety. Addressing these gaps through the implementation of blockchain technology could lead to transformative improvements in vaccine supply chain management, enhancing transparency, traceability, security, and efficiency, ultimately bolstering public health response capabilities.

Table 2.2: Detailed Study of Current and Proposed System

Current System	**Proposed System**
Limited real-time visibility into vaccine movements	Enhanced transparency with real-time tracking of vaccine movements
Lack of robust traceability mechanisms	Precise tracking of vaccine batches from production to distribution using blockchain technology
Centralized data storage prone to tampering and unauthorized access	Decentralized, tamper-proof blockchain technology ensuring data integrity and security
Manual processes leading to inefficiencies and errors	Automation and digitization improving efficiency and accuracy
Lack of robust verification mechanisms	Secure authentication and verification systems preventing counterfeit infiltration
Susceptibility to supply chain disruptions	Increased resilience to disruptions with blockchain technology ensuring continuity

This table compares aspects of the current and proposed systems, highlighting improvements introduced by the blockchain-based solution.

The literature survey section synthesizes key discoveries and highlights existing gaps in the domain of vaccine supply chain management through blockchain technology. Drawing on these insights, the project aims to leverage blockchain's capabilities, addressing these challenges and contributing to the development of a more secure and transparent vaccine supply chain.

Chapter 3

PROPOSED SYSTEM

The proposed system represents a significant advancement in addressing the challenges identified in the current system. This chapter outlines the key features, methodology, materials, and methods employed in the development of the proposed system. With a focus on leveraging blockchain technology, the proposed system offers innovative solutions to enhance efficiency, security, and transparency in the targeted domain.

3.1 Features of Proposed System

The proposed system leverages blockchain technology to introduce a decentralized network of nodes, eliminating the need for a central authority and fostering transparency and trust among stakeholders. It enables real-time tracking of vaccine batches throughout their journey from production to distribution and administration, providing stakeholders with immediate access to critical information about the status and location of vaccines. Through the immutability of blockchain, the system ensures the integrity and security of vaccine records, making them tamper-proof and resistant to unauthorized changes or manipulation. Precise tracking and tracing capabilities allow stakeholders to verify the authenticity and journey of each vaccine, reducing the risk of counterfeit infiltration.

In the proposed system utilizing Hyperledger Fabric with the Practical Byzantine Fault Tolerance (PBFT) algorithm, an unparalleled level of reliability and trust in vaccine information management is poised to be established. PBFT, renowned for its resilience against Byzantine faults, ensures the consistency and validity of transactions within the distributed network. This algorithm enables nodes to reach consensus even in the presence of potentially malicious actors or network disruptions, thereby fortifying the integrity of vaccine data stored on the blockchain. By employing PBFT alongside Hyperledger Fabric, the system not only guarantees the authenticity and immutability of vaccine records but also bolsters confidence in the transparency and security of the entire vaccination ecosystem.

The system ensures resilience during disruptions, fosters collaboration, scales efficiently, and enhances transparency, traceability, security, and efficiency. PBFT's consensus mechanism fortifies trust, paving the way for effective global health management.

3.2 Proposed Methodology

The methodology outlined below delineates the systematic approach for the development of a blockchain-based vaccine supply chain management system. With the aim of addressing the transparency, traceability, and security challenges inherent in existing vaccine distribution systems, this methodology offers a structured framework to design, implement, and integrate various components essential for effective vaccine management.

1. **API Design**

   This stage involves defining the endpoints and functionalities that the system will provide through its API (Application Programming Interface). The defined functionalities include registering new vaccines, tracking vaccine batches, verifying vaccine authenticity, and retrieving vaccine information.

2. **Data Models**

   In this phase, data structures are defined to organize and manage information related to vaccine batches. Attributes such as batch number, manufacturer, production date, etc., are identified and structured to facilitate efficient data management. Additionally, structures for transactions and blocks specific to the Hyperledger blockchain are defined to ensure compatibility and interoperability with the chosen blockchain platform.

3. **Middleware Development**

   Middleware development involves implementing a layer of software, typically using a programming language like Golang, to expose the defined API endpoints. Libraries such as Gorilla Mux are utilized for routing and handling HTTP requests, ensuring smooth communication between the frontend and backend components of the system.

4. **Hyperledger Integration**

   This step focuses on integrating the Golang middleware with the chosen Hyperledger blockchain platform, such as Hyperledger Fabric or Composer. Smart contracts are implemented to define the business logic and rules governing vaccine transactions and authenticity verification on the blockchain.

5. **Authentication and Authorization**

   Authentication mechanisms such as JWT (JSON Web Tokens) are implemented to secure the API endpoints and prevent unauthorized access. Roles and permissions are defined to regulate access to different functionalities within the system, ensuring data security and privacy.

6. **Testing**

   Testing is conducted to validate the functionality, performance, and reliability of the developed system. Unit tests are developed to verify the correctness of individual API endpoints and middleware functions. Integration tests are performed to ensure seamless interoperability between the developed components and the Hyperledger blockchain platform.

   Overall, this methodology provides a structured approach to developing a secure, transparent, and efficient vaccine supply chain management system leveraging blockchain technology. Each stage is essential for ensuring the successful implementation and deployment of the system to address the challenges faced by the existing vaccine supply chain.

3.2.1 Algorithm

The Practical Byzantine Fault Tolerance (PBFT) algorithm is a consensus mechanism designed to achieve agreement among a distributed network of nodes, even in the presence of Byzantine faults, where nodes may exhibit arbitrary or malicious behavior. Developed by Castro and Liskov in 1999, PBFT is one of the pioneering algorithms in the field of distributed consensus. PBFT operates by dividing the network into a set of replica nodes, typically numbering at least 3f+1, where 'f' represents the maximum number of faulty or malicious nodes the system can tolerate while still maintaining consistency. Each replica is uniquely identified and communicates with other replicas in the network.
The consensus process in PBFT involves several phases:

1. **Request:** A client sends a request to the network, specifying the operation it wants to be executed.

2. **Pre-Prepare:** The primary replica (leader) assigns a sequence number to the request and sends a pre-prepare message to other replicas, proposing the operation and sequence number.

3. **Prepare:** Upon receiving a pre-prepare message, each replica verifies the request and then broadcasts a prepare message to indicate acceptance of the proposed operation and sequence number.

4. **Commit:** Once a replica receives 2f+1 prepare messages for the same sequence number and operation, it broadcasts a commit message to finalize the decision.

5. **Execute:** Replicas execute the operation specified in the request, applying it to their local state machine.

PBFT also incorporates checkpointing to enhance efficiency and reduce message overhead. Checkpoint messages allow replicas to discard old messages and simplify the recovery process in case of failures.

Additionally, PBFT handles leader failures through a view change mechanism. If a replica suspects the primary of being faulty, it initiates a view change, and the network switches to a new primary replica to continue the consensus process.

PBFT is known for its fault tolerance, as it can tolerate up to f Byzantine faults while ensuring safety (no two different nodes commit different transactions with the same sequence number) and liveness (every correct node eventually commits a request). Moreover, PBFT provides low latency and high throughput, making it suitable for applications requiring fast transaction finality and resilience against Byzantine faults.

Overall, PBFT is a robust consensus algorithm that offers practical solutions for achieving distributed agreement in a Byzantine fault-tolerant manner, making it suitable for various blockchain and distributed systems applications where trust and reliability are paramount.

3.3 Materials and Methods

This section outlines the tools, technologies, and environmental setup used in developing the vaccine supply chain management system. It provides a detailed overview of software, hardware, and setup procedures, enabling stakeholders to understand the technical infrastructure supporting the project's objectives and methodologies.

3.3.1 System Specification

System specification provides an overview of the software or application including what it should do and what its parameters are, how it will interact with its environment, end users, hardware and software requirements.

Hardware Specification

- CPU: Intel Core i5 or higher
- RAM: 8 GB or higher
- Hard disk: 512 GB or higher
- Input Device: Mouse, Keyboard
- Output Device: Monitor with 1280 x 720 resolution, Printer

Software Specification

- Blockchain Development Framework: Hyperledger Fabric
- Smart Contract Development: Golang (Go)
- Database: MySQL
- IDE: Visual Studio Code
- Containerization Platform: Docker
- Front-end Framework: Django

3.3.2 Software Tools

1. **Hyperledger Fabric**
   Hyperledger Fabric [9] serves as the foundational framework for constructing a permissioned blockchain network tailored precisely to the unique needs of the vaccine supply chain management project. Through its customizable access control mechanisms, the platform empowers administrators to finely manage permissions for network participants, ensuring precise control over data access and operations. Furthermore, Hyperledger Fabric boasts robust security features, including private transactions and endorsement policies, which collectively safeguard the privacy and integrity of data circulating within the blockchain network. These features culminate in a secure and efficient infrastructure, vital for maintaining trust and reliability in the vaccine supply chain ecosystem.

2. **Docker**

   Docker [10] plays a pivotal role in streamlining the development and deployment processes within the vaccine supply chain management system, particularly in conjunction with Hyperledger Fabric. By containerizing applications and their dependencies, Docker ensures consistency across various development and deployment environments. This consistency is crucial for maintaining uniformity and predictability in the system's behavior. Furthermore, Docker's ability to package software into lightweight containers simplifies sharing and running applications across different systems, fostering seamless collaboration among developers and facilitating deployment across diverse infrastructure setups. Additionally, Docker optimizes resource utilization and offers scalability features, allowing the vaccine supply chain management system to efficiently scale as demand grows. These capabilities make Docker an ideal choice for deploying and managing the complex network infrastructure required by Hyperledger Fabric, ensuring smooth and efficient operation of the entire system.

3. **Golang (Programming Language)**

   Golang [11] commonly referred to as Go, plays a pivotal role in the development of the vaccine supply chain management system, serving as the primary language for coding smart contracts and building the backend infrastructure. Its attributes, including simplicity, efficiency, and inherent support for concurrency, render it exceptionally suitable for crafting scalable and dependable blockchain applications. Moreover, Golang's statically typed nature and integrated garbage collection mechanism contribute to the robustness and maintainability of the codebase. These features streamline the development process, enabling the creation of intricate smart contracts and backend services essential for the vaccine supply chain management system.

4. **Django**

   Django [12] is a high-level Python web framework known for its simplicity and rapid development capabilities. It features an MVC architecture, ORM for database interactions, built-in admin interface, URL routing, template engine, and security features. Its vibrant community and extensive ecosystem make it ideal for building scalable and secure web applications.

3.3.3 System Architecture

Figure 3.1 illustrates the proposed framework, a blockchain-based system designed for vaccine supply chain management.

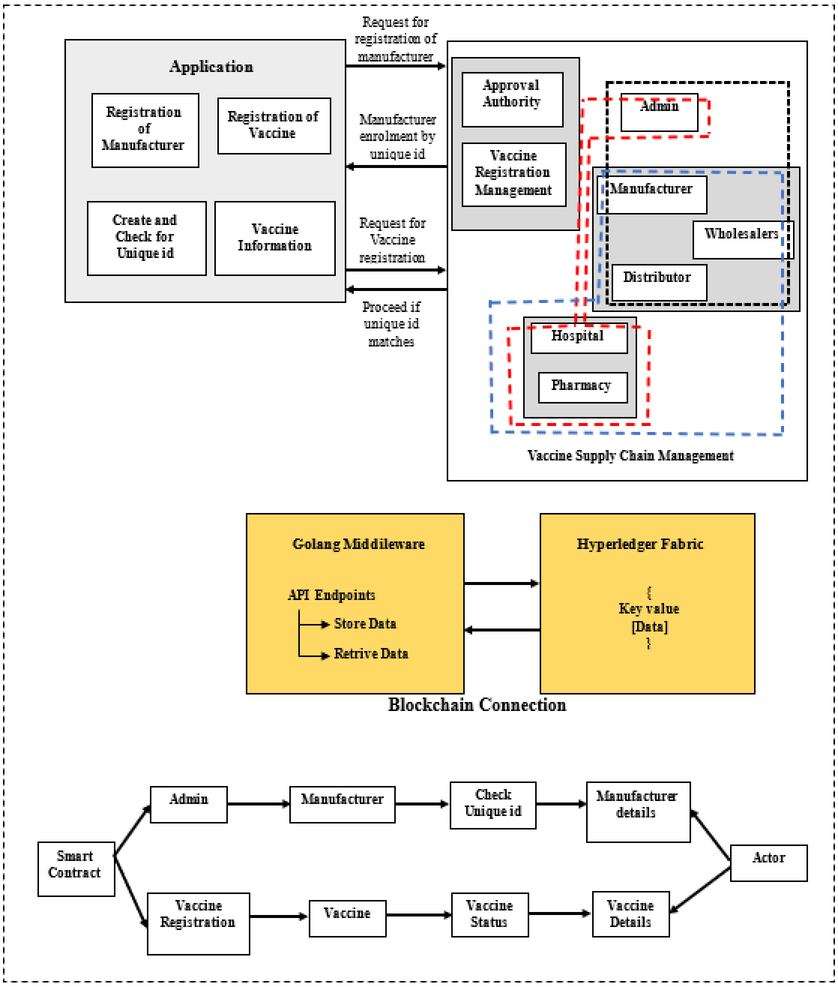

Figure 3.1: System Architecture

The framework involves various entities, including regulatory authorities, manufacturers, distributors, wholesalers, pharmacies/hospitals, and consumers. The diagram visually represents the flow of the entire process, with all information being stored on the blockchain to ensure immutability, transparency, and security of vaccine supply chain management. On the left side of the diagram, all the actors involved in the supply chain are listed, while on the right side, the specific activities of each actor are detailed. The bottom of the diagram contains the flow of the entire process, showcasing the movement of vaccines from the manufacturer to the various entities involved, such as distributors, wholesalers, pharmacies/hospitals, and ultimately to the end consumer.The application of blockchain technology is facilitated by smart contracts, which handle the registration of the manufacturer and vaccine by assigning an offline unique address to the manufacturer. The framework ensures the integrity and immutability of vaccine data at every node, with information stored on the blockchain at each step to ensure its immutability and integrity.

It shows the proposed framework in which actors like regulatory authorities, manufacturers, distributors, whole salers, pharmacies/hospitals, and consumers take their part in vaccine supply chain management. The application of blockchain is based on smart contracts which are composed of the registration of the manufacturer and vaccine by giving an offline unique address to the manufacturer. If the unique address of the manufacturer matches, then that specific man ufacturer can produce a specific vaccine. Distributors can deliver it to the wholesaler, from where it can be dispatched to hospitals/pharmacies, so consumers can buy and use it. On the left side, all the actors are mentioned in Fig. 3.1, and on the right side, the actor and their relevant activities are mentioned. The bottom of the diagram contains the flow of the entire process. In every step, all the information is stored on the blockchain which ensures the immutability, transparency, and security of vaccine supply chain management.

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