Cloud Computing Based Real Time Supply Chain System For Vaccine Distribution

by

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submitted by Usama Zafar Ansari in partial fulfilment of the requirements of the degree of Master of Applied Science

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Abstract

The supply chain monitored in real-time using the sensors makes supply chain flow efficient and reliable. The Coronavirus Disease of 2019 (COVID-19) pandemic has added pressure on the federal and provincial governments to identify appropriate vaccine distribution solutions. In order to reduce the losses of the vaccines throughout the supply chain, such a solution was needed to notify the supply chain stakeholders to take action if the temperature or humidity of a batch of vaccines begin to cross its threshold level and also to allow the stakeholders to view the location of a specific batch of vaccines while in transit. There has been a great loss of vaccines in transit which is resulting in an expensive overhead for the supply chain.

So, there is a need for cloud computing based monitoring of vaccine shipment using sensors embedded into the shipping container to track the location, temperature, and humidity of vaccine batches during transportation. Since these sensitive properties will be monitored in real-time which would ultimately lead to fewer losses of the vaccines. The simulation of sensor data is done to achieve the real-world condition for vaccine movement. The cloud computing services architecture is used to make the working of supply chain efficient and transfer of ownership between the entities involved in delivering the vaccines in a trusted way. The data generated through this transfer of ownership is immutable and it would generate the efficient trust of entities in the supply chain. This would build a reliable supply chain and provide the visibility to take timely actions to prevent the vaccines from getting damaged. Reliability would build trust in the supply chain from the immutability of the database. As a result of visibility, timely action should be taken to prevent vaccines from getting damaged by the environmental conditions through which it is being transported.

Lay Summary

The sensors are widely used in reporting the data in terms of temperature, humidity, location, pressure, etc... Using the simulated values of different sensors data, the monitoring of a product in real-time can be set up. Similar monitoring is adopted in the supply chain of vaccine distribution. As the vaccines are temperature and humidity dependent, a slight change in the temperature and humidity range can make the vaccines inefficient to use. So, real-time monitoring of vaccines throughout the supply chain is required so that vaccines reaching the end of the supply chain is efficient and in good condition. The data of the effective supply chain needs to be trusted and immutable, this makes the transfer of ownership of the vaccine in the supply chain trustworthy. These all solutions are achieved with the use of cloud computing services which can be scaled up and down and makes it cost-efficient.

Preface

This thesis is based on the research work conducted in the School of Engineering at the University of British Columbia, Okanagan Campus, under the supervision of Prof. Zheng Liu. This research work has been published on different platforms as:

- **Ansari, U. Z.**, & Liu, Z. (July, 2021). *Cloud Computing based Real Time Monitored Supply Chain System.* Extended Abstract published in 7th World Congress on Electrical Engineering and Computer Systems and Science (EECSS'21), Avestia Publishing.

- *Vaccine Distribution Supply Chain Prototype – UBC/MCG — Community Health Cloud Innovation Centre.* (2021, May 28). UBC Cloud Innovation Centre.

I am the principle contributor for the work in this thesis. Prof. Zheng Liu provided me with suggestions to improve my research work. Besides, Mr. Artur Rodrigues, the Solution Architect at Amazon, helped me with the architecture of the solution and Mr. Clinton Liu, the CEO of Modular Clinton Global, helped me with the business logic part of the solution that are used in the thesis.

Table of Contents

List of Figures

Glossary

API	Application Programming Interface. 16, 21
AWS	Amazon Web Services. 11, 16, 20, 45
AZ	Availability Zone. 18
COVID-19	Coronavirus Disease of 2019. iii, 1
CRM	Customer Relationship Management. 6
DApps	Decentralized Applications. 6
ERP	Enterprise Resource Planning. 6
GPS	Global Positioning System. 3
IOT	Internet of Things. 4, 20
JWT	JSON Web Tokens. 44
KDG	Kinesis Data Generator. 11, 21, 45
KDS	Kinesis Data Stream. 11, 22
LR	Lorry Receipt. 33
OOP	Object Oriented Programming. 16
PI	Physical Internet. 7
QLDB	Quantum Ledger Database. 12, 18, 19, 22, 25, 40, 42, 45, 47, 53
QR	Quick Response. 32, 46
SHA	Secure Hash Algorithm. 18
SPA	Single Page Application. 16
SQL	Structured Query Language. 18
UI	User Interface. 44
URL	Uniform Resource Locator. 45
WHO	World Health Organization. 1

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First of all, I would like to give my immense gratitude to my supervisor, Professor Zheng Liu, whose guidance and encouragement throughout my graduate study journey has been a great learning journey. Under his guidance, I have also gained very valuable research skills and technical writing skills which are going to stay with me for the rest of my life. Additionally, I would also like to thank him for providing me with the opportunity to work with the industries, which has brought great working experience. All these experiences in my graduate study helped me build a professional attitude and skills.

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Chapter 1

Introduction

1.1 Background and Motivation

The Coronavirus Disease of 2019 (COVID-19) pandemic has added pressure on the federal and provincial government to identify appropriate vaccine distribution solutions which would be efficient to deliver the vaccines in a traceable and monitored way. In order to reduce the losses of vaccines, a solution was needed to allow distributors to take action if the temperature or humidity of a batch of vaccines begins to exceed its required threshold, and to allow the stakeholders to view the location of a specific batch of vaccines while in the supply chain. World Health Organization (WHO) has also highlighted in their past report about the importance of monitored pharmaceutical products in the supply chain [3]. The monitoring process keeps the pharmaceutical products in good quality and their efficacy is also maintained.

Historically, up to half of all the vaccines manufactured worldwide have typically been lost due to issues related to transportation. In the process of transportation, these vaccines were not monitored in real-time which could have prevented their loss [4]. As the vaccines are transported in the long chain of distribution, from manufacturer to national storage facilities to regional storage facilities and finally to local cities, vaccines can often be spoiled before they reach their final destination. Reefer (Refrigerated) containers can improve these operations by controlling the factors that could be harmful to vaccines in these processes. These containers maintain the stable temperature and controlled humidity condition to keep frozen or cold food or medicines at stable conditions [5]. That enables the stakeholders to monitor these factors remotely and analyze available data more efficiently. The temperature and humidity sensitive products travel globally and go through extreme weather conditions in the whole process of packing, storage,

and distribution [6]. So, these containers keep stability and prevent from damaging the products in the supply chain process. These containers provide visibility to the products as it is carrying them in the supply chain. This visibility is considered in terms of the condition of the container environment(temperature, humidity, etc...), the real-time location, or the current owner of the container in the supply chain process. This allows the smooth management and functioning of the supply chain to execute. Smoothness in terms of building the trust of transferring the ownership from one stakeholder to another stakeholder. The functioning of registering the stakeholders securely and registering the product that needs to be real-time monitored is set up together. In the past practices, the use of mutable databases were used which were less reliable and to trust with. The mutable database means that the data can be easily altered or tampered with without leaving the trace of a person altering it. The transaction logs that hold the details of all the transactions happening in the mutable database can also be altered by the person with system admin privileges leaving behind no trace. So, verification is needed to make sure the changes that occur are saved along with the previous history. This lays the need of using the immutable, transparent, and cryptographically verifiable database to manage the transactions happening in the supply chain.

The use of cloud computing provides the on-demand availability of computing resources, storage, and services [7]. In this way, there would not be any need to buy the servers and area to install those servers. Cloud computing will save a lot of cost in system implementation. It also provides the benefit of easily scaling up and down the resources based on user traffic and expansion of the system. The different services that cloud computing provides can be easily aligned together for the smooth functioning of the system. So, all these points support the use of cloud computing in implementing the system. The supply chain system would become flexible and robust enough to manage the smooth functioning of the flow. The different cloud computing services provide storage, data acquisition, data processing, data storage, system security, etc... to serve the requests and responses flow in and out of the supply chain system.

Figure 1.1: Reefer (Refrigerated) container to record the attributes for tracking and tracing of the vaccines in the supply chain.

This background knowledge about the problem understanding can provide the direction for the solution. This enables the understanding of the need of monitoring the vaccine shipments, using sensor data comprises of Global Positioning System (GPS) for location, temperature, and humidity data embedded in the shipping containers to track the location, temperature, and humidity of the vaccine batches during the transportation as shown in the Figure 1.1. This real-time monitoring of the vaccines in the supply chain provides the base to prevent the losses of vaccines and provide the smooth delivery of vaccines in a monitored way. The use of immutable use of data to provide the trust of the supply chain stakeholders makes the supply chain reliable. The use of cloud computing provides the infrastructure to achieve real-time visibility into the vaccine supply chain system and bring all the stakeholders onto the immutable data-driven platform.

Having a brief understanding of the background of the vaccine supply chain provides the motivation to improve the system with the use of implementation of cloud computing

and the existing current technology stack. Lots of vaccines are wasted in the logistics and shipment-related issues as discussed above in the background, this motivates to prevent the wastage by proposing a reliable and trustable system to prevent the wastage. As we would be able to minimize the wastage using the proposed system, this would lead towards a sustainable supply chain in vaccine distribution. This proposed system or framework can be applied to different sectors in which real-time monitoring and trustable database is required among the different stakeholders to achieve sustainability. These different sectors can be food, beverages, pharmaceuticals, etc... which require real-time visibility and achievement of trust among different stakeholders.

1.2 Literature Review

Based on the background of the study, sensor data-based supply chain frameworks are reviewed independently and dependently. Especially, sensor-based supply chain data that is generated and is investigated for its immutability and trustworthiness in this chapter. Besides that, cloud computing methodologies are also introduced with potential solutions to enhance supply chain monitoring system. The literature review gives the overall description of the solutions that exist and how the immutability and transparency of the data were missing from the existing solutions.

1.2.1 Sensor Data Reading

The data coming from the sensors attached to the container is streamed lined to process and store it. The quality of data from the sensors is determined by the number of missing information that occurs during the sensor data storage. The time recording with the data is maintained to trace back the time interval of any anomalies occurring during the supply chain process. The anomalies are the states which are different from the normal state [8]. The data generated outside the fixed interval can lead to anomalies detection in the system. Picking up these anomalies can help the stakeholder to take timely action to prevent the quality of vaccines from getting deteriorated. The Internet Of Things (IOT) sensor data provides information about the product condition monitoring

and location tracking of the product in the supply chain so as to have the real-time visibility of the product. These sensing ability plays a vital role in smart transportation and different sensing ability to monitor the process [9].

The aim of the sensor device is to make the tracing of goods in the supply chain efficient as it provides enhanced in-transit visibility to the goods [10]. The real-time monitoring will not only benefit the manufacturer but also other stakeholders involved in the supply chain [11]. It prevents damage to the goods at any time in the supply chain. The data of the sensors is cleansed to make sure it matches the right values to be stored in the database. This cleaned data will tell the whole monitored journey of the product in the supply chain [12]. This monitoring data of the product will determine whether the product reaching the destination is in the right condition to consume or it has been compromised in the journey of the supply chain.

1.2.2 Supply Chain Flow Process

Supply chain flow of product ownership from one stakeholder to another completes the supply chain. In the last few years, the need for a solution to have a track and trace supply chain system for the importing and exporting of goods was in need [13]. There were solutions existing to keeping track of goods in the supply chain using traditional database storage which can be mutable and no ways of verifying the authenticity of the data. The verification highlights that the data has not been tampered with or altered while after it is saved into the database. The achievement of trust, transparency, and security of supply chain data makes the agile system.

The containers used for the supply chain to transport the temperature and humidity sensitive vaccines are known as Reefer (Refrigerated) containers [6]. These containers are intermodal containers with an integrated refrigeration unit with climate-controlled capabilities for transporting the temperature-sensitive products in the supply chain [14]. The products that travel globally need to be monitored including packaging, storage, and distribution. The demand for temperature-sensitive products to be monitored in the supply chain is going to be increased.

The supply chain flow process makes the smooth transition of product from different

stages in the supply chain to reach from source to destination. The smooth transition makes sure the efficient transfer of ownership of the product from one stakeholder to another. The increased transportation of vaccines requires this smooth transitioning in the supply chain. This would have a higher impact on the availability of the vaccine as increasing of the transport, it will decrease stationary storage of the vaccines [15]. This increase in transport needs to be smoothly transitioned.

The cloud-based supply chain process provides agility to the system which can be helpful in easily coping with the business agility i.e quickly adapting to the changes. The cloud-based supply chain also provides the advantage of the integration of different systems and software related to Enterprise Resource Planning (ERP) and Customer Relationship Management (CRM). The other reason for support of a cloud-based supply chain is that planning can be done efficiently. The planning of database and integrating new cloud services to make the supply chain plan works efficiently. The easily scalable solution makes the scaling of servers up and down easily on the basis of load traffic it experiences. This helps in keeping the cost as low as possible as you pay for the service which you use [16]. The cloud-based supply chain solution also helps to be ahead of the competition in the supply chain industry by providing speed and accuracy in executing the process. Once that cloud infrastructure is in place then this would create room for integration of other cloud services which would make the system efficient. These services would maybe comprise from image recognition to Big data analysis to machine learning or Artificial Intelligence.

There is also an emergence of new technology such as Blockchain. It offers the shipment movement in the supply chain using the decentralized secured distributed ledger technology [17]. It governs and manages the communications between the sender and receiver without the involvement of third parties [18]. This solution is an immutable and decentralized way of keeping track and trace of products in the supply chain. The Decentralized Applications (DApps) can be made out of the blockchain technology which manages the whole supply chain system in a decentralized system. This system makes the product visibility, tracking of it, and automation of the process feasible.

The ways physical objects are stored, moved, transported, and delivered are going

under drastic changes. The concept of adopting the similarity of Digital Internet to Physical Internet (PI) is being used in developing supply chain systems. The Physical Internet will lead to sustainability, economic benefit and efficiency [19]. The advantage of PI is that the goods or products transported through this would be less time-consuming and more efficiently optimized to the system.

1.3 Research Challenges and Objectives

From the perspective of supply chain management, the research challenges that were identified were lacking the real-time visibility to monitor the vaccines in the complete steps of the supply chain process. The different stakeholders involved in the supply chain need a common immutable platform to provide trust in the data of the supply chain. The product in the supply chain needs to be real-time monitored which would prevent it from being affected by the environmental conditions in which it is being transported. Providing the transparency of ownership of the product is the supply chain provides stakeholders responsible for the product at the different stages. These both i.e. real-time monitoring and transparency are achieved using cloud computing services which make it scalable and cost-efficient. The product that is being focused on in the research is the vaccine. Since the vaccines that are transported through the supply chain are temperature and humidity sensitive. So, they need to be real-time monitored to make sure they reach the final destination in good condition. The objectives of this research are that firstly, monitoring will make sure that the vaccines are not compromised at any stage in the supply chain. If there are any anomalies occurring during the supply chain stages then that can be noted and prevent the harmful vaccines from reaching the people. Secondly, the data generated in the supply chain process needs to build the trust of other stakeholders that are involved in the process. This trust-building is achieved through the use of an immutable database for coordinating the flow and making sure the data is cryptographically verifiable (keeping the integrity of data). Creating the whole cloud computing infrastructure to make the elements of the supply chain process work efficiently and easy to scale as the system grows with time. Thirdly, to architecture the

cloud computing infrastructure and deploy it to test the smooth movement of vaccines in the supply chain process in the real-time monitored way. This would give the owner of the vaccines in that process to take timely action to prevent them from getting wasted. The secure on-boarding of all the stakeholders takes place which is also included in the creation of the cloud infrastructure for the supply chain system. We also made use of reusable component-based for system implementation with the help of the latest technologies available in the current technology stack. This would prevent redundancy in the implementation part of the system.

1.4 Thesis Outline

This section highlights the thesis outline of this research in the real world. The thesis is organized into five chapters:

Chapter 1 presents the background of sensor data based supply chain system and the current solutions to make the supply chain system efficient. In addition, this chapter provides a literature review for the sensor data based system monitoring the conditions of the surroundings in real-time and supply chain process flow to work efficiently. Furthermore, the research challenges and objectives are also stated in this chapter.

Chapter 2 investigate about the real-time monitoring of the vaccines with the use of conditional(temperature and humidity) and location sensor information to provide the current environment situation of vaccines in the complete supply chain process. Finally, the state of the art of this real-time monitoring framework that is investigated lays the foundation for the implementation of the system.

Chapter 3 explains the introduction of the supply chain and the description of the cold supply chain being monitoring the vaccine in the whole process using cloud computing. The entities involved in making the supply chain work efficiently are on-boarded securely and the ownership of vaccines is transferred to other entities in a trustworthy way. The data is reliable and immutable to make this trustworthy ownership get transferred.

Chapter 4 summarizes the system implementation of the whole framework on cloud computing, which gives the system the ability to scale up and down according to the

needs. The case study of the system implementation shows the interaction of different cloud services to make the system work efficiently. This would also break down the cost of implementing the system on the cloud. This case study opens up the new dimension of integrating different functionalities in the supply chain to make it work in improved ways.

Chapter 5 is the final section that concludes the thesis which highlights the summary of the thesis through contributions made. This chapter also suggests the future work that can be undertaken to improve the vaccines distribution supply chain.

Chapter 2

Sensor Data Processing: Real Time Monitoring

The real-time monitoring of vaccines in the supply chain makes the supply chain trackable and traceable. The vaccines in the supply chain can undergo changes in the environment in which they are getting transported. These changes can result in making the vaccines ineffective if their temperature or humidity is compromised in the supply chain process [20]. So, real-time monitoring will make it more transparent and which leads to timely actions taken to avoid the vaccines in the supply chain from being compromised. Along with that, tracking the vaccines with respect to their location gives visibility with respect to where the vaccine is in the supply chain. This will help the distributor plan for the last mile delivery of vaccines beforehand [21]. The last-mile delivery is the final stage in the supply chain that makes the product reach the consumer. In our system scenario, it is the people receiving the vaccines from the hospitals and clinics.

The system notifies the current owner of the container in the supply chain about the drop or rise in temperature and humidity threshold being crossed to make sure that timely actions be taken to prevent it from getting damaged. The changes in the environment of the containers are recorded and providing the visibility of such environment can help check the condition of the vaccines throughout the supply chain journey.

2.1 Sensor Data Generator

The real-time monitored supply chain system needs real-time data to monitor the system and to point out the anomalies occurring during the phase. The sensor data stages are divided into three stages i.e. data acquisition, data processing, and data

storage as shown in Figure 2.1. In the data acquisition stage, the use of Amazon Kinesis Data Generator (KDG) provides the real-time streaming data for the system to be tested. Most of the system when in the developing phase wants to be tested in that phase, so testing the system with data that is similar to production data gives the authentication that their system is robust and will not break in the production phase.

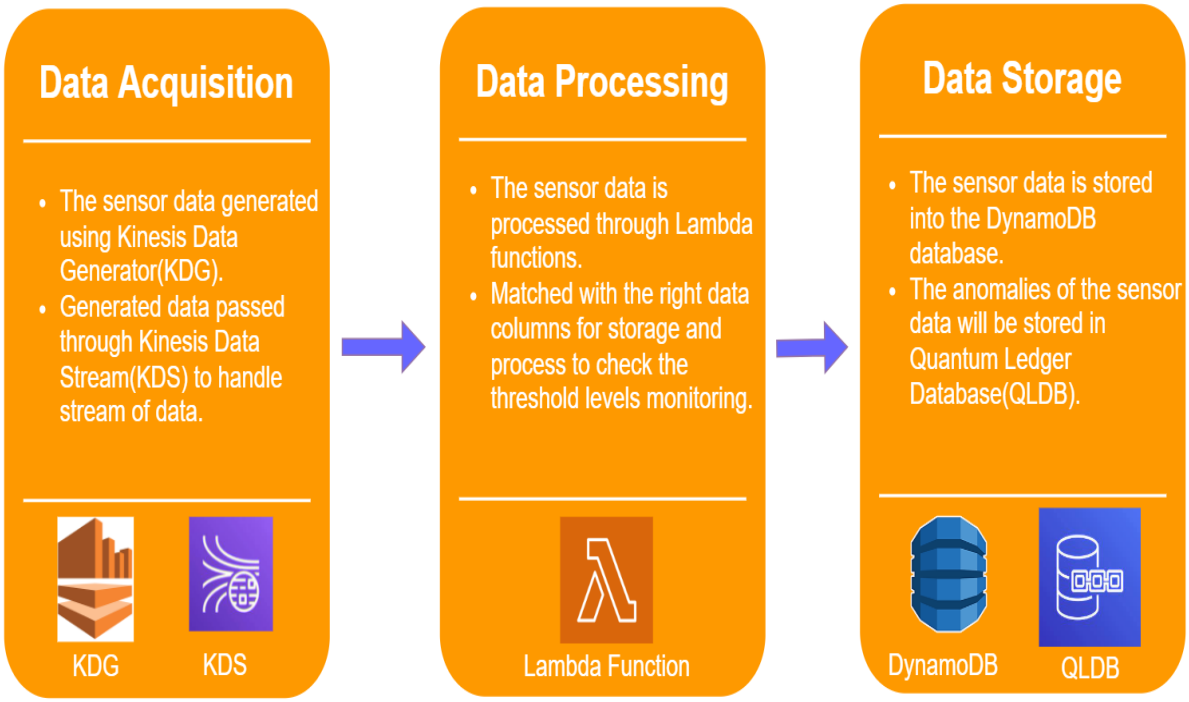

Figure 2.1: The sensor data stages are divided into three stages as data acquisition, data processing and data storage.

The data generated by Kinesis Data Generator (KDG) is streamed lined through Kinesis Data Stream (KDS), which is a massively scalable and durable real-time data streaming service. Kinesis Data Stream makes it easy to capture, transform and load data efficiently. The data that is collected becomes available in milliseconds to enable real-time analysis use cases such as real-time dashboards, real-time anomaly detection, dynamic pricing, and more [22]. In the data processing stage, this data stream is processed and ready with the built-in integration to AWS Lambda service. The data coming through this streaming service is made sure to get the right format of data. A check is put in

the processing time that the threshold levels are not breached by the system using these lambda services. There is also a check that exists which identifies the anomalies in the streaming data and notifies the system about the anomalies. Once the right format is matched then it will be redirected to the database for storage. In the final stage of data storage, once the data processing of the sensor data is finished, the data is stored into the Dynamodb database. The anomalies that occur in the sensor data i.e. threshold level of temperature and humidity crossed, then these anomalies will be stored in the Quantum Ledger Database (QLDB). These storage will provide a strong foundation for the real-time monitoring of the vaccines in the system implementation.

2.2 Cloud Computing for Sensor Data Storage

The sensor data coming in the form of information of the container which comprises of Temperature, Humidity, Latitude, Longitude, SensorId, and Timestamp is directed to record into the database. The sensor's information is then matched to the container id to which it is attached. So in this way, we can visualize the container conditions through the sensor. The real-time monitoring of the condition of the container keeps updating about the environment in which the vaccines are transported and if there is any point in the supply chain in which their thresholds have been breached is also recorded. This would raise the warning notification to the stakeholder having the ownership of the vaccine to raise the alarm about the breach so that timely actions can be taken place. This would prevent the loss or wastage of the vaccines in the supply chain and also keep the efficiency of the vaccine intact. So, the vaccines reaching the people are in good condition and safe to be injected with. The cloud services as discussed above when the data acquisition, data processing, and data storage occurs, then different cloud services were aligned together to complete those stages. The secure movement of data at different stages is achieved in the cloud platform. The different services handling the different events of data stages can scale up and scale down according to the data load required by each cloud service. This opens up the scope for the future in which different cloud services can be aligned in these stages to perform automated tasks in handling the data.

2.3 Summary

To summarize the sensor data flow, the efficiency in real-time monitoring is achieved through data acquisition, data processing, and data storage. The significant data variables coming from the sensors data are recorded and help to give the overall condition and location of the container carrying the vaccines. The result is mainly to make sure that the vaccines reaching to the people at the destination was under the controlled environment and nowhere in the supply chain its conditions were compromised. The sensor data coming through in the form of stream is matched and saved with their corresponding information. Having the data storage on the cloud makes it easy to scale up and down depending on the data load coming through the stream. This data is redirected from the data storage onto the front-end dashboard, where the sensor data is streamlined to show the data onto the graph. Through this visual representation, the whole monitored journey can be backtracked so as to make sure that the vaccines whole journey was within the threshold level assigned to it. This builds the trust of the people in the efficiency of the vaccines.

Chapter 3

Supply Chain Process Flow

3.1 Introduction

The Supply chain is defined as the integrated process flow which includes various entities like suppliers, manufacturers, logistics, distributors, and retailers who work together to supply the finished product in a trustable way. This flow is categorized as the forward flow of material, backward flow of money and both directional flow of information [23]. The way to achieve this trustable way in the supply chain flow is by involving the entities into the transparency and immutability of supply chain data flow. As in this section we talk about the supply chain process flow, the smooth transitioning of product ownership is also taken into account when going through the supply chain. The system uses cloud computing services to make the flow of the system implemented in a secure and expandable environment. The cloud computing system is flexible in implementation and makes the system robust.

3.2 Supply Chain Framework

The supply chain framework is implemented by designing the flow of transferring the ownership of the vaccines in the supply chain. This framework will act as the base of the implementation of the system on cloud computing. This framework will highlight the entities involved in completing the supply chain as shown in Figure 3.1 and different steps these on-boarded entities have to take during the whole supply chain process flow.

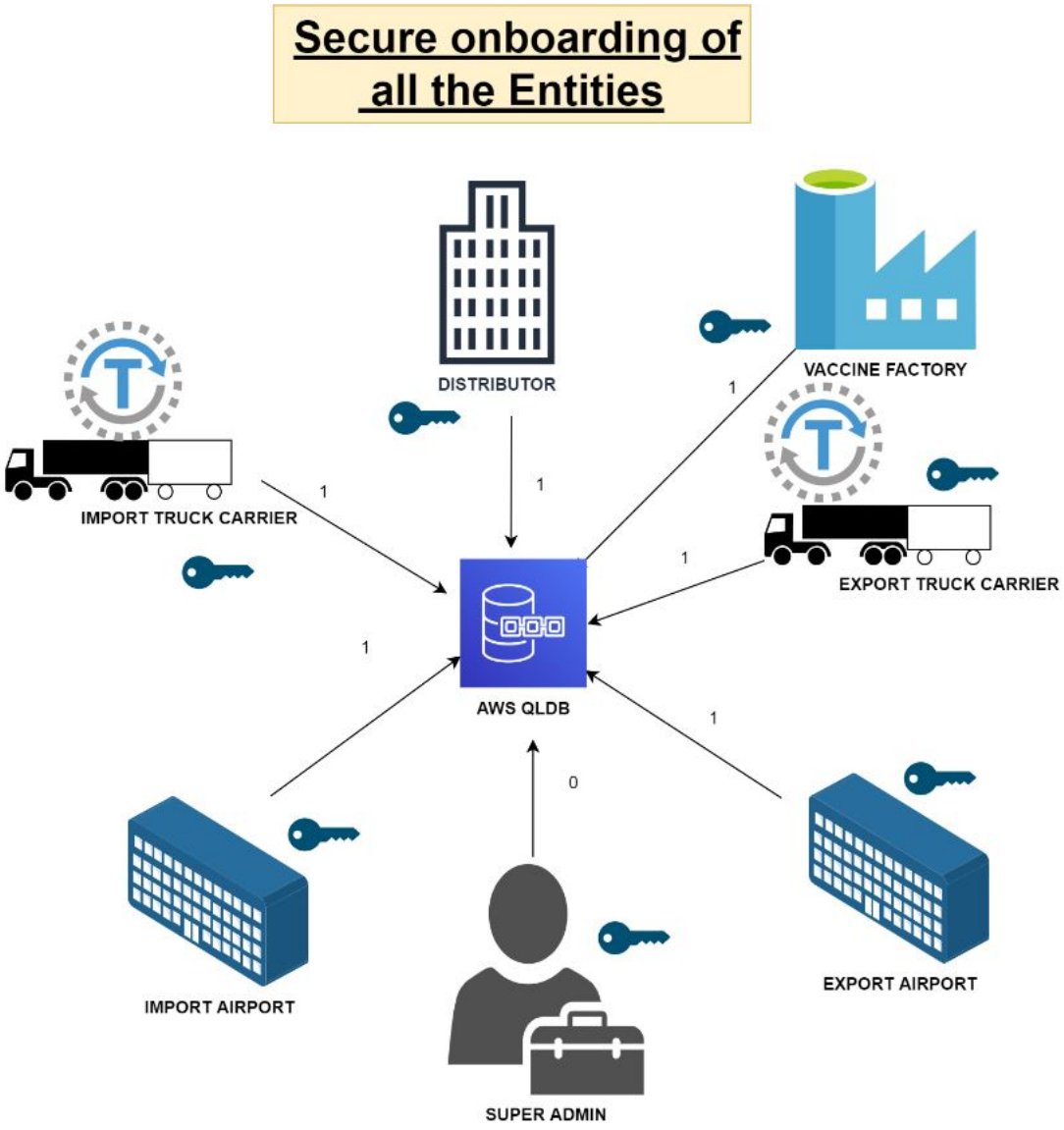

Figure 3.1: Securely on-boarding of all the entities in the supply chain for the smooth functioning of the system.

3.2.1 Framework Structure

The framework structure of the system builds a strong foundation for the supply chain process flow. The supply chain flow makes the combination of end-to-end supply of vaccines in a real-time monitored way as a smooth flow.

The system is accessed securely to prevent unauthorized users to access the system

and protect the integrity of the system. This builds the trust of the stakeholders in the supply chain system. The use of Amazon Web Services (AWS) Cognito to execute the secure access of system and create the profile to become part of the supply chain as entities and helps in completing the supply chain to finish the complete process of vaccine delivery.

The front end of the system is built on the React JavaScript language which is a component-based language. The component-based language signifies that the section that is built once can be used on different parts of the system [24]. This reduces the redundancy of functions and makes them reusable. It develops the Single Page Application (SPA), which is a web application implementation that loads only a single web document, and then updates the body content of that single document when different content is to be shown. In this way, the user uses the website without loading the whole new pages from the server. This would increase the performance of the web application and provide a dynamic experience to the user.

The back end of the system is written in Python, which can be used as an Object Oriented Programming (OOP), procedural oriented, and functional oriented language that provides the environment for the programmers to write the clean, logical, and robust code for small and large scale projects. When both these front-end and back-end aligns together then it brings together the swift movement in the supply chain. The Application Programming Interface's (API) are developed, which interacts with the immutable database and processes the requests coming from the front end. These requests are handled and provided the relevant response to the front-end to display the results.

3.2.2 Cloud Computing Methodologies

Since implementing the system on the cloud makes it a robust system, cloud computing plays an important role in achieving this robustness. The use of different services and integrating them in the system gives the flow to the supply chain as shown in Figure 3.2. Adopting cloud services gives the reduction in cost, easy to use, better collaboration, increase in reliability, security, and privacy of the system is achieved [25]. The cloud computing service AWS Cognito supports the secure Sign-up and Sign-in of the

users. This takes into the registration details of the user which includes the username, email id, password, and phone number. After clicking the register button, the user will be prompted to enter the verification code received on their email address used in the registration. This verification process will verify the user's email address and activate the account to sign-in into the system. This cloud computing service makes the integration for secure registration and sign-in into the system.

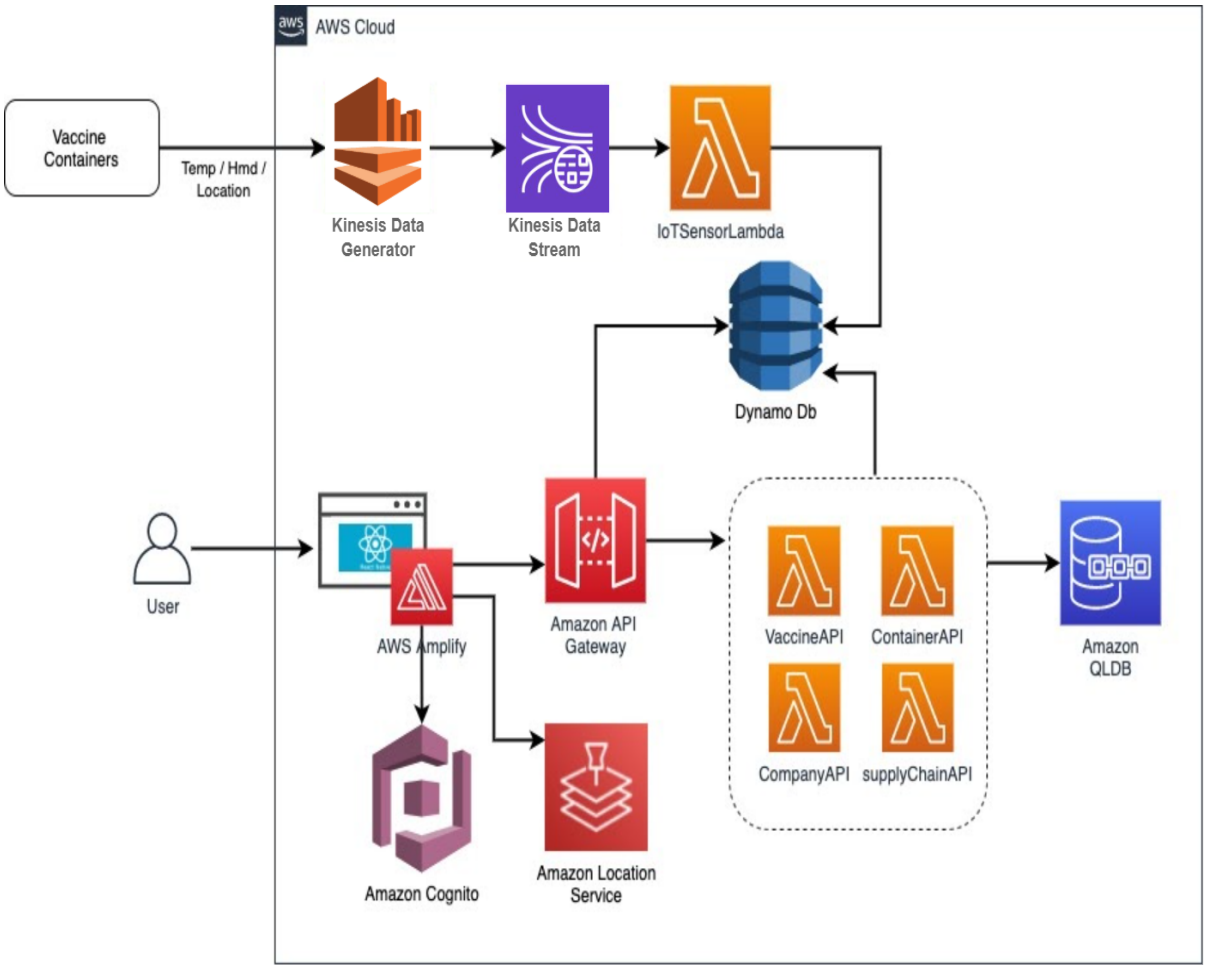

Figure 3.2: Vaccine delivery supply chain system cloud architecture for the flow of requests and responses.

These sign-in details will be used to access the other features of cloud computing in token verification to access the system data. The cloud computing services and their methodologies implementation help the system performance. The different cloud com-

puting services are as follows:

1. Amazon Quantum Ledger Database (QLDB): It is a fully managed ledger database that provides a transparent, immutable, and cryptographically verifiable transaction log as shown in Figure 3.3. It is owned by a central trusted authority. The ledgers are used to record the history of economic and financial activity in an organization. In the supply chain system, it records the journey of the product in the supply chain. The disadvantage of using a relational database was that it was mutable and hard to track changes [26]. So, QLDB provides the solution to this issue in a precise way. The blockchain system adds complexity to set up an entire blockchain network with multiple nodes, manage its infrastructure, and requires nodes to validate each transaction before it can be added to the ledger. So, to overcome these complexities of the process of achieving the immutable database, the QLDB provides the features for achieving the immutability of data in a simplified way. Here are some of the Amazon QLDB Benefits:-

    - Immutable and Transparent: Journal keeps record of changes over time.
    - Cryptographically Verifiable: Use of cryptographic hash function (SHA-256) to generate secure output file of data's change history known as a digest.
    - Performance and Highly Scalable: It can execute 2-3X as many transactions than ledgers in common blockchain framework. Multiple-party consensus takes time on a single platform.
    - Serverless: It automatically scales to support the demands of the application.
    - Easy to use: QLDB support PartiQL, which is a new, open-source, SQL compatible query language. QLDB is a document-oriented data model that enables to store and process both structured and semi-structured data.
    - Highly Available: Replicating multiple copies of data within an Availability Zone (AZ) for data storing.
    - Streaming Capability: Stream data directly to Kinesis, Lambda, etc... Help develop event-driven workflow and perform real-time historical data analysis.

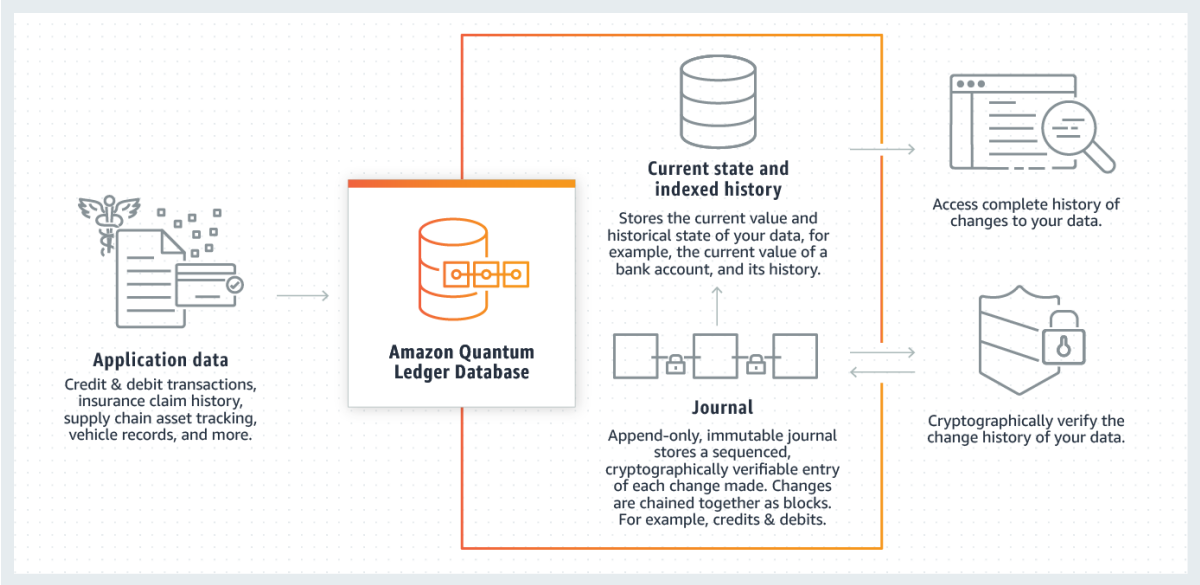

Figure 3.3: AWS Quantum Ledger Database architecture flow. [1](Source: AWS QLDB, 2020)

Amazon QLDB Use Cases:-

- Finance: The banks can use QLDB for recording centralized ledger for an accurate and complete record of all financial transactions. This would help them to overcome the problem of maintaining auditing transactions and logs.
- Manufacturing: Track the full manufacturing history of the product so that quality is not compromised. The impact on product quality of immutable transparency and right monitoring is that products which are sensitive to external conditions if any breach in their boundary conditions occurs through different stages of manufacturing then it would impact their quality and the product integrity. The timely notifications and alert warns can provide the stakeholders enough time to take actions in maintaining the product quality if the boundary conditions are breached at any stage of the manufacturing. So, having real-time visibility and immutable transparency of those effecting conditions can help in monitoring the conditions easily and which results in better quality products received at the end of the manufacturing.
- Insurance: It would help in tracking the history of claim transactions in which

all the records are shown as no record is deleted from the ledger. This feature of immutability can be very useful in avoiding manipulations in insurance records.

- HR Payroll: Track employee's details such as payroll, bonus, benefits, performance history, and insurance. It would help in keeping the digital history of employees in a single place.
- Retail and Supply Chain: Access information of product at every stage like location, source, destination, ownership, etc... Using QLDB track the full history of inventory and supply chain transactions at every logistical stage of the product.

2. Amazon DynamoDB: It is a fast and flexible NoSQL database service for any scale [27]. Amazon DynamoDB is a key-value and document database that delivers millisecond performance at any scale. It's a fully managed, multi-region, multi-active, durable database with built-in security, backup and restore, and in-memory caching for internet-scale applications. Hundreds of thousands of AWS customers have chosen DynamoDB as their key-value and document database for mobile, web, gaming, ad tech, Internet of Things (IOT), and other applications that need low-latency data access at any scale. Amazon DynamoDB provides benefits in performance at scale, no servers to manage and enterprise ready.

3. AWS Cognito: This service provides secure user sign-up, sign-in and access control. This service take all the functional implementation related to securely on-boarding the users to the system. It adds access control to your mobile and web app quickly and easily. Managing the authentication and authorization of system becomes easy with the use of this cloud service.

4. AWS Amplify: This service provides the fastest and easiest way to build mobile and web apps that scale. AWS Amplify provides benefits in configuring back-ends fast, seamlessly connect front-ends, deploy in few clicks, connecting app's repository, and easily manage content as the flow is shown in the Figure 3.4.

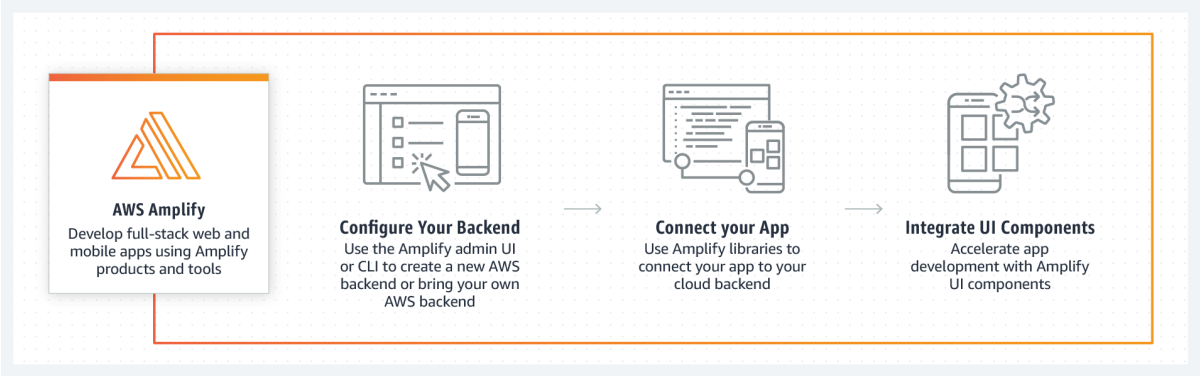

Figure 3.4: AWS Amplify architecture flow. [2](Source: AWS Amplify, 2020)

5. Amazon Application Programming Interface(API) Gateway: This service create, maintain and secure API's at any scale. API's acts as a front door for application to access data, business logic or functionalities from back-end services.

6. AWS Lambda: This AWS service run code without developer thinking about servers or clusters. It provides the service of only pay for what your system use. There are testing environment for the API's before integrating them into the system. It provides the flexibility to use favourite language (Node.js, Python, Go, Java and more) for writing the code. Since our system uses the Python language to develop the API's. AWS Lambda provides benefits such as no servers to manage, continuous scaling, cost optimized with millisecond metering, and consistent performance at any scale.

7. Amazon Kinesis Data Generator (KDG): This AWS service makes it simple to send test data to your Amazon Kinesis Stream or Amazon Kinesis Firehose delivery stream for mocking up the system. The KDG simplifies the task of generating data and sending it to Amazon Kinesis. This service provides the tool that runs directly into the browser and generates the testing data for the system in the desired format. With the KDG, we can do the following: - Create templates that represent records for a specific use cases - Populate the templates with fixed data or random data - Save the templates for future use - Continuously send thousands of records per second to the Amazon Kinesis Data Stream or Firehose delivery stream.

8. Amazon Kinesis Data Stream (KDS): This AWS service collects the streaming data, at scale, for real-time analytics. KDS can continuously capture Giga Bytes (GB) of data per second from hundreds of thousands of sources such as website click-streams, database event streams, financial transactions, social media feeds, Information Technology (IT) logs, and location-tracking events. The data collected is available in milliseconds to enable real-time analytics use cases such as real-time dashboards, real-time anomaly detection, dynamic pricing, and more.

3.2.3 Supply Chain Process

The supply chain process makes the movement of vaccines efficient. Identifying different steps that make the flow of vaccines smooth helps in achieving efficiency. The transfer of ownership of vaccines from one stakeholder to other provides the base for the supply chain process flow as shown in Figure 3.5. This figure highlights the complete supply chain flow from manufacturer to third party logistics to airport to distributors to clinics to patients. Keeping this flow as the base, the system is created where the flow of the data is from the QLDB to keep the data in it as immutable and transparency among the stakeholders in the supply chain is maintained.

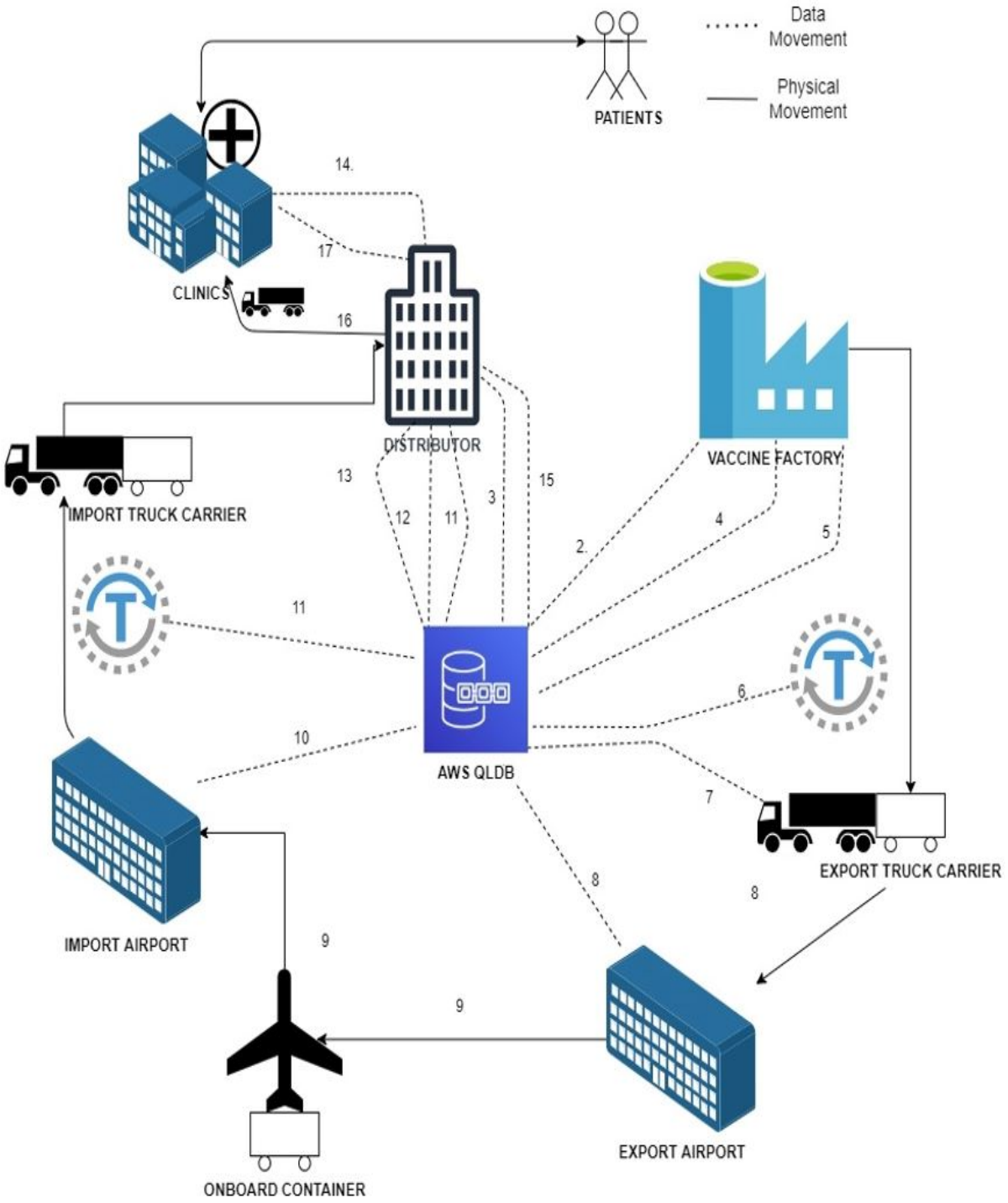

Figure 3.5: Supply chain flow of the entities and transferring of ownership of the vaccine container. Step(2-18).

The steps involved in making this supply chain flow are as follows:

0. On-boarding of Admin: Admin builds the ledger, creates tables and indexes. The creation of tables and indexes will create the database infrastructure required for the supply chain system. It is created on Amazon QLDB, which is an immutable and cryptographically verifiable database. Once the tables and indexes are created then the admin sign up through the system as shown in Figure 3.6 and is assigned to the admin user pool.

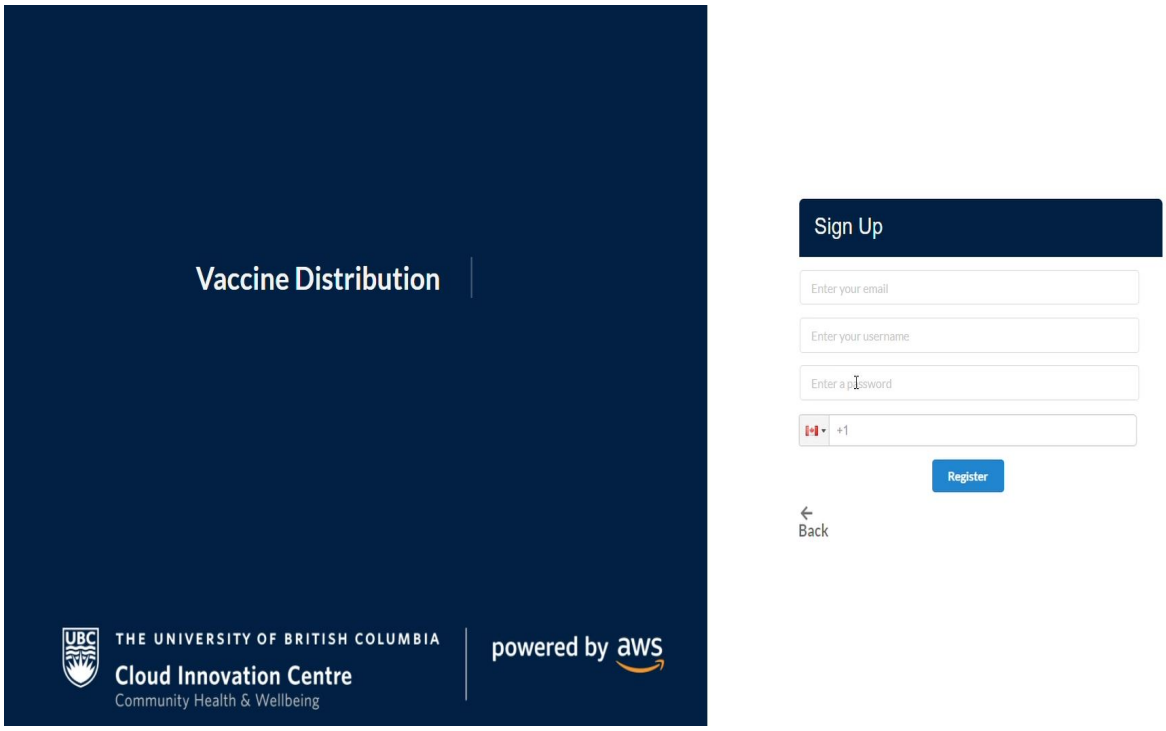

Figure 3.6: Securely register the user on supply chain system.

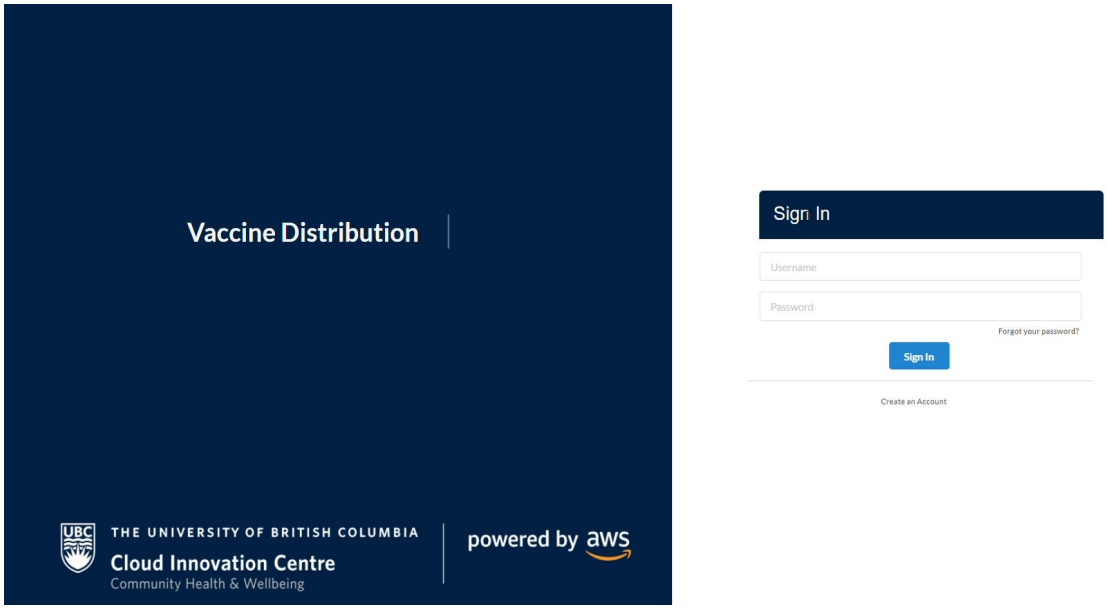

Figure 3.7: Securely Sign-in the user on supply chain system.

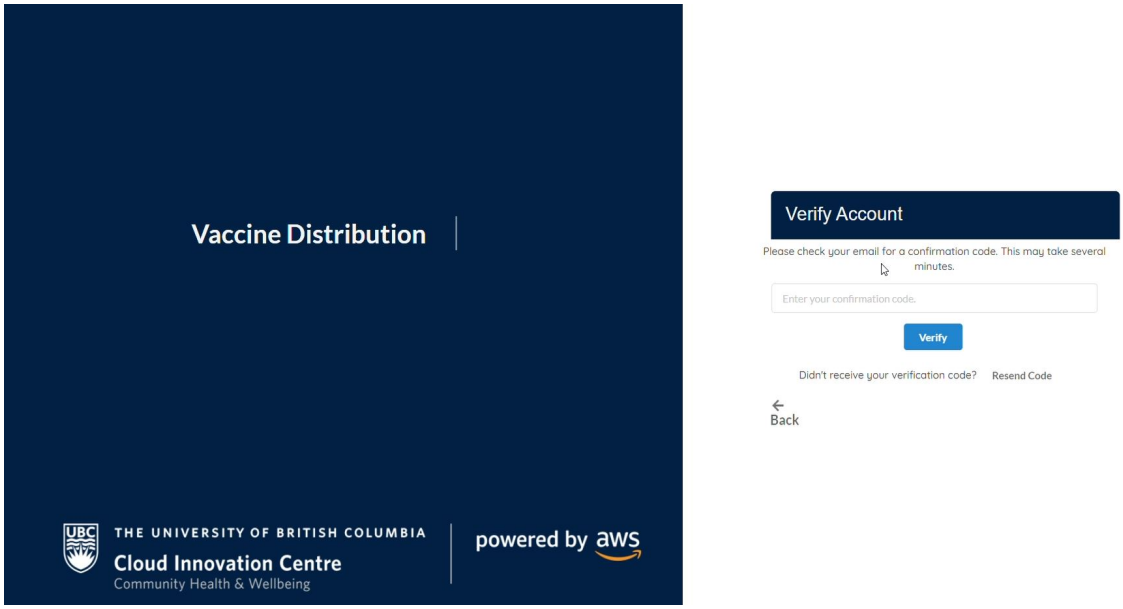

Figure 3.8: Verify the email of the user after registration on supply chain system.

1. On-boarding of Stakeholders: All the respective stakeholders (companies, airports, and hospitals) sign up by creating their new user and register entity on QLDB as shown in Figure 3.9. These registration requests goes to the admin panel for approval as shown

in Figure 3.10. Once this request is approved by the admin, entities can buy or sell things. After this, any new user who wishes to join the approved entity can pick/search the entity and send a joining request which can be approved by the admin of that entity.

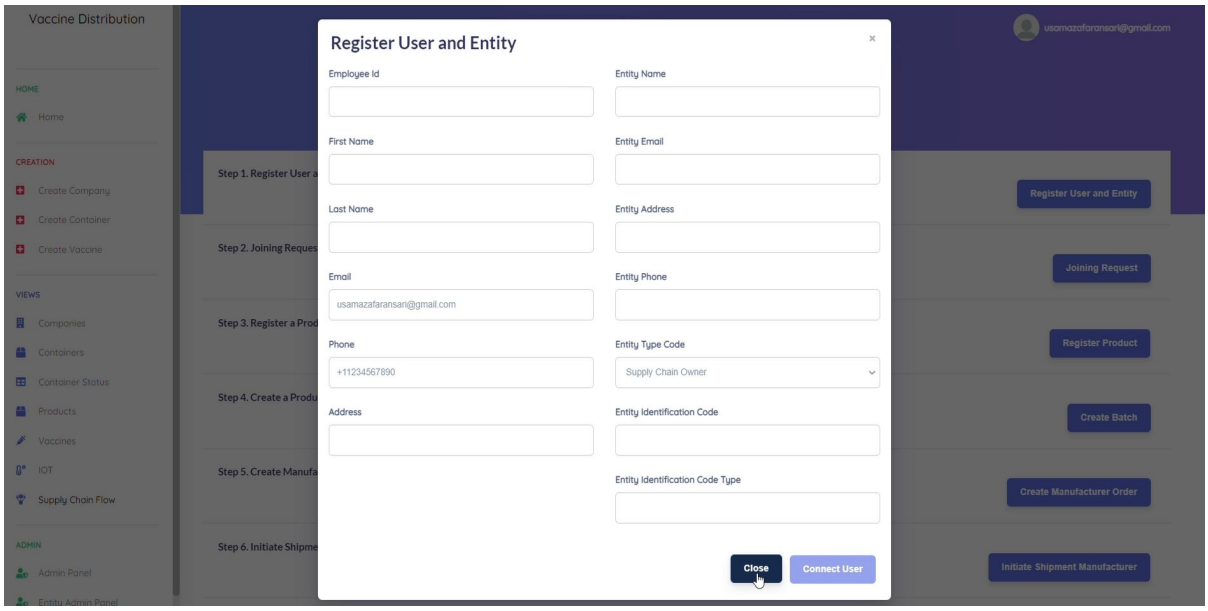

Figure 3.9: On-boarding of stakeholders and their entity on supply chain system.

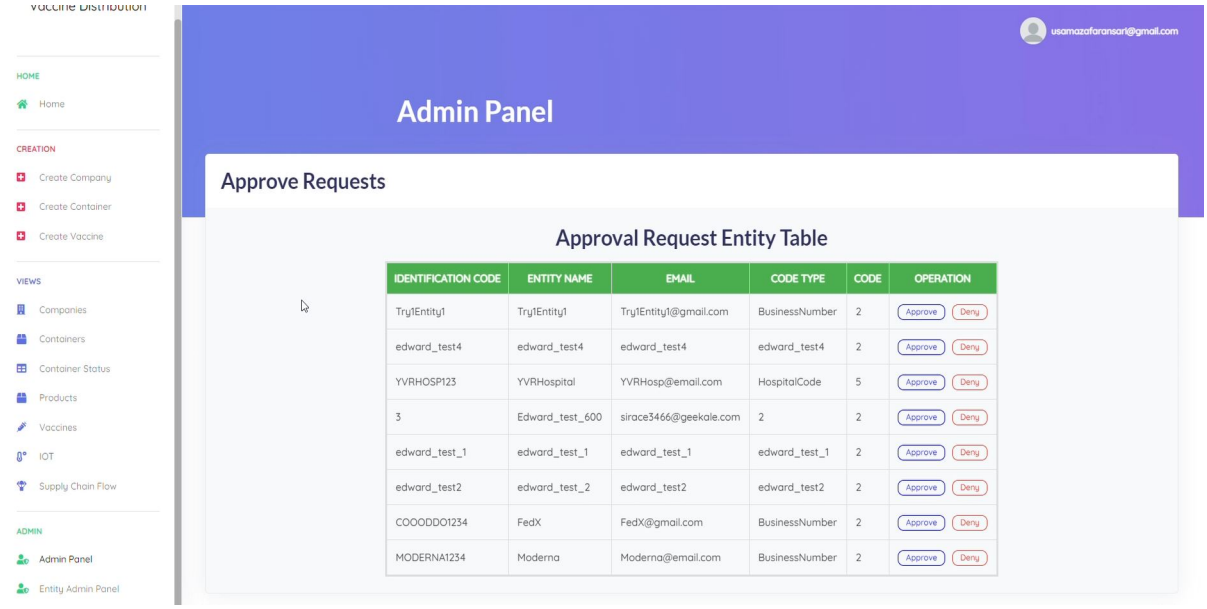

Figure 3.10: Approval of request by the admin to let the entity join on supply chain system.

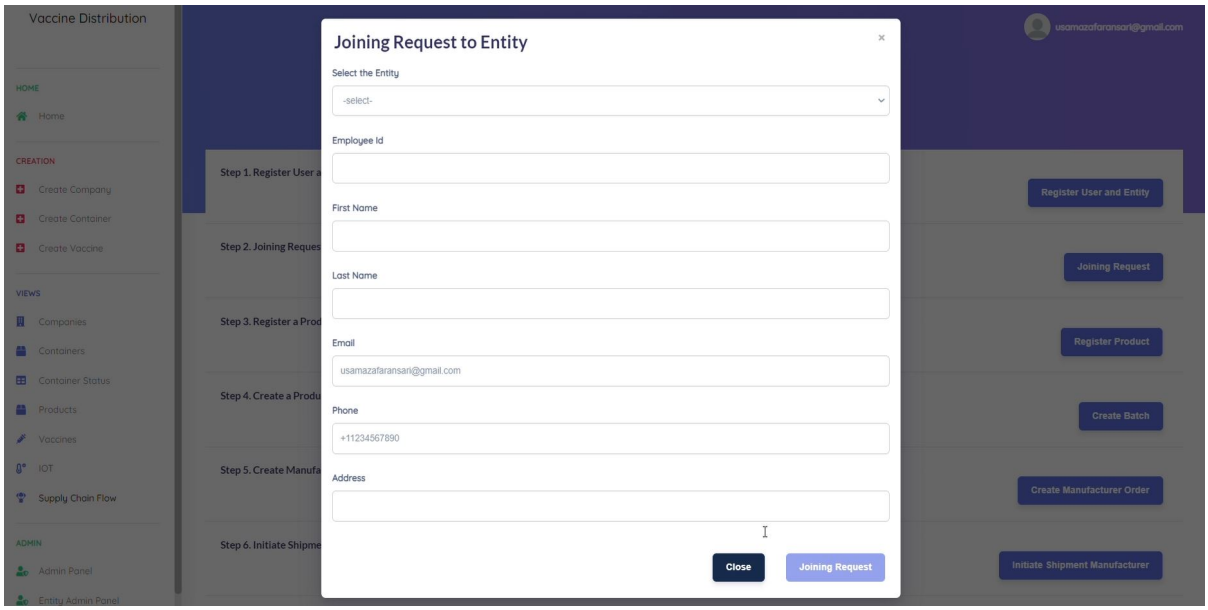

Figure 3.11: Joining the existing entity on supply chain system.

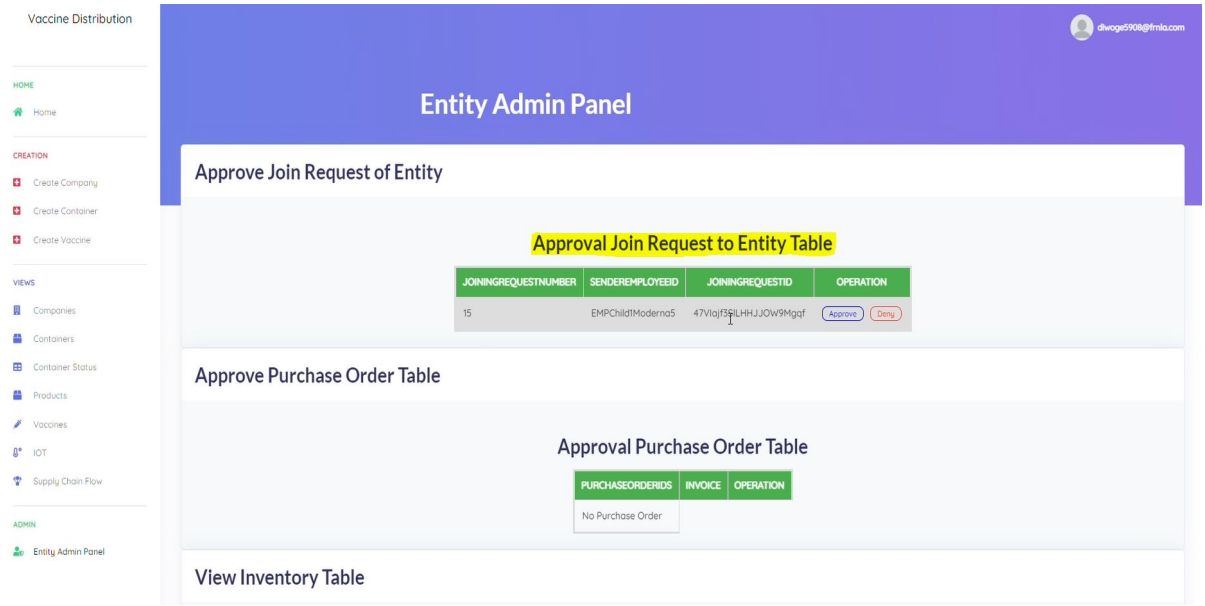

Figure 3.12: Approve the joining request by the entity admin on supply chain system.

2. Register New Products: In this step, the manufacturer can register their products into the database through the register product form as shown in Figure 3.13. So, this adding of the product will send the request to the admin of the system for approval. Once the product is approved by the admin, the manufacturers can now register the inventory or create a vaccine batch that will be available to buy or place an order by the distributor.

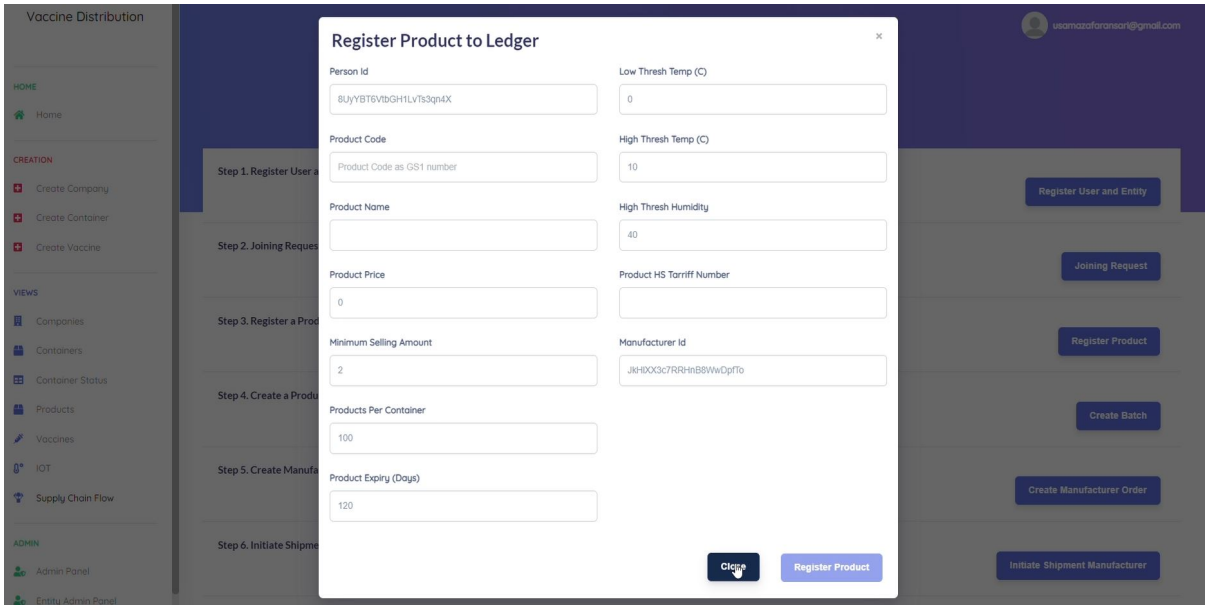

Figure 3.13: Register product into the supply chain so that the order for it can be placed.

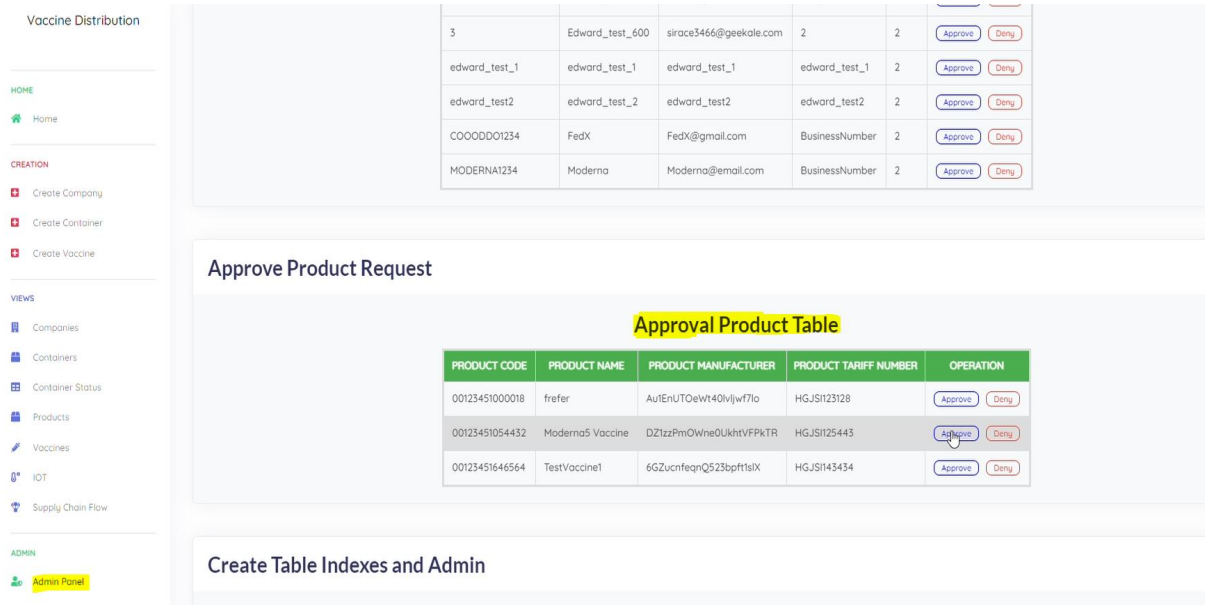

Figure 3.14: Approval of request by the admin to let the entity join on supply chain system.

3. Place Orders: Once the product is added and approved into the supply chain, then the Distributor can place an order for the product. The distributor can select the

product in this case are vaccines. The request for the placed order is received by the manufacturer and they would approve it for further processing of it. The order details can be fetched for approval from the manufacturer.

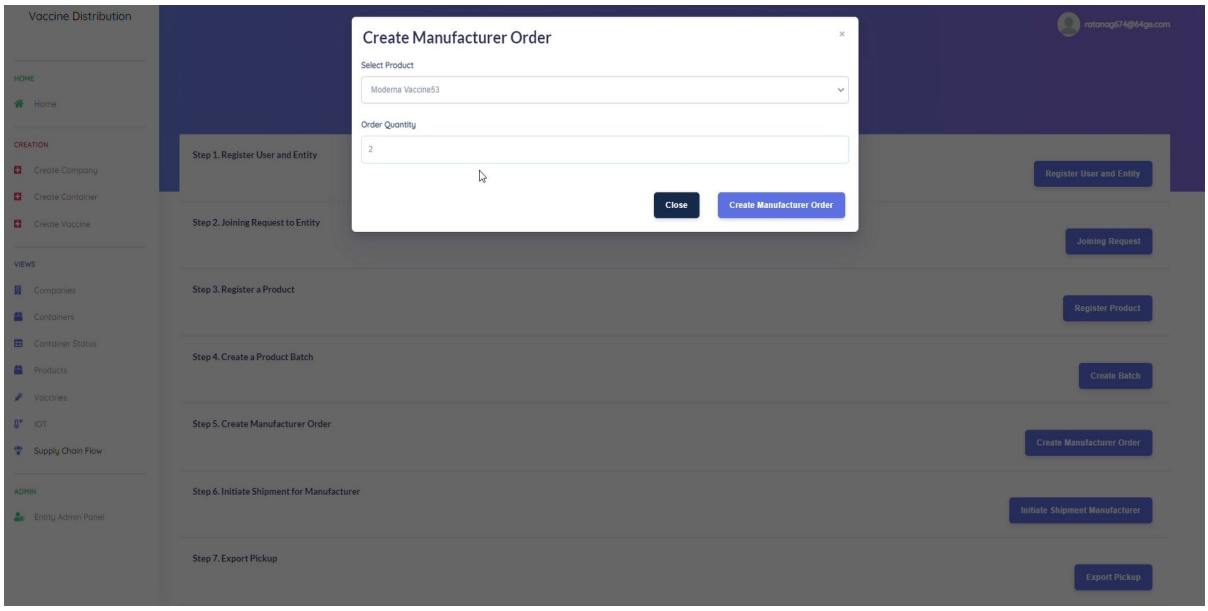

Figure 3.15: Creating the order for the manufacturer to get it delivered on supply chain system.

4. Accept Order/Create Invoice: If enough vaccines are registered for the order, then the manufacturer can accept the order as shown in Figure 3.16. This will create an invoice that can also be viewed by the distributor. This invoice contains the details related to vaccine order which comprises of timestamp, quantity, price, unit price, etc...

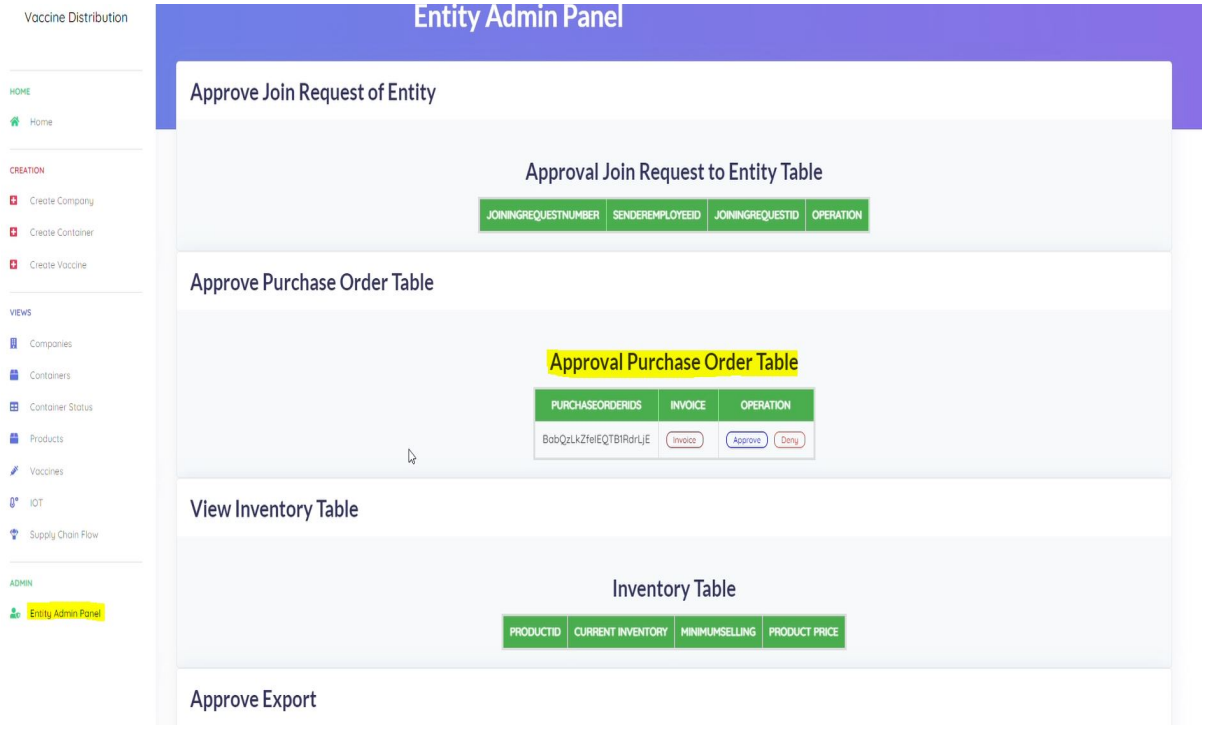

Figure 3.16: Approval of the purchase order by the manufacturer on supply chain system.

5. Initiate Shipment: Assuming the distributor approves the invoice, the manufacturer proceeds with initiating the shipment. This will assign the product to be exported by the entities in the supply chain. If the transport type is 1(air), 2 (ocean), or 3(road) then it means the manufacturer wants to export it as shown in Figure 3.17. The backend automatically maps products to cases to pallets to the containers. It also creates a "certificate of origin" and a "packing list" and assigns them to respective container ids. It also creates a pickup request for the carrier that was assigned pickup. This request will be used in the next step.

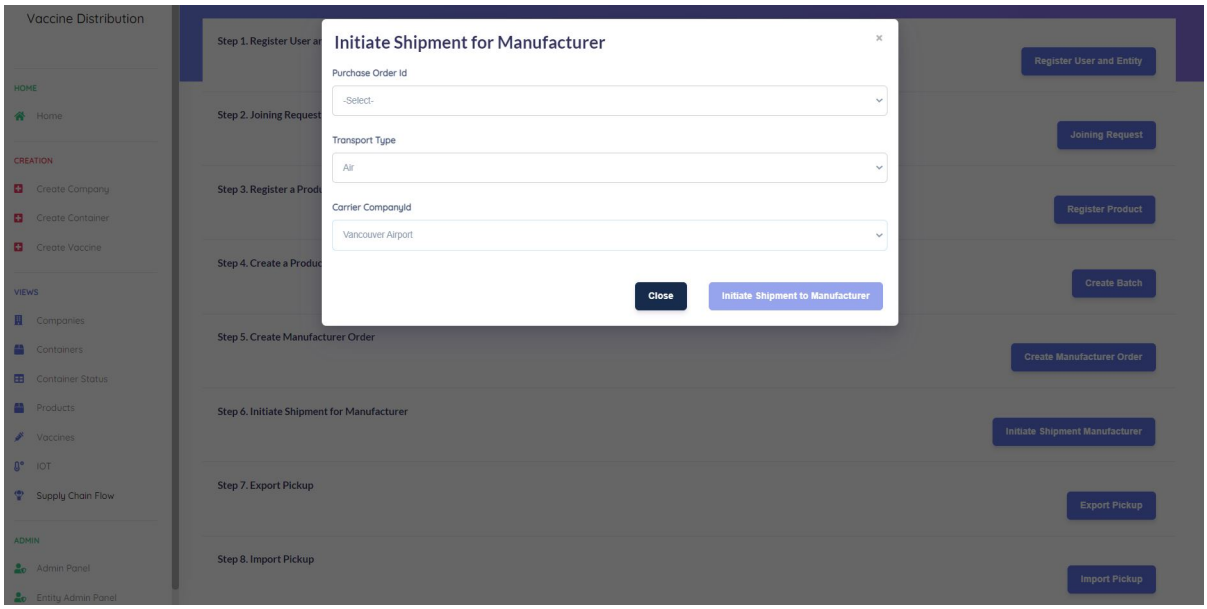

Figure 3.17: The shipment is initiated by choosing the transport type and carrier transporting it.

6. Driver Scans Container IDs: Driver arrives at the manufacturing facility with the smart container that has been leased by admin. It requires them to know the containerId from the manufacturer in the form of QR code which will be attached to the container. These QR code once scanned through the system as shown in the Figure 3.18, the details of the container which will be directly input into the Database. This would prevent the manually entering the details which can sometimes be prone to human error.

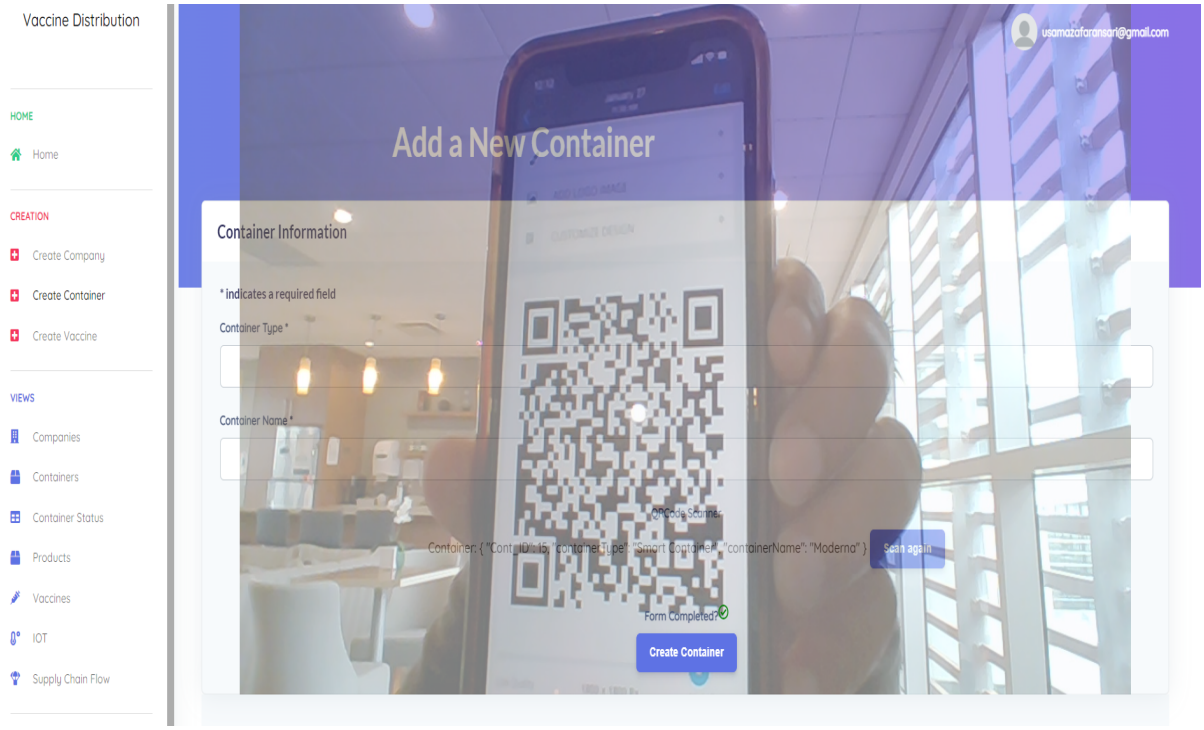

Figure 3.18: The Scanner is build to record the QR code data to make the container details input easy.

7. Driver Requests Approved for Pickup: This step generates a Lorry Receipt (LR) and an Airway-Bill/Bill of Lading depending upon the transport type chosen. Manufacturers can use this LR and Bills to query the state of the shipment.

8. Check Vitals of Container: During the supply chain journey sensors can fire alarms in case the temperature breaches the safety threshold pre-established. If anything is wrong it marks the container as unsafe and the next steps won't go through. This makes sure that only reliable vaccines reach the distributor. The truck transports the container to the airport. Here the exporting airport can check the details of documents, and if everything is right it can approve containers to board.

9. Approve Lading Bill: After approval from customs, containers arrive at the transport carrier's facility. Carriers approve the airway bill or bill of lading.

10. Approve Import: Once the containers arrive, import customs can review details and then approve the container so it can be assigned to a warehouse for pickup by the

import airport as shown in Figure 3.19.

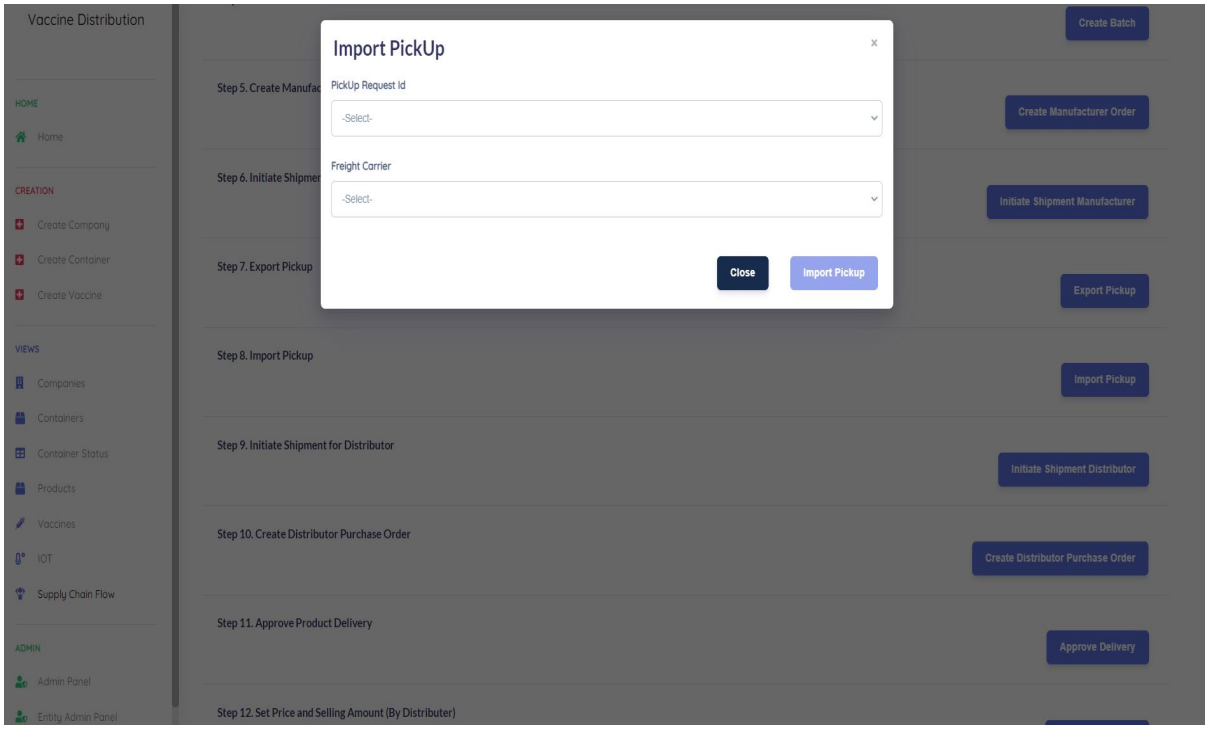

Figure 3.19: Pickup is initiated once the container is imported.

11. Request Pickup: The requests to pickup can be made either by the distributor or transportation can continue without it. If a request is made then a new pickup request is created to the carrier of the choice, which can be used to pick up the container as shown in Figure 3.20. If not, then the same pickup request can be used by the carrier assigned by the manufacturer to continue the shipment.

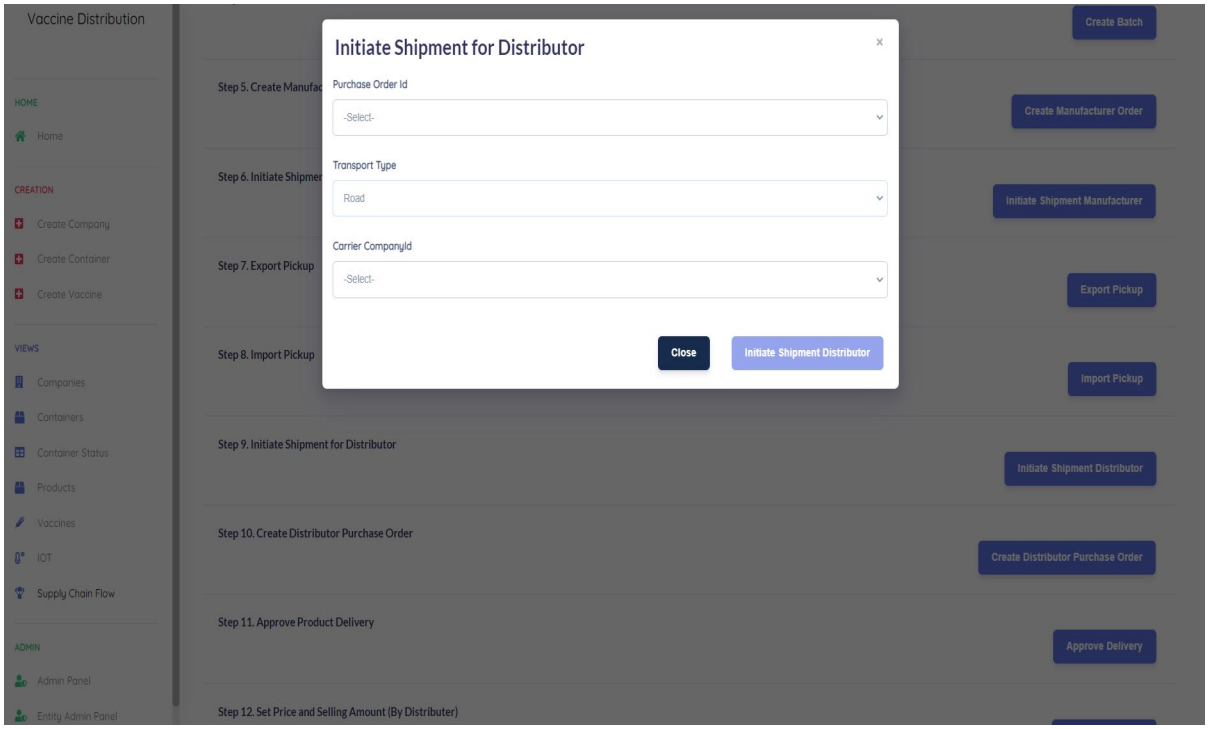

Figure 3.20: Initiate the shipment for the distributor to receive the delivery.

12. Check Vitals (again): Distributors can check everything to approve the shipment. This updates the invoice with a new payment amount of missing/unsafe containers and approves the invoice, lorry receipt, and other documents for delivery. It also creates a new inventory table for the distributor and adds the product inventory to it. If the inventory table or product already exists in the inventory, it updates it.

13. Set Price: We don't have any payment functionality yet. We will just continue the supply chain process for the prototype. Distributors can set the price and minimum selling amount for product as shown in Figure 3.21.

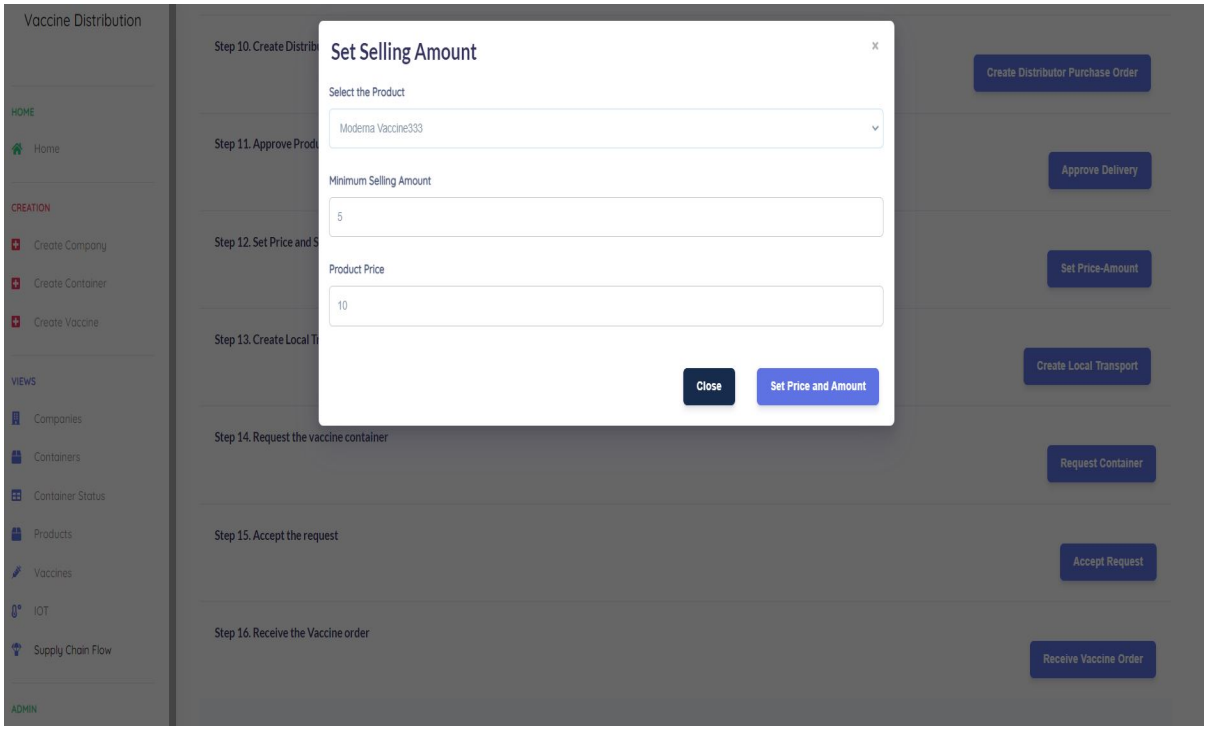

Figure 3.21: The selling amount of the vaccines are set through this for selling to their customers.

14. Place Order: A personnel from the hospital can place the order to the distributor for the product as shown in Figure 3.22.

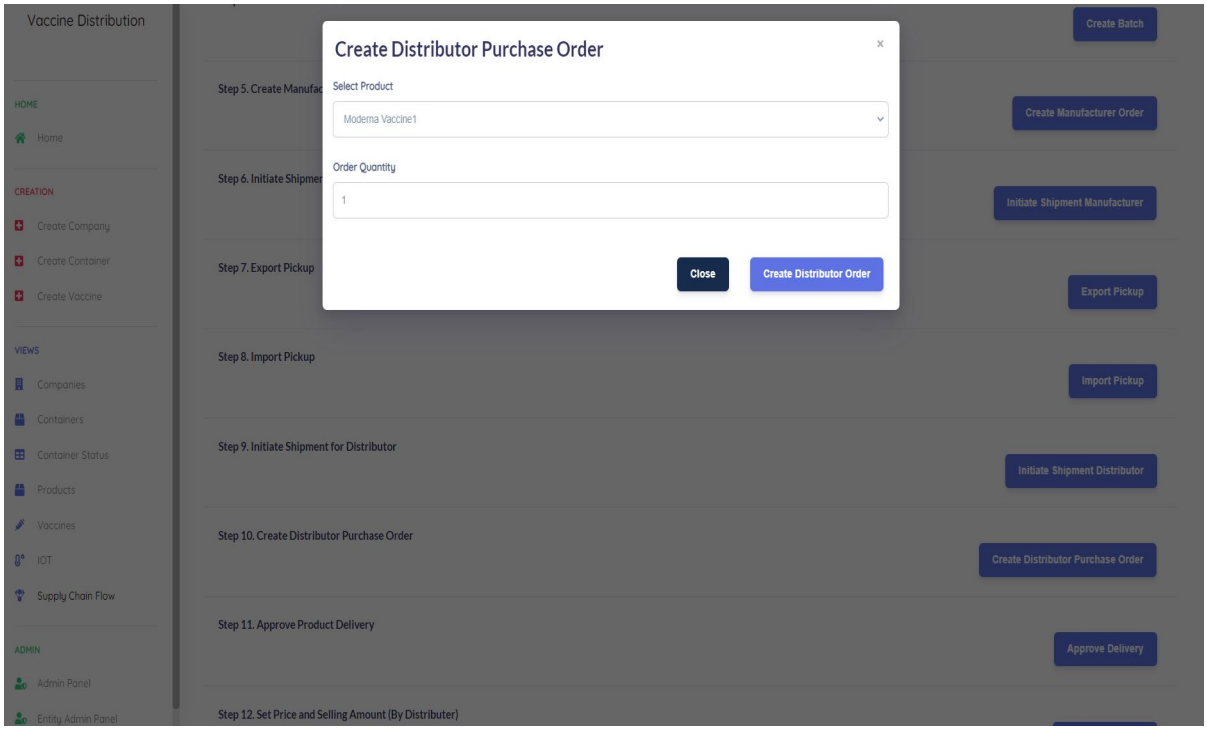

Figure 3.22: The order can be placed to the distributor for last mile delivery.

15. Accept Order: The distributor can accept the order to create an invoice and then initiate the shipment to create a pick-up request for the local transporter.

16. Pickup Request: The carrier company can pick up the container, which will make only a Lorry Receipt as shown in the Figure 3.23.

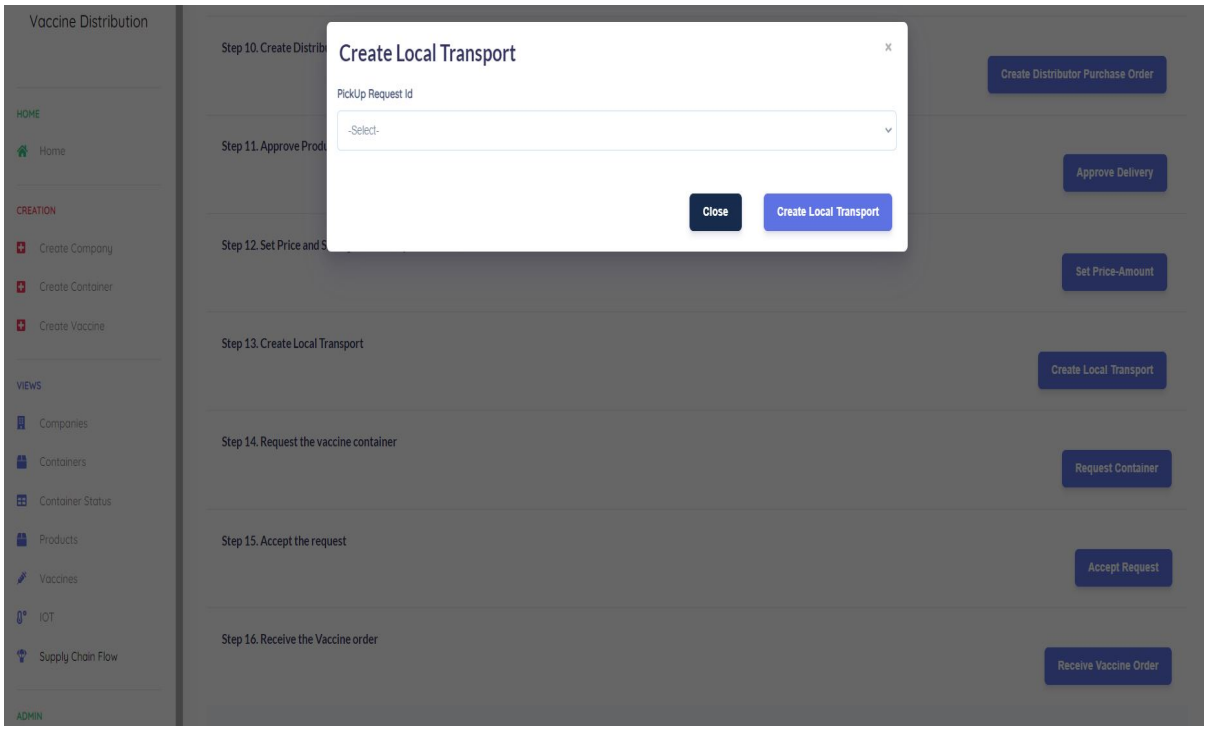

Figure 3.23: This show the local pickup request can be created for last mile delivery.

17. Approve Delivery: Hospitals can approve Lorry Receipt and Invoice and complete the process. It eventually creates an inventory table, if it doesn't exist for them.

These steps complete the supply chain process. They are smoothly transitioning from one stakeholder to another and the data generated throughout the process is trusted and immutable.

3.3 Supply Chain Data Monitoring

The real-time data monitoring of the supply chain is done on the dashboard of the created system. This gives the freedom to access the sensor data of a particular vaccine container and visualize the condition levels in real-time as shown in Figure 3.24. As from the figure, the monitoring of the sensor data shows two lines on the dashboard which signifies the use of dual sensors. If there is a breakdown occurring in either of the sensors then there is dependency in monitoring the vaccines in the supply chain on

other sensor. This complete data monitoring gives the stack-holders in the supply chain, the reliability to put the trust in the authenticity of the vaccines reaching through the cold supply chain under monitored conditions. This reliability of the trust further helps in better collaboration and transparency of the system among the stakeholders which further leads to the better financial and environmental performance of the supply chain [28]. The anomalies that occur during the supply chain are recorded into the immutable and cryptographically verifiable Quantum Ledger Database which keeps the records as unchangeable to keep for future verification of the vaccines reliability. This real-time monitoring of the supply chain builds trust in the quality of the vaccines.

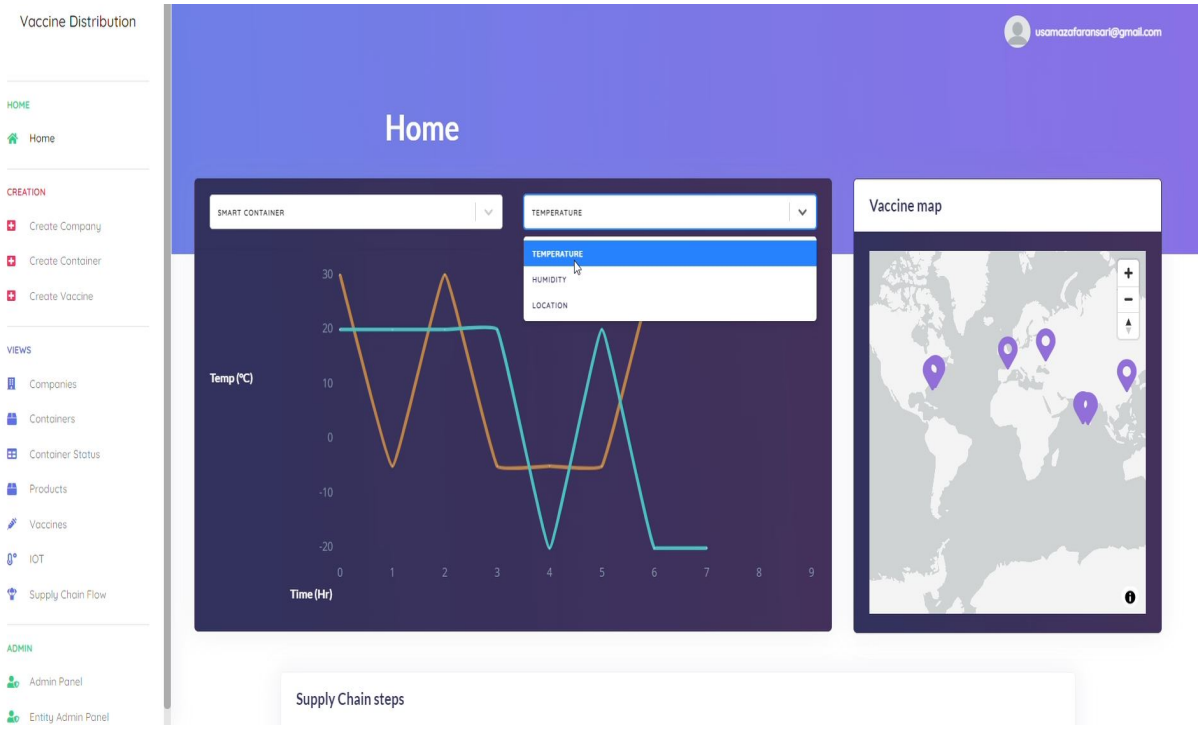

Figure 3.24: Dashboard of the supply chain system to monitor the temperature, humidity and location of the container.

3.4 Evaluation Metrics

The evaluation of metrics highlights the smooth transition and transfer of ownership of the vaccines in the supply chain. The evaluation of running the system and observing

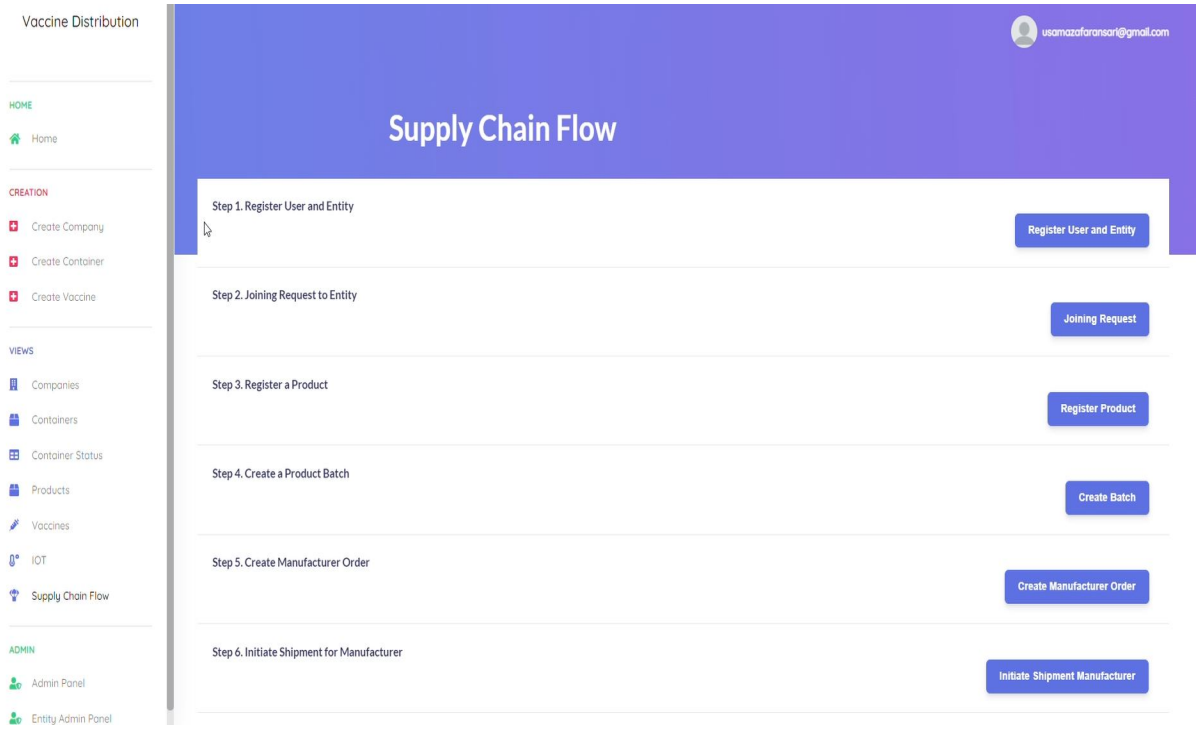

Figure 3.25: The flow of different process of the supply chain.

each step involved in the supply chain performing efficiently without breakage at any step solidifies our claim of an efficient supply chain that can be trusted and immutable. The vaccines monitored in the complete supply chain provide the measures to evaluate the quality of it. The efficacy of it was maintained in the complete supply chain flow. This satisfies the end-user that the vaccines they were injected make it trustable. If there is the occurrence of any anomalies in any stage of the supply chain then it can be stopped from further moving and maintaining the authentication of the vaccines. Performance of the system can be assessed by running the complete steps of the supply chain as shown in Figure 3.25 and verifying the records input and output occurring at different transactions. The history of the ownership transfer of the container in the supply chain stored in QLDB can be extracted. The cloud service such as cloudwatch can also be used in identifying the time taken by each transaction and this would give highlights of the quality of the system in terms of speed and performance.

3.5 Summary

The summary of the supply chain process shows the development of smooth transitioning or transfer of the vaccines from one stakeholder to another. The recording of data of the supply chain is recorded at each step. The data that is getting recorded is immutable and cryptographically verifiable. The movement of the vaccines are approved and assigned to make it properly working. So, the vaccine reaching at the destination is reached through a well-monitored process and through the transfer of different stakeholders' efforts. The dashboard provides the overall description of the monitoring and also different supply chain steps that needs to be taken for execution.

Chapter 4

System Implementation and Case Study

4.1 Dataset Description

In this study, the data set of the sensor data is streamlined to the database to record the updates coming from the container about its location, temperature, humidity, timestamp, and sensorId. This sensor data is then visualized onto the dashboard of the system to see the fluctuations in temperature and humidity conditions inside the container in which the vaccines are being transported. This dataset also comprises of the location (latitude and longitude) to track the exact position of the container in the supply chain. The database schema of the supply chain flow follows the relational database of the table with other tables and is normalized to create the efficient database schema implies with the ACID (Atomicity, Consistency, Isolation, and Durability) properties [29]. The database schema generated in the AWS Quantum Ledger Database (QLDB) is immutable and cryptographically verifiable to build trust on the dataset of the supply chain flow among the different stakeholders involved in the process. The database schema for the QLDB is made and all the respective tables are filled with their columns. The relationships between the tables are identified and linked together to manage the database flow as shown in Figure 4.1. There is the building of different database relationships such as one-to-one, one-to-many, and many-to-many. This relationship structure helps in navigating through the data for the supply chain and the APIs to work efficiently in processing the data for the front end.

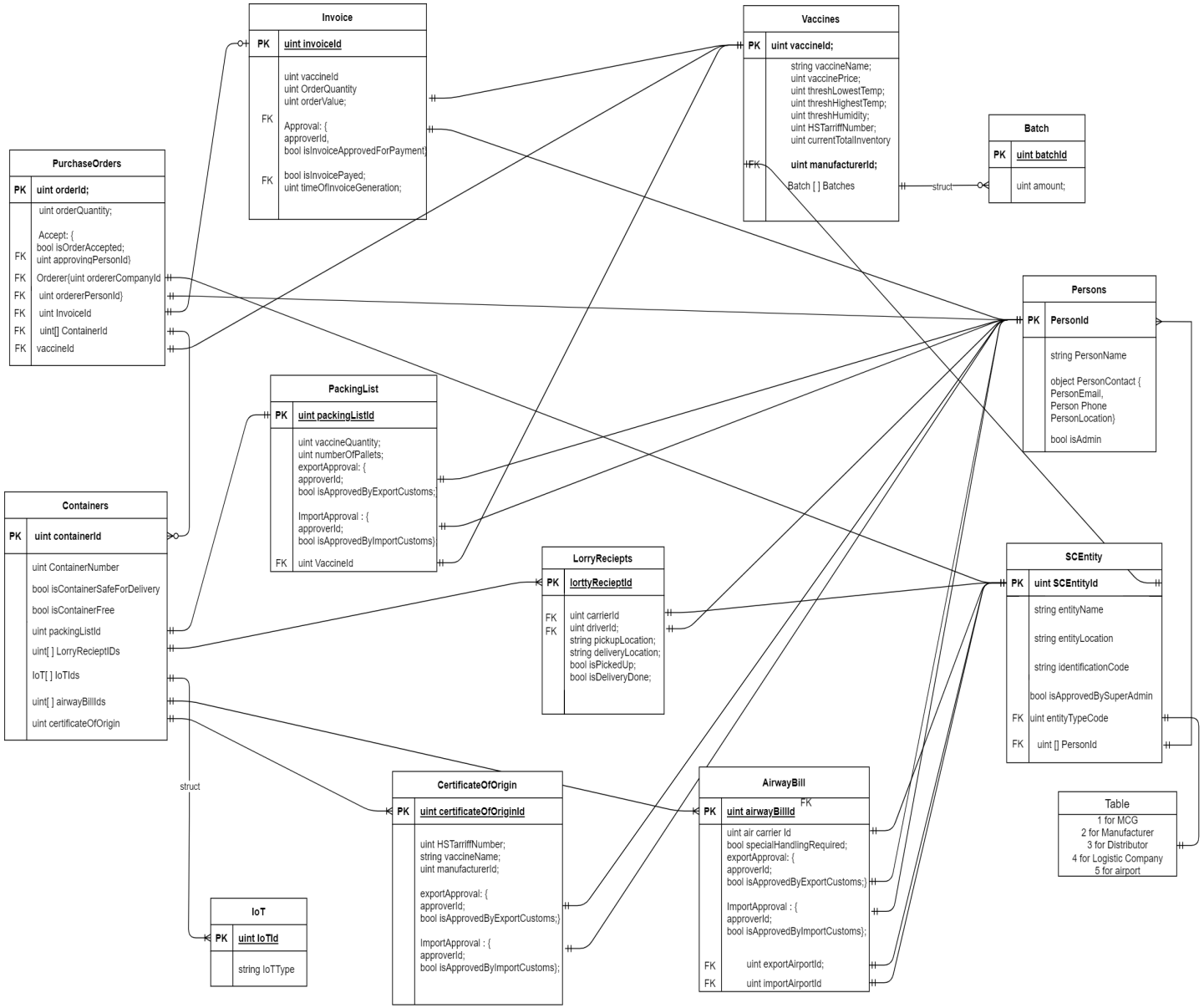

Figure 4.1: This is the schema diagram to show the immutable database schema for supply chain flow.

4.2 Experimental Setup

The experiments were conducted using the computer with i7-6700HQ CPU (Central Processing Unit) using 16GB RAM (Random Access Memory). The system used the processing power of cloud computing which processes the data from the back-end on the cloud and displays the processed data onto the front-end of the system. The back-end processing which occurs on the cloud is performed in a secured way which involves the verification of access tokens whenever the request is sent from the front-end onto the back-end. The experimental setup elements are as follows:

- Front-end:

  1. The React Javascript framework was used to develop the front-end of the Vaccine Distribution System (VDS) as the core framework. The life cycle of react components makes the real-time interaction feasible. These life cycle events comprise of Mounting, Updating, and Unmounting of the components.

  2. Argon Dashboard, which provided the inbuilt standard User Interface (UI) components, was used to keep the design of the whole application consistent.

  3. AWS Amplify was used to bind the Authentication UI component with Amazon Cognito. Amplify is used to host the application on the cloud platform.

- Database:

  1. Amazon DynamoDB was used to store the sensor data. The data is processed in the lambda function and filtered with the associated columns and then redirected to be saved in the DynamoDB.

  2. AWS QLDB (Quantum Ledger Database) was used to store the supply chain process in the form of a centralized blockchain.

- Authorization/Authentication:

  1. Amazon Cognito provided JSON Web Tokens (JWT), to access users depending on their authorization level. The access tokens generated are also verified in accessing the API's for the supply chain system. The user with the Uniform Resource

Locator (URL), which is a reference to web address cannot access the API's with put the availability of proper authentic access token. Authentication is the process of verifying the user whereas Authorization is once the user is verified, what are the resources and API's user can access to.

- Data Processing:

  1. In the back-end, there are Lambda functions that process the data coming from the Kinesis Data Generator(KDG) in the form of a data stream with the sensor details mapped in the DynamoDB table. This processed data is displayed onto the front-end on the graphs to show as sensors readings.

  2. The other Lambda function was used to perform the operations coming from the front-end to execute the supply chain flow. These Lambda functions process the data from the AWS QLDB. These lambda functions require the dependency environment to execute. That is provided by selecting the environment while creating the functions and adding a dependency layer to these functions.

4.3 Case Study and Discussions

The case study of the system is made which aligns the different elements of the system together and forms the intact system for real-time monitored supply chain flow. In chapter 1, the research objectives and research questions have been highlighted. These objectives and research questions were made considering the different cases in the supply chain process framework being proposed, cloud computing methodologies, implementation of immutable storage, and computational cost required to implement the system.

4.3.1 Supply Chain Process Framework

The supply chain process framework is proposed and executed to streamline the vaccine delivery flow in a real-time monitored way. The entities were responsible for making the supply chain flow executable are securely onboarded into the system and approved by the admin before they can be part of the supply chain. The framework is a step-wise

framework that involves the participation of the entity that is given ownership of the vaccines to be delivered. The data that is moving in and out of the system is immutable and cryptographically verifiable so that the trust of the supply chain entities is maintained. This trust is achieved by the use of AWS Quantum Ledger Database (QLDB) which supports the immutability and cryptographical verification of the supply chain flow data. The back-end of the framework is modularly divided into a small function to execute to prevent the redundancy of the modules. This creates a reusable code base to interact with the supply chain flow in an efficient way.

The supply chain process framework is executed to make the real-time monitoring of the vaccines in the complete supply chain. So that the vaccines reaching the end of the supply chain are trusted for their authenticity and are in good healthy condition in which it is monitored. The implementation of a Quick Response (QR) code reader is used which automatically scans the QR code for the vaccines/containers and extracts the information from the QR code reader and them automatically streamlines the storage of vaccines/containers data into the database. This saves the manual entry of data for vaccines/containers, which can be a time-consuming task.

The use of unique id for identifying the entities in the database table uniquely. This functionality helps in joining the tables, extracting the information about the entity with the unique identity, and resolving duplicators in the table. This unique key management helps to normalize the tables in the database to efficiently make the system work. The concept of database management of linking the tables together helps in identifying the links in each table. This makes the foreign key assigned in one table can be linked to the primary key of another table [30]. This keeps the records in separate tables but linked together.

4.3.2 Cloud Computing Methodologies Used

Cloud computing methodologies have aligned together to perform smoothly and the data pipeline required to execute the system has been able to function properly. The advantage that cloud computing provides is that it is easily scalable up and down depending on the requirement of the system load. This suggests that the admin of the system does

not need to worry about the resources allocation in terms of increasing or decreasing the servers on the back-end. Cloud computing comprising of different services to create the infrastructure for the system to work properly, which includes the Lambda services, API Gateway service, Amplify service, Kinesis Data Generator, Kinesis Data Stream, Cognito service, etc... These services are combined together to set up the complete infrastructure on the cloud to make the system work efficiently.

4.3.3 Immutable Data Storage

The immutability of the supply chain data builds the trust of stakeholders involved in the supply chain. The data once stored into the database will not be deleted and all the historical records of the data will be recorded for future verification of the transfer of ownership of products from one stakeholder to another. The fully managed ledger database is achieved by Amazon Quantum Ledger Database (QLDB) that provides the transparent, immutable, and cryptographically verifiable supply chain transaction log. The record of all the changes are kept as record over time. The transparency and immutability of the data make the access to information of product at every stage easily accessible. The information such as location, source, destination, ownership, etc... are recorded makes QLDB to track the full history of the inventory and supply chain transactions at every logistical stage of the product in the supply chain. The immutability of supply chain data is very much efficiently trusted and reliable when applying data analytics to get insightful information from the supply chain data. The immutability does not allow the editing of any transactions and it also does not allow any transaction to be deleted [31]. This property is very advantageous in going through the different transfer of ownership of vaccines among the stakeholders and keeping track of vaccine containers at each step.

4.3.4 Computational Cost

The computational cost of the system comprises of the two components. First being the sensor data computation and second being Supply chain flow components. Both which are discussed below:

- Sensor computation has 500,000 events sent in a month. The total of the AWS component to process the events per month will be approximately 12 USD (United States Dollar). This solution is built on 3 components, which are as follows:

  1- Kinesis: Shard hour (1MB/second ingress, 2MB/second egress) 0.015 USD

  750 hours in a month = 750 shared hours per month; 750 X 0.015 = 11.25 USD per month [32].

  2- Lambda: 1 million free requests per month and 400, 000 GB - seconds of compute time per month. This resulted in estimate cost: 0 USD [33].

  3- DynamoDB: For upto 1 million write request units: 1.25 USD and for upto 1 million read request units : 0.25 USD [34].

- Supply chain flow cost is focused on the prices associated with AWS Quantum Ledger Database [35] which is as follow:

  1- Write I/Os: 0.70 USD per 1 million requests.

  2- Read I/Os: 0.136 USD per 1 million requests.

  3- Journal Storage Rate: 0.03 USD per GB-month.

  4- Indexed Storage Rate: 0.25 USD per GB-month.

This system is based on a fictitious supply chain flow scenario where transactions and storage won't be the same as used in the real world in future. The scenarios provided at the Quantum Ledger Database (QLDB) pricing speak more accurately about estimates that could be predicted in this system.

Seeing the estimated cost of the implemented system makes it easy to understand the cost analysis. It helps in making better supply chain management decisions cost-effectively. The direct cost associated with the cloud computing resources will impact the supply chain directly. The indirect cost would be mainly associated with the delay in shipments, change in purchase orders, aligning stakeholders at different steps of the supply chain, rent of warehouses for storing inventory, the overhead cost of sensors used, etc... The comparison of the above-stated parameters helps in identifying the benefits

with respect to the direct and indirect costs. Cloud computing provides the infrastructure to perform all operations securely, easily scalable, and faster supply chain transactions processing.

4.4 Discussion

Furthermore, the cloud computing services come together to form the infrastructure of the system. The secure way of implementing the cloud services creates immutable data storage for building the trust of the stakeholders involved in the supply chain process. The cloud computing services are aligned to each other in a flow that is securely provided. The sensor data generated is streamed lined through kinesis service that redirects the stream of data to lambda services which handles it by mapping it with the respective data columns and saving them in the DynamoDB database. The anomalies that occur during that process are recorded and the warning is notified depending on the threshold levels of vaccines in terms of temperature or humidity is breached. This real-time monitoring and then getting notified in real-time gives enough time to take action to prevent the damage getting caused to the vaccines in the supply chain. This real-time action helps in delivering reliable and monitored vaccines to the end-users. This builds the trust on the vaccines that they were kept in the monitored conditions and these conditions can be verified to make sure the efficacy of the vaccines is not breached at any point of time in the complete supply chain journey.

4.5 Summary

In this chapter, the case study of the system is discussed. The supply chain process framework highlights the streamflow of the vaccine delivery from one stakeholder to another. The real-time monitoring of the vaccines through this framework would give the stakeholders to take action if the vaccine temperature or humidity level crosses the assigned range. The location data from the sensors provides the current location of the container to track the position where the container is in the supply chain flow. The cloud

computing services very well support the supply chain flow by the secure movement of requests and responses from one service to another service. These services can be easily scalable up and down depending on the load of the supply chain. This scalability feature minimizes the cost of the resources that are involved in use.

Chapter 5

Conclusion

In this thesis, the cloud computing-based real-time monitored supply chain is proposed which develops the trust on the data and on the vaccines that are being monitored to pass on to different stakeholders in the supply chain. The need for such a system makes the authenticity of vaccines delivered in a good and reliable state to use, is provided by this system. The secure transfer of requests and responses related to supply chain transactions is implemented that lays the better-connected system framework. The implemented system can be applied and used into different disciplines of the supply chain according to the need. This makes it agile enough to easily adjust to different business requirements use cases like in agriculture and food, pharmaceuticals and health, etc... These different implementations help in resolving logistics and shipments related issues using cloud computing technology.

5.1 Contributions

The study and system implementation carried out in this thesis, promises a significant contribution in the field of cloud computing-based vaccine distribution supply chain. The following contributions were observed:

- Sensor data pipeline which streamlined the flow of sensor data information into the system for real-time monitoring. The recording of different conditional factors like temperature and humidity of the container in which they are being transported. The sensor data is aligned with the respective information so that the right results are displayed on the monitoring dashboard.

- Supply chain process is proposed where all the stakeholders involved in the process,

help them in trusting the supply chain data and smooth transferring of ownership of the product in the supply chain. The secure on-boarding of all the stakeholder in the supply chain provide them with authentication to access the system and become part of it. The immutability, transparency, and cryptographically verifiable supply chain data is achieved that further builds the trust on the supply chain data by stakeholders.

- Real-time monitoring of vaccines in the supply chain gives sense to the end receiver that the vaccines that have been received are in good condition. This build the trust about the vaccines that nowhere in the supply chain journey their environmental conditions were compromised. If at some point there was an occurrence of any anomalies in the supply chain then timely actions had been taken to prevent that.

- The data collected is being used to demonstrate the goods have remained within regulated temperature and humidity thresholds throughout their journey. This real-time data enabling leads to better optimization of the entire supply chain.

5.2 Future Work

The thesis provides a great approach to execute the real-time monitored supply chain system for vaccines delivery. Nevertheless, there are still some future possibilities that can be applied to it in order to improve the flow of it. The potential future studies and researches are highlighted below:

- Additional features can be explored such as adding predictive capability (apply machine learning) regarding the demand of vaccines on a distributor location based on past vaccine delivery data, which can help in the coordination of vaccine distribution.

- The solution is modular enough to convert it into the decentralized version of it using Blockchain technology by replacing the backend API's with the smart contract to perform the transactions happening in the supply chain.

- The solution can also add the optimal operation of distribution of supply chain. The optimized operations include minimizing transportation cost, distribution cost, optimization of inventory, and following the optimized route in the vaccine distribution supply chain.
- Database normalization can be done further to reduce the complexity of entities in Quantum Ledger Database (QLDB).

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